Valence of Elements (1886)

Aluminium III
Calcium II
Carbon IV
Chlorine I
Fluorine I
Hydrogen I
Iodine I
Iron II
Lead II
Magnesium II

THE

STUDENT'S MANUAL

Manganese II

OF

Mercury II
Nitrogen III

GEOLOGY.

Oxygen II
Phosphorus III
Potassium I
Silicon IV
Sodium I
Sulphur II

[illegible] minerals (1886)

I. Quartz group.

Silica, anhydrous or hydrated SiO_2 p. 30.

Quartz, p. 30 anhydrous, sp. grav. 2.6

Amethyst p. 30 stained by iron

Opal p. 30 hydrated

Sinter

Chalcedony | p. 30 | [illegible]

Flint, | | 1234

Chert | | 1234

Jasper

Agate

II Feldspar group

Acidic: rich in SiO_2

Orthoclase p. 44. Trisilicate of Potash & alumina ([illegible])

Sanidine. p. 45 glassy [illegible]

Albite p. 45 [illegible] feldspar, [illegible]

Basic: less SiO_2

Oligoclase p. 45. Soda-lime

Labradorite p. 42 Lime soda

Anorthite p. 41 Lime

Leucite p. 43 anhydrous potash (1st system)

Nepheline p. 44 " soda-potash

III Mica group [illegible] magnesia, [illegible]

Mica. p. 48 [illegible] - mica. 5th system

(a) Muscovite p. 47. potash - mica [illegible]

(b) Biotite p. 47 magnesian - mica

IV. Hornblende group [illegible] Sil. of magnesia, lime [illegible] alumina

Hornblende p. 36 Sil. of [illegible]

Augite p. 35 Silicate of Magnesia & iron [illegible]

Olivine p. 34.

V. Talc & Chlorite group [illegible] magnesia [illegible]

Talc p. 35

Chlorite p. 39 [illegible] alumina [illegible]

VI. Calcareous group.

Calcite p. 31 & Aragonite

Dolomite p. 32

Selenite p. 32. [illegible]

Apatite p. 31

VII. Iron group, p. 27.

Hematite

Magnetite

Limonite

Spathic Iron [illegible]

THE

STUDENT'S MANUAL

OF

GEOLOGY

BY

J. BEETE JUKES, M.A., F.R.S., &c.

LOCAL DIRECTOR OF THE GEOLOGICAL SURVEY OF IRELAND, AND LECTURER ON GEOLOGY TO THE MUSEUM OF IRISH INDUSTRY.

EDINBURGH:

ADAM AND CHARLES BLACK.

MDCCCLVII.

Igneous Rocks. (See also p. 154 -)

A. Acidic Class. acidic feldspar & free quartz. Light & surfusible. The feldspar is orthoclase. Poor in lime, magnesia & iron

1. Quartzose Trachytes (sanidine & quartz.) p. 63.
Varieties Porphyritic trachyte,
Macro- & Micro-crystalline Trachyte.
Compact Trachyte or Rhyolite p. 64.
Glassy or Obsidian p. 65.
Vesicular or Millstone Porphyry p. 64
Pumice. p. 65

2. Felstones (orthoclase & quartz) plutonic rocks. p. 69
Glassy form = Pitchstone or Retinite p. 71
Compact " = Felsite or Eurite p. 79
Coarsely crystalline = Elvanite. p. 71, 79, 80

3. Granites (quartz, orthoclase & mica) p. 77

Syenite (hornblende instead of mica. p. 79.

B. Basic Class. a basic feldspar: with augite or hornblende. No free quartz. The feldspar is plagioclase. Heavy. Often intrusive. Rich in lime, magnesia & iron. Dark.

1. Basalts (labradorite & augite) labradorite or anorthite
Glassy form = Tachylite p. 66
Compact - Basalt p. 66

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Finely crystalline = Dolerite p. 65 = "Trap
Coarsely " = Gabbro. p. 73

2. Diorites (oligoclase & hornblende or sometimes mica.) Plutonic
Compact form, Aphanite
Granular Diorite p. 72 fund.
Porphyritic "

3. Melaphyres (oligoclase & augite) p. 73
Plutonic.

C. Intermediate Class. many of them.
a basic feldspar with quartz, or an acidic feldspar without free quartz

1. Quartzless trachytes.
Sanidine & frequently mica & hornblende
with ...

2 Dacite. same basic feldspar with grains & crystals of quartz. Hungarian

3. Minette. magnesian Mica in a paste of orthoclase

4. Hypersyenite. Orthoclase & Hornblende, with much less Quartz than in ~~granite~~ syenite.

Sedimentary Rocks.

A. Mechanical Deposits.

1. Siliceous.
   Sandstone p. 101
   Conglomerate p. 100

2. Argillaceous
   Clay
   Shale p. 105
   Marls p. 106

B. Organic accumulations p. 107

3. Calcareous
   Limestone p. 107, 123
   Chalk p. 123
   Marble p. 123
   Argillaceous limestone (Hydraulic limestone)

To the Memory of

EDWARD FORBES,

BY WHOSE LAMENTED DEATH THE AUTHORSHIP
OF THIS WORK,
WHICH WAS TO HAVE BEEN HIS OWN,
DEVOLVED ON ONE OF THE MANY WHO WILL
NEVER CEASE TO REGRET HIS LOSS AND
CHERISH HIS REMEMBRANCE.

4. Carbonaceous.
   Peat.
   Lignite
   Coal p. 119, 130
   Anthracite p. 133

C. Chemical deposits.

5. Siliceous.
   Sinter
   Agate

6 Calcareous
   Travertine p. 110
   Dolomite p. 149, 116.

Metamorphic Rocks.

1. Retaining their bedding
   - Quartzite p. 147
   - Clay Slate p. 148
   - Porcellanite.
   - Marble
   - Anthracite
   - Graphite

2. Foliated p. 149. 249.
   a. Schists consisting of Quartzite with laminae of (produced by layers of) some other mineral.
   - Mica Schist p. 150
   - Hornblende Schist, p. 151
   - Talc Schist.

   b. Gneiss, a laminated mixture of quartz, orthoclase & mica. p. 151
   - Protogine contains talc.
   - Granulate has garnets.

3. Amorphous Rocks.
   - Some Granites
   - Felsitic Schist: intermediate between felstone & gneiss & diorite.

From W. W. S.'s Lectures

The acidic class of igneous rocks are all essentially mixtures of silica & orthoclase: oligoclase, mica & hornblende may also be present. Each of the three groups has varieties distinguished by texture: of importance as showing the conditions of formation.

Quartzose trachyte. The coarser are crystals of sanidine & some oligoclase, & grains and crystals of Quartz imbedded in a paste which is a mixture of orthoclase & quartz. Quick cooling without [illegible] glass, obsidian: white glass, vesicular [illegible].

PREFACE.

EARLY in the year 1854 the late Professor Edward Forbes asked me to be his fellow-labourer in writing the article on Geology in the new edition of the *Encyclopædia Britannica*, and a text-book to be founded on it. At the meeting of the British Association in Liverpool, we had agreed each to sketch out a plan and submit it to the other, but before even that could be done, death deprived the world of his services. When after some time had elapsed, the publishers decided to entrust the work to my hands, I immediately commenced it; but as I could only devote to it occasional hours not occupied by my official duties, I found myself unable to complete the article in time to come in in its proper place in the *Encyclopædia*. It was necessary, then, to defer it till the publication of the letter M made it possible to bring it in under the term "Mineralogical Science." In the meantime, I had felt in my own lectures the want of a text-book, which should treat the subject of Geology more systematically and more succinctly than any yet published, and the same want had been expressed to me by others.

The *Principles of Geology*, by Sir C. Lyell, must be read and re-read by every one aspiring to be a geologist, and the perusal of his excellent *Elementary Manual* is almost equally necessary. They are, however, more adapted for the advanced student than the mere beginner, and presuppose the possession of much knowledge of collateral subjects, some of which I have here endeavoured to supply.

Instead, then, of wishing to supersede, my object is rather to lead up to the study of these works, and in some respects to supplement them. Neither do I aim at supplanting the excellent treatises of Phillips (full of sound original matter and information), of De la Beche, of Ansted, of Portlock, or of Page. I have wished to enable the student to arrange in his mind, and digest the knowledge he may acquire, either from the books above mentioned, or from those great works of Murchison and others who have treated of more special portions of Geology.

In order to be able to impart to the student some of that collateral information which is necessary for the geologist in order rightly to understand his own science, I had taken some trouble to make myself master of the rudiments of chemistry, so far as its nomenclature and principles of classification were concerned. In this I fancied I had succeeded, though some parts still seemed to me obscure if not contradictory. I had accordingly prepared the chapter on this subject, but before printing off, submitted the proof sheets to my friend and colleague Dr. W. K. Sullivan.

He pointed out to me many errors into which I had fallen, not so entirely from any fault of my own, as from the absence of precise information on certain points, and the presence of certain anomalies in the use of terms which characterise every elementary book that I have met with; and he was good enough to supply me with a large amount of excellent MS. material, which I regret that the limits of this little work did not allow of my inserting entire. I accordingly reconstructed this part, condensing the information thus supplied to me as far as I could, weaving it in with my own matter, and inserting certain passages, more or less complete, which are marked with his initials.

In selecting the minerals for description, I wished to limit myself to those which are rock-constituents either commonly or occasionally. Dr. Sullivan also examined these descriptions for me, and pointed out a certain relation which might be traced in them, between the proportions of oxygen in the acid to that in the base, by means of which relation the close connection between allied minerals is made more obvious, and placed on a more systematic basis than hitherto. This relation is indicated by the expression, "O in a : O in b," in the line which Dr. Sullivan has added to each of the minerals. It will be, I believe, of interest and importance to the chemical mineralogist. By means of it the essential connection, for instance, between Labradorite and Comptonite, and between Orthoclase or Albite and Stilbite, and the fact that the zeolite is merely a hydrated form of the feldspar, is made remarkably prominent.

The attempt at the classification and description of rocks, though avowedly imperfect, will, I hope, be found useful. This subject is just now in a state of transition from a merely empirical to a really scientific treatment. It is to be hoped that by the labours of Haughton, D. Forbes, Sorby, and others at home, and of Delesse and others abroad, it may shortly be placed in a more satisfactory state than at present.

The part here called Petrology is the one, perhaps, which contains most matter of my own. I must hope that it will not be found to contain any great errors, and shall be thankful, here as elsewhere, for any corrections and improvements that may be supplied to me.

In the Palæontological part, Professor Huxley has assisted me with some advice and with his classification of the animal kingdom; and Professor Morris and Mr. Salter with some information. It consists mainly, however, of what I could recollect of Edward Forbes' teaching, gathered either from his works or from conversations with him on the subject. Necessarily imperfect, I may yet hope that this part will serve as a foundation either for the lectures of the professor or the studies of the pupil. In addition to this, I have given a complete abstract of the new edition of Pictet's work, slightly modified, and a list of fossil plant genera from Bronn. As I feel this will be useful to myself, I may anticipate its being equally so to others.

In the History of the formation of the series of stratified rocks, I at first intended only to give, under each group, a few of the more abundant and most characteristic species of fossils. I found, however, that the task of selection would often be so difficult and critical a one, that I determined at last to mention all the genera and most of the species given in Morris' Catalogue, omitting merely, when the species of any genus became very numerous, those that seemed least certain or important. No one, I think, can doubt that all, or at least most, lists of species require revision, and a comparison not merely of the descriptions, but of the specimens on which they are founded. A great diminution in the numbers of species, especially where there are many under one genus, would doubtless be the result of the process.

I have only to say in conclusion, that should this little work answer my expectations, and be found generally useful to the professors and students in our universities, or the teacher and learner elsewhere, that I shall always be greatly obliged by any criticism or suggestion which may enable me to improve it hereafter.

Table of Igneous Rocks ([illegible])

	Acidic			Basic	
Volcanic Rocks occurring in overflows,	Rhyolite Base + xx {Quartz Orthoclase (Sanidine)	Trachyte Base + xx {Orthoclase (Sanidine)	Phonolite Base + xx {Sanidine Nepheline	Andesite Base + xx {Plagioclase Augite or Hornblende	Basalt Base + xx {Plagioclase Augite Olivine
Plutonic Rocks occurring in intrusions,	Quartz Porphyry Micro xx groundmass + xx {Orthoclase Quartz	Felsite Micro xx {Orthoclase Quartz		Diorite as below	Diabase. as below
[illegible]. occurring massive	Granite xx {Quartz Orthoclase Mica	Syenite. xx {Orthoclase Hornblende		Diorite xx {Plagioclase Hornblende.	Diabase xx {Plagioclase Augite

CONTENTS.

PART I.—GEOGNOSY.

SECTION II.—PETROLOGY.

PART II.—PALÆONTOLOGY.

PART III.—HISTORY OF FORMATION OF SERIES OF STRATIFIED ROCKS.

Iron abounds in soils. The iron may be removed from a bed by leaching, giving clays that make white bricks. Organic agencies deprive beds of their iron thus the clays in coal formation, "fire-clays" [illegible] being infusible having neither iron nor alkali. The iron's tone is often interstratified with these. The fuel, the metal, & the fireclay all together.

Mountain Chains (W.B.S.)
Formerly horizontal thrust: erosion removing the capping strata. (Patches remaining on the Sierras.)
Have enormously thick rocks: Appalachians 40 000 ft.: Wahsatch 50 000. It seems that their origin is connected with this. In the Appalachians there was a slowly advancing depression in which sediments & limestones accumulated: so that the tops of the sediments remained near the surface of the water. And near shore can such accumulations occur, & parallel to coast line. Why should elevation occur here? Great accumulations cause subsidence: aqueo-igneous fusion of the lower parts of these follows. This weakens the crust along these lines.

INTRODUCTION.

IT is not easy to give an accurate and comprehensive definition of the science of Geology; for its nature is so complex and various, that it is difficult, in a few words, either to specify its object or to assign its limits.

It is, indeed, not so much one science, as the application of all the physical sciences to the examination and description of the structure of the earth, the investigation of the processes concerned in the production of that structure, and the history of their action.

We might, perhaps, without impropriety, classify all the physical sciences under two great heads, namely, Astronomy and Geology. The one would comprehend all those sciences which teach us the nature, the constitution, the motions, the relative places, and the mutual action of the Astra, or heavenly bodies; while the other singled out for study the one Astrum on which we live, namely, the Earth.

Giving this wide meaning to Geology, it would include all the sciences which treat of the constitution and the distribution of the inorganic matter of our globe, as well as those which describe to us the living beings that inhabit it. These sciences are—first, that of Chemistry and Mineralogy (which may be called one), which teaches us what are the elements of which terrestrial matter is composed, and what are the laws which govern the combinations of those elements into all the variety of known substances, solid, fluid, or gaseous, and the forms, properties, and qualities of those substances; secondly, the science of Natural History (or Biology, the science of life), including botany and zoology in their widest acceptation; and thirdly, that of Meteorology and Physical Geography (which may also be looked on as one), which describes to us the form and disposition of land, and water, and air, and the distribution of the temperatures and motions that affect them.

The sciences commonly included under the head of Physics, those which teach us the nature and laws of magnetism, electricity, light, heat, force, and motion, would be common ground to Geology and Astronomy, serving to bind together all human knowledge of matter and its laws into one great whole.

Let it not be supposed that the giving this high place to Geology, arises from a wish unduly to exalt it at the expense of the other sciences. I have no such wish; my object is to show that this large view of Geology is not only a true, but a necessary one, and that if we do not sometimes look at it from this aspect, I cannot fully describe, nor can the reader rightly understand and appreciate what Geology is.

That it is true, is shown by the very fact of the late appearance of geology in the world of science. It was not till some very considerable advances had been made in all the physical sciences which relate directly to the earth, that geology could begin to exist in any worthy form. It was not till the Chemist was able to explain to us the true nature of the mineral substances of which rocks are composed; not till the Geographer and the Meteorologist had explored the surface of the earth, and taught us the extent and the form of land and water, and the powers of winds, currents, rains, glaciers, earthquakes, and volcanoes; not till the Biologist (naturalist) had classified, and named, and accurately described the greater part of existing animals and plants, and explained to us their physiological and anatomical structure, and the laws of their distribution in space;—that the Geologist could, with any chance of arriving at sure and definite results, commence his researches into the structure and composition of rocks, and the causes that produced them, or utilise his discoveries of the remains of animals and plants that are inclosed in them. He could not till then discriminate with certainty between igneous and aqueous rocks, or between living and extinct animals, and was therefore unable to lay down any one of the foundations on which his own science was to rest.

Neither would it be a satisfactory classification if we were to limit the range of Geology to any period of the earth's history; to assign to it, for instance, all time previous to the existence of the human race, and, uniting all the natural sciences under it up to that time, consider it then to be brought to an end, or to split up and diverge into the many independent sciences that concern our contemporary existences, whether organic or inorganic. For not only is there no trace of any hard boundary line between the human and the pre-human period of the earth's natural history; but there appears in each one of the separate natural sciences a perfect blending and continuity from the remotest geological era to the present time. The present is but a part of the past. The inorganic objects we see around us are the result of processes going on in past time, such as are still at work producing the same results; the living beings around us are either the direct descendants of those that lived formerly, or their substitutes and representatives, the living and the extinct forming parts of one great connected series and chain of species, genera, and orders, each of which parts would be incomplete without the other. There is, therefore, no possibility of making any division in geology such as we are now considering it, or assigning any limit to its range from the earliest period of the earth's ascertainable history to the present moment.

Moreover, as there is no natural science to which the geologist has not to appeal for information upon some point or other in his researches, so there is none which can be fully and completely studied without the help of the geologist, or without including facts or theories which are commonly and rightly reckoned parts of his peculiar intellectual domain. If he has to call upon the professors of each one of the physical sciences in turn, for assistance in his own investigations, he is sure, sooner or later, to repay the obligation, by the discovery of a number of facts that enlarge the boundaries of the science he has applied to, or the statement of many problems whose solution throws light upon parts of it that have been hitherto imperfect and obscure.

It is not intended that the reader should infer from what has been said, that in order to be a geologist, he must be thoroughly acquainted with the whole circle of the physical and natural sciences. Such universal acquirement few men have the power to attain to, and of these still fewer retain the ability and the will to make original advances in any particular branch.

No man, however, can be a thorough geologist without being acquainted, to some extent, with the general results of the other sciences, and being able both to understand them when stated in plain untechnical language, and to appreciate their application to his own researches. Such a general acquaintance involves neither profound study, nor requires any great power of mind above the average of human intellect. It is, indeed, what every well-educated man ought to possess.

The necessary preliminary to the science of Geology is not the possession of great and accurate knowledge of the whole circle of the natural sciences by any individual persons, but that this knowledge must exist somewhere. Some man or men must have this knowledge, and must be able to combine it, either piecemeal or at once, with the special knowledge of the geologist, before the latter can hope to solve the many difficult and profound problems that arise in the course of his researches.

It may be said with perfect truth that the geologist is less able than any other student of science to pursue his investigations alone, and independently of the assistance of others; but this is, in fact, only saying in other words that which I am insisting on, namely, that geology in its highest and widest sense embraces all the physical and natural sciences, and is, as it were, made up of them.

If, however, this wide scope be properly given to the term geology, and it be made to include every physical science that treats of anything belonging to the earth, what, it may be asked, is the special business to which the geologist devotes himself as distinct from the follower of other sciences? What is that which he does, and the others do not? Above all, what is that which he teaches to the rest in return for the knowledge communicated to him?

The answer to these questions will show us that there is another and a more restricted sense of the word geology than the wide and general one in which we have been using it. This sense is rather the one formerly attached to the word geognosy, by which we may understand the knowledge of the nature and position of the different masses of earthy or mineral matter of which different districts and countries are composed, without reference to the history of their production. This was the early and simple meaning of the word geology, when considered as synonymous with geognosy, namely, the examination and description of the different varieties of rocks and the minerals they contained. Geology was looked upon in the light of a geographical mineralogy, and even yet it is regarded more or less under this aspect by many persons. No one, indeed, could have anticipated, from the mere study of masses of stone and rock, where, to a partial and local view, all seems confusion and irregularity, the wonderful order and harmony which arise from more extended observation and the almost romantic and seemingly fabulous history which becomes at length unfolded to our perusal. To discover the records on which this history is founded, and to understand their meaning aright, frequent, long-continued, and wide-spread observation and research in the field, and patient and conscientious registration and comparison of the observed facts in the closet, are absolutely necessary.

This collection and co-ordination of facts it is which is the proper and peculiar business of the geognost. The ditch, the "cutting," the quarry, and the mine, the cliff, the gully, the mountain-side, and the river-bank, these are his "*subjects*," that which he has to study, to examine, to dissect, to describe the minutiæ of the structures they expose, and to classify and arrange the facts they may afford, depicting their lineaments on maps and sections, and recording them in written descriptions. The business of the geognost, then, is to make out, from indications observed at the surface and in natural and artificial excavations, the internal structure, the *solid geometry*, of district after district, and country after country, until the whole earth has been explored and described. If, while so doing, he notes all those facts which may enable him or others to understand and explain how that structure has been produced, he then becomes a geologist.

It might at first be thought that in order to make out the solid structure of lands and countries it would only be necessary to understand the nature of the mineral matters of which they were composed, and that for this purpose no knowledge of organic or living beings would be required.

It is, however, one of the most remarkable results of geological science that an acquaintance with organic, and especially with animal forms, is at least as necessary for a geologist as a knowledge of minerals, and that a correct knowledge of organic remains (portions of fossil plants and animals) is a more certain and unerring guide in unravelling the structure of complicated districts than the most wide and general acquaintance with inorganic substances.

The cause of this necessity, puzzling and paradoxical enough, perhaps, at first sight, may be briefly stated as follows. When we come to examine the structure of the crust of the globe we find that its several parts have been produced in succession, that it consists of a regular series of earthy deposits (all called by geologists rocks) formed one after another during successive periods of time, each of great but unknown duration. Now, the mineral substances produced at any one period of this vast succession of ages do not appear to have had any essential difference from those formed at another. We cannot, therefore, with any certainty discover the order of time in which the series of rocks was formed, or the order of superposition which they consequently preserve with regard to each other, from an examination of their mineral character or contents only. The animals and plants, however, living at one period of the earth's history were different from those living now, and different from those living at other periods. There has been a continuous succession of different races of living beings on the earth following each other in a certain regular and ascertainable order, and, when that order has been ascertained, it is obvious that we can at once assign to its proper period of production, and therefore to its proper place in the series of rocks, any portion of earthy matter we may meet with containing any one, or even any recognisable fragment of one, of these once living beings.

Just as when we find under the foundation-stone of any ancient building a parcel of coins of any particular sovereign, we know that the erection of that building took place during his reign, so when we find a fragment of a known "fossil" in any piece of rock, we feel sure that that rock must have been formed during the period when the animal or plant of which that fossil is a part was living on the globe, and could not have been formed either before that species came into existence or after it became extinct.* In cases, therefore, where the original order of the rocks has been confused by the action of disturbing forces, or where the rocks themselves are only at rare and wide intervals exposed to view, their order of deposition and consequent succession of place may be more easily and certainly ascertained by the examination and determination of their fossil contents than by any other method.

Practically, it has been found that while a very slight acquaintance with the most ordinary forms of some ten or a dozen of the most frequently occurring minerals is all that a geologist must *inevitably* learn of mineralogy, the number of fossil animals and plants, with the forms and the names of which he will have to make himself familiar, will often have to be reckoned by hundreds.

This branch of geological knowledge is now known under the name of Palæontology.

Perhaps, however, the tendency of late years has been to neglect to too great an extent the bearing of mineralogical knowledge on geology. There are many subjects on which we have still to ask the chemist and mineralogist to enlighten us.

* The very rare and exceptional cases in which ancient coins *may* have been deposited in the foundation of a recent building, or fossils originally in one rock may have been washed out and buried in another, need not more than a passing notice.

One deficiency which is particularly obvious in Britain is the want of a good and precise nomenclature of rocks, and especially of igneous rocks. Since the publications of Jameson and Maculloch, no attempt has been made in English to supply this deficiency, and to bring up our lithological nomenclature to the present state of chemical and mineralogical knowledge. Neither was the want succinctly supplied in any other language till the appearance of the *Gesteinslehre* of Bernhard Cotta, of which it is hoped a translation will shortly appear in English, to which we may refer the reader. By the assistance of this and other works we hope to some slight extent to supply the deficiency in this treatise.

Distribution of the Subject.

In order to reduce the great subject of geology to something like order, it appears to me advisable to divide it into three heads, for which we may use the terms—1, Geognosy; 2, Palæontology; and 3, The History of the Formation of the Series of Stratified Rocks.*

This will enable us to describe separately those general facts in structure which either are or may be common to the rocks of all ages, and those general laws which regulated the distribution of life in all epochs of the world's history, and leave us free to give a condensed statement of the third part without stopping to describe special instances of general facts.

By Geognosy I would understand, then, the study of the structure of rocks independently of their arrangement into a chronological series, and I would divide it into two parts—Lithology and Petrology. By Lithology I would mean the study of the internal structure, the mineralogical composi-

* Stromatology (from στρῶμα, stratum) might perhaps be used to express this portion of geology.

tion, the texture, and other characters of rocks, such as could be determined in the closet by the aid of hand specimens.

Under Petrology I would arrange the larger characteristics of rocks, the study of rock-masses, their planes of division, their forms, their positions and mutual relations, and other characters that can only be studied in "the field," but without entering on the question of the geological time of their production.

Under the head of Palæontology I propose to give the heads of several great questions as to the laws which have governed the distribution of life both in space and in time, as also to indicate some of the chief points in the structure of the more important extinct races, and their relations to those now living. I shall also endeavour to point out the practical bearings of this subject, both scientific and economical.

Having thus described under separate heads facts and generalisations common to the whole subject, and structures and phenomena which may recur during every geological period, I shall, under the head of "History of the Formation of the Crust of the Globe," give a condensed abstract of that history, in the form of a chronological classification, mentioning some of the principal and typical groups of rocks known to have been produced, and a few of the fossils known to have lived at different parts of the earth during each of the known great periods of its existence.

PART I.

GEOGNOSY.

SECTION I.—LITHOLOGY.

CHAPTER I.

CHEMISTRY AND MINERALOGY.

LITHOLOGY, or the study of the mineral structure of rocks, is based on mineralogy. For a knowledge of mineralogy I must refer the student to special works upon the subject, as for instance to those of Nicol, Dana, Phillips, Millar, Brooke, and Mitchell and Tennant. But for the proper understanding of mineralogy a knowledge of chemistry is essential. This must be gained from many works, and from study in the laboratory; but I would point to Gmelin's Handbook, translated for and published by the Cavendish Society, as containing full and accurate details on the chemical part of mineralogy.

In order to understand lithology, however, an acquaintance with mineralogy in general, though always useful, is by no means necessary, since the minerals which enter into the composition of rocks are very few compared with the whole number of minerals. But as regards these few minerals, it is their chemical composition, still more than their physical characters, which we have to regard in their lithological relations. It is, therefore, absolutely necessary to understand so much of chemical nomenclature and chemical laws as shall enable us clearly to comprehend the precise meaning of this chemical composition.

As, however, geologists, from the very nature of their pursuits, are unable to devote much of their time to closet study or laboratory work, unless at the expense of their own more proper field of investigation, I will here endeavour to assist the student by giving him a condensed abstract of so much of the elements of chemical mineralogy as may enable him to understand rightly the lithological descriptions which follow.

Chemical Nomenclature.

Laws of Composition.

Simple Bodies.—All known substances are either simple or compound. If simple, they are some of the sixty enumerated in the following list of elementary or simple substances, in which the letters preceding the names are the symbols ordinarily used for them, the figures following some of them are their specific gravities, and the italic letters after a few indicate their ordinary physical state—*g.* meaning gaseous, and *l.* liquid, the rest being all solid:—

TABLE I.—List of Elementary Bodies.

Metalloids.

Organogens (forming animal and vegetable bodies.)

O. Oxygen. *g.*	
H. Hydrogen. *g.*	
N. Nitrogen. *g.*	
C. Carbon.	3.5

Amphigens (whose compounds with other elements, possess a marked dualism, i.e. *some strongly acid, some strongly basic. Oxygen is amphigenous also.)*

S. Sulphur.	2.0
Se. Selenium.	4.3
Te. Tellurium.	6.2

Halogens (forming salt-like bodies with metals, as common salt.)

F. Fluorine. *g.?*	
Cl. Chlorine. *g.*	1.3
Br. Bromine. *l.*	2.9
I. Iodine.	4.9

Phosphoroids.

P. Phosphorus.	1.7
As. Arsenic.	5.9

Hyalogens (glass-formers, because the salts in which their oxides, Silica and Boracic acid, act as acids, fuse into glass at a high temperature.)

B. Boron.	
Si. Silicon.[1]	

Metals.

1. *Which decompose water at ordinary temperatures.*

(*a.*) *Whose protoxides are alkalies.*

K. Potassium.	0.86
Na. Sodium.	0.97
Li. Lithium.	0.59

(*b.*) *Whose protoxides are alkaline earths.*

Ba. Barium.	4.0?
Sr. Strontium.	2.54
Ca. Calcium.	1.57
Mg. Magnesium.	1.74

2. *Metals whose oxides are earths.*

Al. Aluminium.	2.67
G. Glucinum.	2.10
Zr. Zirconium.	
Y. Yttrium.	
Tb. Terbium.	
E. Erbium.	
Th. Thorinum.	

3. *Metals whose oxides resemble earths.*

Ce. Cerium.	
La. Lanthanum.	
D. Didymium.	

4. *Metals whose protoxides are isomorphous with magnesia.*

Mn. Manganese.	8.01
Fe. Iron.	7.84
Co. Cobalt.	8.95
Ni. Nickel.	8.82
Zn. Zinc.	7.14
Cd. Cadmium.	8.60
Cu. Copper.	8.92
Pb. Lead.	11.44

5. *Metals isomorphous with phosphorus and arsenic.*

Sb. Antimony.	6.71
Bi. Bismuth.	9.80

6. *Metals not included in foregoing whose oxides are not reduced by heat alone.*

St.* Tin.	7.29
Ti.* Titanium.	5.33
Cr.* Chromium.	7.01
V.* Vanadium.	
W.* Tungsten.	17.60
Mo.* Molybdenum.	8.62
Os.† Osmium.	10.00
U. Uranium.	9.0
Ta. Tantalum.	
Nb. Niobium.	

7. *Noble metals, or those whose oxides are reduced by heat alone, and which are usually found native, and rarely or never combined with oxygen.*

Hg. Mercury.	13.59
Ag. Silver.	10.53
Au. Gold.	19.34
Pt.† Platinum.	21.50
Pd.† Palladium.	11.80
Ir.† Iridium.	21.80
R.† Rhodium.	11.20
Ru.† Ruthenium.	8.60

[1] Silicon is now shown distinctly not to be a metal, but to be nearly allied to carbon in some of its properties. It will combine with the metals like carbon, especially with aluminum, forming *cast aluminum*, as carbon and iron form *cast iron.—Comptes Rendus*, 1854, p. 821; and Sulivan's *Journal of Industrial Progress*, vol. i. p. 305.

* Those marked thus have isomorphic relations with the metals that are isomorphous with magnesia.

† These are found associated in native platinum.

These simple or *elementary* substances are arranged in this table in an order, which is intentionally an arbitrary one, adapted for a particular purpose, by my friend and colleague Dr. W. K. Sullivan.

Compound Substances.—All other substances are *combinations* of two or more of the simple substances contained in Table I. A combination is not a mere *mingling* of two substances producing a mixture intermediate between the two, but a *union* producing a *third substance* different from either.

These combinations do not take place indifferently, but according to certain strict rules or laws. One substance will combine with another in preference to a third, or, in some cases, in preference to any other. This preference is denoted by the term "elective affinity."

By means of this, some combinations may be *decomposed*. If, for instance, there be a compound substance (*x*), composed of two simple substances (*a*) and (*b*), having a slighter affinity for each other than one, as (*a*), of them has for some third simple substance (*c*); then if we bring this third substance (*c*) into connection with them, under the requisite conditions the one having the greatest affinity for it, as (*a*), will unite with it to form another compound substance (*y*), while the simple substance (*b*) will be left free.

These combinations are not only not indiscriminate as regards the respective substances, but they are also not indefinite as regards the quantities of each. Each simple substance will only combine with another in certain definite proportions. Thus eight parts by weight of oxygen will combine with one part by weight of hydrogen to form one equivalent of water; any surplus of either that might be present remaining unused.

The numbers denoting these proportions are called the equivalent numbers, 8 being the equivalent of oxygen, for instance, and 1 that of hydrogen.*

The equivalents of the compound substances are the sums of those of their elements; thus the equivalent of water is $(8 + 1 =)$ 9.

The union of two simple substances is termed a binary

* Any other numbers having the ratio 8 : 1 would do equally well; accordingly it is often found more convenient to make the equivalent of oxygen 100, and that of hydrogen 12.5, etc., for $12.5 \times 8 = 100$.

(twofold) compound, or may be called a primary compound, as denoting the *first* possible combination.

The two substances entering into combination are always considered as in opposite electrical conditions, one being electro-negative, and the other electro-positive.

The generic name of a binary compound is formed by adding the affix *ide* (or *uret*) to the first syllable of the name of its electro-negative element, placing after it the name of the other element with the word *of* between. Thus—

The Compounds of	Are termed	Example.	Symbol.
Oxygen.	Oxides.	Oxide of zinc.	Zn O.
Nitrogen.	Nitrides.	Nitride of mercury.	Hg_3 N.
Carbon.	Carbides, or carburets.	Carbide of iron. Carburet of hydrogen.	Fe_4 C. H_4 C_4.
Sulphur.	Sulphides, or sulphurets.	Sulphide, or sulphuret of potassium.	K S.
Fluorine.	Fluorides.	Fluoride of calcium.	Ca F.
Chlorine.	Chlorides.	Chloride of sodium.	Na Cl.
Phosphorus.	Phosphides, or phosphurets.*	Phosphide, or phosphuret of calcium.	Ca P.

As bodies may combine in several proportions, so there may be several oxides, chlorides, etc., of the same body. The names of such compounds are formed by placing a prefix to the generic name expressive of the number of equivalents of the electro-negative element in it. Except the first compound in the following list where the prefix *di* refers to the electro-positive element. Thus—

* Chemists are now gradually leaving off the use of "uret" as a termination. The unions of two metals are called "alloys;" those, however, with mercury, are called "amalgams."

TABLE II.

When the proportion is as	The prefix is	Examples.	Symbols.
1 : 2	Di or sub.	Dioxide of copper. Diniodide of copper. Subchloride of mercury.	Cu_2 O. Cu_2 I. Hg_2 Cl.
1 : 1	Proto.	Protoxide of iron.	Fe O.
3 : 2	Sesqui.	Sesquioxide of chromium.	Cr_2 O_3.
2 : 1	Deuto, or bi.	Deutoxide of lead. Binoxide of manganese. Bichloride of platinum.	Pb O_2. Mn O_2. Pt Cl_2.
3 : 1	Tri, or ter.	Tritoxide of osmium. Teroxide of gold. Terchloride of arsenic.	Os O_3. Au O_3. As Cl_3.
4 : 1	Tessara, or quadri.	Tessaroxide of osmium. Quadri-sulphide of osmium.	Os O_4. Os S_4.
5 : 1	Penta.	Pentachloride of phosphorus.	P Cl_5.
When in a series of compounds one has the largest number of equivalents of the electro-negative element, whatever that number may be.	Per.	Peroxide of iron. Peroxide of hydrogen. Peroxide of osmium. Perchloride of antimony.	Fe_2 O_3. H O_2. Os O_4. Sb Cl_5.

Acids, Bases, and Salts.—These binary compounds have different properties from which they are called *acid, basic*, or *indifferent;* thus :—

There are ox-acids, sulph-acids, chlor-acids, etc., oxy-bases, sulpho-bases, chloro-bases, etc., and indifferent oxides, etc.

Of the compounds with oxygen, the bases, and in part the indifferent bodies, are alone termed oxides. The acid compounds have special names, formed by appending a syllable to the termination, or modifying the final syllable of the electro-positive element, and adding the word "acid." Thus the acid oxide of carbon (CO_2) is termed carbonic acid, and one of the acid oxides of sulphur (SO_3) sulphuric acid.*

When a simple body forms with oxygen, two oxides having acid properties, the name of that which contains most oxygen ends in *ic*, and that having least in *ous*. Examples—(*a*), sulphurous acid; (*b*), sulphuric acid.

At the time of the framing of this nomenclature no bodies were known forming more than two acid oxides. Others, however, have since been discovered, and they are described by the prefix of *hypo* "under," placed before the words ending in *ic* or *ous*, according to the relation which it is desired to express. If an acid be discovered containing more oxygen than the one previously known, and ending in *ic*, it takes the prefix *per*. Examples—(*a*), hypochlorous acid; (*b*), chlorous acid; (*c*), hypochloric acid; (*d*), chloric acid; (*e*), perchloric acid.

A salt is formed by the union of an acid and a base, the electro-negative element being most usually the same in each; that is to say, an oxygen acid with an oxygen base, a chlorine acid with a chlorine base, etc.†

These salts, then, may be called *ternary* bodies, or *secondary* compounds, as being the second possible combinations.

Many acids have a sharp taste (whence the term "acid" originated), and have the property of reddening many blue vegetable colouring matters, such as that of the violet, red (purple) cabbage, litmus, etc. Such acids are, of course, soluble; but there are many which are insoluble, and exhibit no action upon colouring matters, and have no sharp taste. Hence chemists no longer consider those properties as the essential qualities of an acid, and have accordingly agreed to consider that body as an acid which appears at the positive

* "The existing nomenclature having been framed chiefly for oxygen compounds, no special names have been given to the acid compounds with sulphur, chlorine, etc., except those where hydrogen is the electro-positive element. Sometimes, however, where a body forms with sulphur, etc., as the electro-negative element, an acid analogous to that which it forms with oxygen, it receives the name of the latter, with the requisite distinctive prefix, as sulpho-carbonic acid, *i.e.*, the sulphide of carbon corresponding to the oxide of carbon, which is called carbonic acid. The acids formed by sulphur, chlorine, etc., with hydrogen, are called hydrosulphuric acid (for the sulphide of hydrogen), and hydrochloric acid (for the chloride of hydrogen); hydrogen being supposed to act as the electro-negative element. Since, however, hydrogen is invariably the electro-positive constituent of such compounds, those names are now incorrect. They are nevertheless universally used, and ought therefore to be known."—W. K. S.

† There are, however, some artificial and some natural substances composed of unions of different elements, especially oxygen and chlorine. These are termed acichlorides when an acid oxide unites with a chloride, and oxychloride when an oxygen base unites with a chloride.

pole when a salt is decomposed by the action of a voltaic battery; or, in other words, *an acid* is the *electro-negative* constituent of a salt.

Some bases which are soluble have the property of changing the blue colouring matter of red cabbage to green, and the bright yellow of turmeric to brown, and of restoring the blue of litmus reddened by an acid. But as many substances are considered as bases which do not possess this property, chemists have agreed to consider as *a base* the *electro-positive* constituent of a salt, or that which appears at the negative pole in the process of electrolysis. Some bodies possess the acid or basic properties so weakly, that they are capable of acting in either capacity, according to circumstances, that is, they act as bases with strong acids, and as acids with strong bases. Such bodies may be termed *indifferent*.*

Compound substances combine with each other in the same way that simple substances do; that is, through elective affinity for each other, and in definite proportions with each other.

The unions of acids and bases, therefore, may be expressed in the same way, and by using similar prefixes, affixes, etc., to those which denote the union of the simple substances.

The name of an oxygen salt is formed by modifying the termination of the acid, changing "ous" into *ite*, and "ic" into *ate*. Example—Sulphurous acid and soda form sulphite of soda, sulphuric acid and potash form sulphate of potash.

"If the acid have the prefix *hypo* or *per* that is retained in the name of the salt—example, hypochlorous acid and soda form hypochlorite of soda, perchloric acid and potash form perchlorate of potash. Now, as the different acids thus formed by the union of the same simple substances with different proportions of oxygen, yield different salts with the same base; so likewise the different basic oxides which the same body may form can produce different salts with the same acid: for example—

Protoxides give protosalts as	Sulphate of protoxide of iron, or protosulphate of iron.
Sesquioxides give sesquisalts	Sulphate of sesquioxide of iron, or sesquisulphate of iron.
Peroxides give persalts .	Sulphate of peroxide of iron, or persulphate of iron.
Suboxides give subsalts .	Nitrate of suboxide of mercury, or subnitrate of mercury.†

* Alumina is an example of such a substance, as it acts as the acid in spinel, and is supposed to replace silica in some hornblendes, and as a base in alum and in most aluminous silicates.

† The above combinations are spoken of as either sulphate of protoxide

"Any arrangement of the elements in salts, and therefore in sulphates, silicates, etc., can only at present be made entirely on theoretical principles. The opinion of chemists is at present divided between two modes of representing the constitution of salts.

"According to one, a salt is made up of an acid and a base, both of which must be considered to exist in the salt as distinct molecular groups. This is termed the acid or binary theory. According to the other, a salt is itself a binary compound (and not a union of two binary compounds) formed by a metal with a salt-radical, which may be either a simple body, or a compound which is capable of performing the combining functions of a simple body, even though it may be incapable of existing in a free state. In this the salt-radical theory, the acid and the base, are not supposed to exist as such in the salt.

"According to the acid theory, the hydrated acids are salts, the water being the base, while common salt, and all similar binary compounds, formed merely by the union of the halogen elements with the metals, are not true salts, and only become so when they unite with other chlorides, etc., to which they act as acids or bases.

"According to the salt-radical theory, on the other hand, common salt is not only a true salt, but it may be considered as the type upon which all others are formed. Examples—

	Acid Theory.	Salt-radical Theory.
Sulphate of potash	$KO + SO_3$	$K + (So_4)$.
Nitrate of potash	$KO + NO_5$	$K + NO_6)$.
Chloride of sodium	...	$Na + (Cl)$.

"In the salt-radical theory, therefore, the ordinary oxygen salts are completely assimilated to common salt, the SO_4 in the sulphate, and NO_6 in the nitrate, being compound radicals, while chlorine is a simple radical. The nomenclature now in use was constructed for the acid theory; the language of chemistry is imbued with its spirit, and its reasoning is chiefly used in the construction of chemical formulæ, especially those used in mineralogy and geology. All the phenomena connected with salts may be explained, perhaps, by means of one theory as well as by the other, and we may therefore use the language and reasoning of the acid theory without venturing to express any opinion as to the relative merits of either.

"As we can have compound *salt-radicals* which perform the functions of chlorine, so we may also have compound *basyle radicals* which perform those of metals. Of this kind is the

of iron or protosulphate of iron, etc. etc. The first term, however, is the correct one, as the use of the second lays us open to the mistake of confounding salts having different proportions of oxygen in their base with those having different proportions of acid in their composition.

supposed artificial metal ammonium, which has not yet been isolated, but can be readily obtained combined with mercury as an amalgam."—W. K. S.

In the ordinary use of terms descriptive of salts, the bases of which have no special names, like lime, for the oxide of calcium, the words "oxide of" are often omitted, thus sulphate of iron means sulphate *of oxide* of iron, since in the commonly used nomenclature the simple substance iron is only supposed to combine with the simple substance sulphur (producing sulphide or sulphuret of iron), and not with its oxygen acid (sulphuric acid), which is ordinarily supposed to require an oxygen base.

"Again, the very same acid and base may unite in different proportions, and produce another set of salts. In such cases the one considered to be the neutral salt receives a name formed in the manner just described, while those which contain more acid or base than it are distinguished by prefixes in the following manner:—

TABLE III.

When the equivalent proportion of acid to base is as		There is prefixed	Example.
Acid in excess.	2 : 1	Bi.	Bisulphate of potash.
	3 : 2	Sesqui.	Sesquicarbonate of ammonia.
Base in excess.	1 : 2	Di or dis.	Disulphate of zinc.
	1 : 3	Tri or tris.	Trisulphate of copper.
	1 : 4	Tetra.	Tetranitrite of lead.
	1 : 5	Penta.	Pentasulphate of copper.
	1 : 6	Hexa.	Hexanitrate of lead.

"In a great number of cases the salts composed of one equivalent of a protoxide base, united to one equivalent of acid, are considered the neutral salts; those containing more than one equivalent of acid being called acid salts; those having more than one equivalent of base basic salts. Hence the term basic is sometimes added to the other prefix, as in the case of trisulphate of copper, which is sometimes called tribasic sulphate of copper. This addition, however, may lead to confusion, as there is a class of acids called polybasic, in the salts of which, terms such as bibasic, etc., are used in a different sense."—W. K. S.

Relation of the oxygen in the base to that in the acid.—It is further necessary to consider, not merely the composition of a salt as a union of so many equivalents of acid and base, but also the nature of the combination as regards the proportions of oxygen in each.

"If we take sulphuric acid (SO_3) and potash (KO), for instance, it is found by experiment that they combine to form a neutral salt, sulphate of potash, in such proportionate quantities that the ratio of oxygen in acid : that in base :: 3 : 1. Chemists have agreed to consider, by analogy, all the sulphates of the oxides of the metals as neutral salts which have the same ratio of—

Oxygen in base : oxygen in acid :: 1 : 3.

"The protosulphate of iron $Fe\ O + SO_3$ has this ratio; but sesquisulphate $Fe_2\ O_3 + 3\ SO_3$ has the same ratio, since it has 3 equivalents of oxygen in the base, and 9 in the acid, and 3 : 9 = 1 : 3. The difference between them is, as expressed by the formulæ, that the protosulphate contains one equivalent of the protoxide (base) to one of the *ter*oxide (acid), while the sesquisulphate contains one of the sesquioxide (base) to three of the *ter*oxide (acid), (that is once O_3 to thrice O_3 or 1 : 3 as before.) In other words, all neutral salts require one additional equivalent of acid to every additional equivalent of oxygen in the base. If we represent the metals by the common symbol R, then the following formulæ would represent the composition of the neutral sulphates; for—

		O in base.		O in acid.	Ratio of No. of equivalents of base to		No. of acid.
Protoxides	$RO + SO_3$	1	:	3	1	:	1
Sesquioxides	$R_2\ O_3 + 3\ SO_3$	1	:	3	1	:	3
Deutoxides	$RO_2 + 2\ SO_3$	1	:	3	1	:	2

"The ratio of the oxygen in the base to that in the acid varies of course for every acid, but is the same for all the salts which are considered neutral that are formed by the same acid with a series of bases; thus :—

In carbonates it is as . . . . . 1 : 2
In chlorates . . . . . . 1 : 5
Etc. etc.

"*Formation of Silicates.*—The salts which silica is capable of forming with the bases are extremely numerous, and are seldom of so simple a composition as those for which the ordinary nomenclature was constructed; hence when the chemical composition of minerals began to be studied, and chemical names given to them, a somewhat different system of nomenclature was unfortunately adopted. Thus, those silicates in which the proportion of acid to base, whether that base were protoxide or sesquioxide, was as 1 : 1, were called silicates or *mono*silicates, where that relation was 2 : 1 *bi*silicates, where 3 : 1 *tri*silicates. Those in which the proportion of acid was less than that of a monosilicate were called *sub*silicates.

"If silica be a teroxide ($Si\ O_3$), then it is clear that what was called a trisilicate of a sesquioxide should, in harmony with the nomenclature just given be considered as the neutral silicate, and the *bi*silicates and *mono*silicates as basic salts. If, on the other hand, we adopt the preferable formulæ $Si\ O_2$, or consider silica a *deut*oxide, then the formerly basic silicate $3\ (R\ O) + 2\ (Si\ O_3)$ would become the monosilicate with the much more simple formula $RO + Si\ O_2$. The determination of whether silica be a deutoxide or teroxide is attended with considerable difficulties; but the balance of evidence now leans strongly in favour of the former; and Kopp, whose experiments formerly opposed that view, has very recently shown the objections to be unfounded. Adopting the formulæ $Si\ O_2$ for silica, the following will represent the general formulæ for all, or nearly all, the simple silicates hitherto examined, whether natural or artificial. It is always better to indicate a particular simple silicate by the relation between the oxygen in the acid and base, and in a double silicate by the same relation in each of the simple silicates forming it. This obviates the necessity of making names for the complicated ones. It is also especially necessary, inasmuch as many names of silicates refer to the silicates of the protoxides, and are inapplicable to those of the sesquioxides. Thus, in the following table, there are two silicates in which the relation of the oxygen of the acid is to that of the base : : 4 : 3—namely, $3\ RO,\ 2\ Si\ O_2$ and $R_2\ O_3,\ 2\ Si\ O_2$. The name of two thirds silicate, as now commonly used, applies only to the former, as having 2 equivalents of acid to 3 of base. If, however, we view it as applying to 2 equivalents of acid to 3 equivalents of oxygen in the base, the name becomes applicable to both silicates. Similarly all the other names would apply upon the same view being adopted.

"All the silicates of the protoxides in the following table either exist naturally or have been formed artificially, but very few of the corresponding silicates of the sesquioxides occur, several of those in the following table having been added merely to show what they would be if they did occur. Those underlined are found most frequently; indeed, we might almost say exclusively in the double silicates of alumina. Such silicates as two-thirds, three-fourths, etc., are perhaps not simple silicates, but compounds of other more simple ones. It may hereafter be found that the number of silicates which exist naturally in combination is much smaller than has been supposed."—W. K. S.

TABLE IV.

Relation of Oxygen in the	Acid. Base.	Name.	Formulæ of Silicates of Protoxides.	Formula of Silicates of Sesquioxides.
Acid in excess.	72 : 1	Triacontahexsilicate.	RO, 36 $Si O_2$.	
	48 : 1	Eicositessarasilicate.	RO, 24 $Si O_2$.	
	36 : 1	Octocaidecasilicate.	RO, 18 $Si O_2$.	
	16 : 1	Octosilicate.	RO, 8 $Si O_2$.	$R_2 O_3$, 24 $Si O_2$.
	8 : 1	Tetrasilicate.	RO, 4 $Si O_2$.	$R_2 O_3$, 12 $Si O_2$.
	6 : 1	Trisilicate.	RO, 3 $Si O_2$.	$R_2 O_3$, 9 $Si O_2$.
	4 : 1	Bisilicate.	RO, 2 $Si O_2$.	$R_2 O_3$, 6 $Si O_2$.
	3 : 1	Sesquisilicate.	2 RO, 3 $Si O_2$.	2 $R_2 O_3$, 9 $Si O_2$.
Neutral Silicate.	2 : 1	Monosilicate.	RO, $Si O_2$.	$R_2 O_3$, 3 $Si O_2$.
Basic Silicates.	1 : 1	Disilicate, or bibasic.	2 RO, $Si O_2$.	2 $R_2 O_3$, 3 $Si O_2$.
	1 : 1½ or 2 : 3	Tribasic silicate.	3 RO, $Si O_2$.	$R_2 O_3$, $Si O_2$.
	1 : 2 or 2 : 4	Quadribasic silicate.	4 RO, $Si O_2$.	4 $R_2 O_3$, 3 $Si O_2$.
	2 : 6 or 1 : 3	Sexbasic silicate.	6 RO, $Si O_2$.	2 $R_2 O_3$, $Si O_2$.
	4 : 3	Two-thirds silicate.	3 RO, 2 $Si O_2$.	$R_2 O_3$, 2 $Si O_2$.
	3 : 2 or 6 : 4	Three-fourths silicate.	4 RO, 3 $Si O_2$.	4 $R_2 O_3$, 9 $Si O_2$.
	5 : 2 or 10 : 4	Five-fourths silicate.	4 RO, 5 $Si O_2$.	4 $R_2 O_3$, 15 $Si O_2$.
	8 : 3	Four-thirds silicate.	3 RO, 4 $Si O_2$.	3 $R_2 O_3$, 12 $Si O_2$.

Laws of Form.

Before entering on the description of compound minerals, it is necessary that we should understand something of some chemical principles relating to the forms of bodies.

Every true mineral has a definite geometrical form, as well as a definite chemical composition. This definite geometrical form is called its crystal. A crystal is not necessarily transparent, many are opaque ; the definite form being its only essential attribute.

The forms of crystals are very numerous, but they may all be classed into six systems of crystallisation, depending on the position of the "axes," or right lines about which their faces are symmetrically arranged.

These systems of crystallisation have been variously named, and may be found described in most chemical and mineralogical manuals. The following combines the description of Regnault * and the Rev. W. Mitchell:—†

1st System. The cubical or octohedral; according as we consider the regular cube or regular octohedron its typical or primitive form. It is characterised by three equal axes at right angles to each other.

2d System. Square, prismatic, or pyramidal. Typical form, a prism on a square base, or octohedron on a square base; characterised by three axes at right angles to each other, of which, however, only two are equal.

3d System. Rhombohedral or hexagonal. Typical form, the rhomboid or the hexagonal prism; characterised by four axes, of which three are equal, situated in the same plane, and cut each other at an angle of 60°; the fourth axis passes through their intersection, and is at right angles to the plane of the other three.

4th System. Prismatic or rhombic. Typical form, a right prism on a rhombic base, or octohedron on a rhombic base; characterised by three unequal axes at right angles to each other.

5th System. Oblique. Typical form, an oblique prism on a rhombic base, or oblique pyramid on a rhombic base; characterised by three unequal axes, two of which are obliquely situated with respect to each other, and the third is at right angles to the other two.

6th System. Anorthic, or doubly oblique. Typical form, a doubly oblique prism or octohedron; characterised by three unequal axes, which are all oblique one to the other.

Isomorphism and Allotropism.—I have said that all minerals, properly so called, possess a definite chemical composition, *i. e.*, are made up of precisely the same ingredients in exactly the same proportion; and also a definite form, that is, are either one of the primary or typical forms mentioned above, or modifications of those forms strictly deducible from them by geometrical rules.

We have now to modify this statement, since it has been found that there are certain groups of substances which have the power of replacing each other, or can be substituted for each other, under certain conditions, without producing any noticeable change of form in the crystal of the mineral, or any essential difference in its chemical composition, so far as the ratio of the oxygen in the base to that in the acid is concerned.

* Regnault's *Crystallography*. Bailliere.

† *Crystallography and Mineralogy*; Orr's *Circle of the Sciences*.

Bodies possessing this property are said to be isomorphous. Among the substances mentioned in Table III., for instance, potash, soda, lime, magnesia, protoxide of iron, and protoxide of manganese (all being simple oxides), are isomorphous, and can thus replace each other. Alumina and peroxide of iron, again (both sesqui-oxides), are isomorphous. One consequence of this law is, that we find considerable differences between the different analyses of the same mineral, according as each specimen analysed, contains more or less of different isomorphous substances. It is hence necessary always to reduce the analyses of minerals to a theoretical or normal formula, which groups the isomorphous bases together, and points out the relations of the group to the acids present in the mineral. Such a group of bases is commonly denoted by the letter R in chemical formulæ.*

* "One of the best examples of isomorphism is presented by the various alums, of which there are no less than twelve, all of which crystallise in regular octohedrons, and may be represented by the following formula:—

$$RO.\ SO_3 + R_2O_3,\ 3\ SO_3 + 24\ HO.$$

Now, in this formula, RO, the protoxide base, may be any one of the three substances KO (potash), Na O (soda), NH_4O (oxide of ammonium); and $R_2\ O_3$, the sesqui-oxide base may be any one of the four substances $Al_2\ O_3$ (alumina), $F_2\ O_3$ (sesqui-oxide of iron), $Cr_2\ O_3$ (sesqui-oxide of chromium), or $Mn_2\ O_3$ (sesqui-oxide of manganese). There are, therefore, $3 \times 4 = 12$ possible combinations.

Perfectly isomorphous bodies or *isotomes* are those which have the same crystalline form, and similar formulæ, and equal atomic volumes. The conditions for perfect isomorphism can only be fulfilled in crystals belonging to the regular system.

Those in which the last conditions are only partially, or not at all fulfilled, are said to be *homoiomorphous*. The replacement of an equivalent of one body by a multiple of the equivalent of another, is termed *polymeric isomorphism*. Thus, for example, according to Scheerer, 3 HO (3 equivalents of water) can replace Mg O (magnesia), without changing the form.

Heteronomic isomorphism is that kind of homoiomorphism in which the condition of equal atomic volumes is fulfilled by dividing the unequal atomic volumes of two homoiomorphous bodies by the number of atoms in each compound. Dana has applied this property to connect together different formulæ. The analysis of some minerals led to the following general formulæ; and from them were calculated the annexed atomic volumes:—

No. 1. $(RO)_3\ (Si\ O_3)_2 + 3\ (R_2\ O_3,\ Si\ O_3) = 1808.$
No. 2. $(RO)_3\ (Si\ O_3)_2 + 6\ (R_2\ O_3,\ Si\ O_3) = 3013.$
No. 3. $(RO)\ (Si\ O_3) + 4\ (R_2\ O_3,\ Si\ O_3) = 1850.$

Now No. 1 contains 41 atoms and $1808 \div 41 = 44.$
And No. 2 „ 68 „ and $3013 \div 68 = 44.$
And No. 3 „ 42 „ and $1850 \div 42 = 44.$

The conditions of equal atomic volume were thus fulfilled.

Homoiomorphism has a very extended meaning, according to some persons, and is not, according to them, like true isomorphism, confined to forms of the same system alone, but may exist between forms belonging to two different systems. Thus, for example, orthoclase or potash feldspar is homoiomorphous with albite or soda feldspar, though the former belongs to the fifth and the latter to the sixth system."—(W. K. S.)

Dimorphism, again, is the property which some substances have of crystallizing in two different forms belonging to two different systems of crystallization. These different crystals of the same substance vary not only in external form, but often also in density, hardness, &c.

They thus form different minerals and go by different names, although they have essentially the same chemical composition.*

This assumption of a different form in the same substance often seems to depend on the different circumstances of temperature, &c., under which the crystals have been produced. "It is often remarked that crystals which have been formed at high temperatures, and which were perfectly transparent at the moment of their production, become opaque and pulverulent after a short time. Disaggregation ensues, because the molecules have a tendency to arrange themselves differently, in accordance with the forces which prevail at less elevated temperatures. It is often possible, when this alteration has occurred, to distinguish, with the aid of a magnifier, that the mass is formed of small rudimentary crystals possessing the form which the substance affects at ordinary temperatures."—*Regnault*.

A mineral, then, when composed of a substance possessing the property of dimorphism, might have an external crystalline form belonging to one system, while internally it is made up of crystalline particles belonging to another system.

Carbonate of lime crystallised from cool solutions takes the form of calcite, but if their temperature exceed 150° it will become arragonite. On the other hand, crystals of arragonite heated by a spirit lamp, decrepitate and fall into powder, which consists of grains having the form of calcite.

"Iodide of mercury, when freshly sublimed, is of a lemon yellow colour, but it gradually becomes scarlet as it cools, or suddenly if vibrated or pressed, or if the surface of a mass of crystals be scratched with a pin; a similar change of colour is observable in many cases where no dimorphism has been traced, because the substances have not crystallized in both states. Sulphide of mercury, for example, obtained by precipitating a salt of mercury with sulphide of hydrogen, is black, but when sublimed it constitutes cinnabar, which in powder forms the pigment vermillion. The change in colour is often accompanied by changes in other properties, and such changes also occur without any change of colour.

"This modification in the properties of a body, not resulting from chemical combination, has been called by Berzelius allotropy

* Some bodies are even capable of assuming three incompatible forms, and are therefore said to be *trimorphous*. Of these, sulphate of nickel is an example. (W. K. S.)

(αλλοτροπος, that can be turned from one thing into another). Dimorphism is merely a particular case of allotropism, of the influence of which many other examples might be given did space permit.

"The glassy structure of bodies is connected with these phenomena. Most of the simple silicates of lime, iron, etc. (except perhaps the very basic silicates of lead), even when formed into perfect glass, do not retain that form, a crystalline structure being developed in them. But a mixture of such silicates forms true glassy masses, which remain permanently so. Even in these however, if kept in a soft state for a long time at a high temperature, a species of crystallization takes place, which is termed devitrification. This was at one time supposed to be the result of a separate crystallization of the simple silicates, but is probably only depending on the allotropism of the mixture.

"The amorphous condition of bodies would, in like manner, appear to be in some instances connected with allotropism. Many substances which are classed as amorphous exhibit a tendency to assume globular structures, which may perhaps be considered a third form, in addition to the glassy and crystalline states. Thus, for instance, carnelian, when polished and plunged into liquid hydrofluoric acid, is acted upon, and its surface in a short time exhibits the concentric layers so characteristic of agates.

"A peculiar kind of allotropism is observed among several metallic peroxides, as also several salts, silicates, etc., that, after being heated to a certain point, they cease to be soluble in acids, and this independently of the fact of those that are hydrates losing their water.

"This seems to be connected with the fact that silica, for instance, is soluble in water in one allotropic state, and insoluble in another. It has quite recently been discovered that even alumina and sesquioxide of iron can be got in such a state as to be soluble in pure water or in weak acids, while at the same time they are insoluble in strong acids.—(See *Journal of Chem. Soc.*, vol. vi. p. 217—Walter Crum's paper on alumina; Pean de St. Gilles on iron, Compt. Rendus, tom. xl. pp. 568 and 1243.)

"When we consider these facts, and reflect on the numbers of bodies that are susceptible of an allotropic condition, and recollect that heat is evolved as a body passes from one state to another, especially, if indeed it be not always, in passing from the least permanent to the more stable condition, and that a difference of its specifi heat exists between different allotropic conditions of bodies, we canc not help believing that a light is dawning upon us that must inevitably modify our explanations of the chemical phenomena of geology."—W. K. S.

Metamorphism and pseudomorphism are most interesting and important divisions of this subject, but they will be considered in a future place. A particular kind of pseudomorphism, called *paramorphism*, will also be hereafter alluded to, and in connection with that, the *paragenesis* of minerals in rocks.

Rock-forming Minerals.

Let us now select from Table I. the following fifteen simple substances, which are more especially necessary for the study of lithology, and arrange them in Table V. with their symbols and equivalents.

TABLE V.

Symbol.	Simple Substances.	Equivalent Number.
O	Oxygen	8.00
H	Hydrogen	1.00
C	Carbon	6.00
S	Sulphur	16.00
Cl	Chlorine	35.51
Si	Silicon	14.22
K	Potassium	39.17
Na	Sodium	23.21
Li	Lithium	6.54
Ba	Barium	68.53
Ca	Calcium	20.16
Mg	Magnesium	12.67
Al	Aluminum	13.69
Mn	Manganese	27.61
Fe	Iron	28.08

These simple substances combine variously with each other to produce various primary compounds.

Confining our attention solely to the production of those substances which commonly form constituents of rocks, we may say, in the first place, that oxygen combines with all the rest, one after another, to produce the most common substances we know, all, namely, except the last, in the following Table VI.

Hydrogen and carbon, uncombined with oxygen, are found only in organic products, and in those mineral substances which are derived from organic products, and do not enter into combination with any of the rest to produce rock-forming minerals. Sulphur, in combination with iron (bisulphide of iron, iron pyrites), frequently occurs in rocks, but cannot be said to be one of their constituent minerals. Chlorine is found in combination with one only of the succeeding substances to produce a rock-forming mineral, namely, with sodium, to produce chloride of sodium or rock-salt.

Table VI. contains all the substances whose composition it is essential to understand for lithological purposes, together with the

Haematite, iron peroxide, Fe_2O_3, red. Specular iron.
Magnetic iron, Fe_3O_4, dark crystals or powder.
Limonite, $2(Fe_2O_3)\ 3(H_2O)$, black to yellow powder.

Spathic iron = Iron Carbonate, $FeCO_3$. blue = Siderite

number of the equivalents of the simple substances of which they are compounded, the symbols representing those equivalents, and the resulting equivalents of the compounds.

Iron Pyrites, FeS_2, yellow crystallised.

TABLE VI.

Name of Primary Compound.	Number of Equivalents of Simple Substances.	Symbol of Compound.	Equivalent of Compound.
1. Water	1 of oxygen to 1 of hydrogen	HO	9.00
2. Carbonic acid ...	2 ,, 1 of carbon	CO^2	22.00
3. Sulphuric acid...	3 ,, 1 of sulphur	SO^3	40.00
4. Silicic acid (or Silica)	2 ,, 1 of silicon	$Si\ O^2$	30.22
5. Potash	1 ,, 1 of potassium	KO	47.17
6. Soda	1 ,, 1 of sodium	$Na\ O$	31.21
7. Lithia	1 ,, 1 of lithium	$Li\ O$	14.54
8. Baryta	1 ,, 1 of barium	$Ba\ O$	76.53
9. Lime	1 ,, 1 of calcium	$Ca\ O$	28.16
10. Magnesia	1 ,, 1 of magnesium	$Mg\ O$	20.67
11. Alumina	3 ,, 2 of aluminum	$Al^2\ O^3$	51.38
12. Protoxide of manganese	1 ,, 1 of manganese	$Mn\ O$	35.61
13. Protoxide of iron	1 ,, 1 of iron	$Fe\ O$	36.08
14. Peroxide of iron	3 ,, 2 of iron	$Fe^2\ O^3$	80.16
15. Rock salt (or Chloride of sodium)	1 of chlorine to 1 of sodium	$Cl\ Na$	58.72

Every mineral substance which enters as an essential constituent into the composition of rocks is either one of the simple substances contained in Table V., one of the primary compounds mentioned in Table VI., or lastly, a *secondary compound* made up of the union of two or more of those primary compounds.

Minerals formed of Simple Substances.

Of the simple substances contained in Table V. two only are ever found as minerals, namely, carbon and sulphur.

1. *Carbon* when crystallized in the first system forms the *diamond;* when in an allotropic state it crystallizes in the third system, it forms *graphite* or *plumbago.* It is, however, only when found as a constituent of coal that we need notice it for the purposes of lithology.

2. *Sulphur* is found crystalline in minute octohedrons about volcanoes, but pure sulphur never occurs as one of the uncombined constituents of rocks.

Minerals formed of Primary Compounds.

Of the compound substances mentioned in Table VI. silica and rock-salt only occur in nature as rock-forming minerals.

3. *Quartz* is formed of pure silica ($Si\ O^2$). It is found crystallized in six-sided prisms, ending in six-sided pyramids, third system; and also amorphous as a hard, compact stone, commonly milk white.

Rock crystal, Bristol, and Irish diamond, etc., are common names for crystallized quartz.

When coloured by slight admixtures of other substances, as iron, manganese, etc., quartz goes under various names, according to the variety and arrangement of colours, state of transparency, etc.

When purple, it is called *amethyst;* smoky quartz is *cairngorm;* blue quartz is *siderite;* green quartz, *prase;* when yellow it is sometimes called *Scotch* or *Bohemian topaz.* *Agate, jasper, carnelian, onyx, sardonyx, catseye, Lydian-stone, bloodstone, chert,* and *flint,* are other forms of quartz.

Opal is hydrated silica, *i. e.*, having water chemically combined with the silica; and *chalcedony* is a mixture of quartz and opal.

Siliceous sinter is an opaline silica deposited on the margins of some hot springs, having been dissolved in the water.

4. *Rock-salt* occurs in large masses in some localities, in beds or veins. It is either amorphous, or more or less completely crystalline; the primary form of the crystal being a cube.

Corundum or crystalline alumina, and *specular iron* or crystalline sesquioxide of iron, come under this head, but cannot be called constituents of rocks.

Minerals composed of a Combination of Two or More Primary Compounds.

We shall take these in the following order, namely—1*st*,

... pattle, phosphate of Lime, in ... prisms, greenish, scratched with a knife.

the combinations with carbonic acid; 2*d*, those with sulphuric acid; and lastly, those with silicic acid.

CARBONATES.—Of the carbonates there are two only which are of importance for our purpose, namely, those of lime and magnesia.

5. *Carbonate of Lime*, *Calcspar* or *Calcite*, is a very abundant mineral. It is a mono-carbonate, or composed of one equivalent of lime and one of carbonic acid (Ca O, C O^2), the bicarbonate of lime, which would be symbolised as Ca O, 2 CO^2, not being definitely known.

Its chemical composition is—	Percentage.	Equiv.	At.
Carbonic acid	43.87	22.00	1
Lime	56.13	28.16	1
	100.00	50.16	

Its primary crystal is a rhombohedron, belonging to the third system, but the modifications of this form are very numerous, particular forms of crystals being often peculiar to particular localities. It is sufficiently soft to be scratched with a knife, and it effervesces freely with any mineral acid, even when dilute. Its specific gravity is about 2.7.

When carbonate of lime dissolves in water holding CO^2 (carbonic acid), a bicarbonate is supposed to be formed, but on the evaporation of the water the CO^2 also escapes, and the simple carbonate alone remains.

6. *Arragonite* is the same substance in a different form, the crystals belonging to the fourth system, and having many secondary forms.

It is rather harder than calcite, and its specific gravity rather greater, being sometimes as much as 3. It not unfrequently contains a small proportion of strontia.

The importance of arragonite as a constituent of rocks is very slight compared with that of calcite.

7. *Magnesite*, or *Carbonate of Magnesia*, is composed of one equivalent of carbonic acid and one of magnesia (= Mg O, CO^2), its normal composition being—

	Percentage.	Equiv.	At.
Carbonic acid . . .	52.38	22.00	1
Magnesia	47.62	20.10	1
	100.00	42.10	

This is by no means an abundant or important mineral, carbonate of magnesia usually occurring in combination with carbonate of lime to form the mineral called—

8. *Dolomite*, *Bitter Spar*, *Brown Spar*, *Pearl Spar*, or *Magnesian Limestone.*

The chemical composition of this mineral varies according to the proportions of the two carbonates which are mingled in it. Its normal composition may be stated at Ca O, CO^2 + Mg O, CO^2, giving the following percentage—

Carbonate of lime	54.3
Carbonate of magnesia . . .	45.7
	100.0

But the proportions vary greatly, and often indefinitely.

Its hardness and specific gravity are not greatly different from those of calcite, and its primary crystal is also rhombohedric; but dolomite may be often distinguished from calcite by its peculiar pearly lustre, and by the comparative difficulty and slowness with which it effervesces in acids.

Sulphates.—The only sulphate which is of any importance as a constituent of rocks is—

9. *Gypsum*, or *Sulphate of Lime.*—The chemical composition of this mineral is one equivalent of lime, one of sulphuric acid, and two of water, being a bihydrated sulphate of lime. Its normal formula is Ca O, S O^3 + 2 H O, giving the following percentage—

Lime	32.56
Sulphuric acid	46.51
Water	20.93
	100.00

Its crystalline system is the fifth or oblique prismatic. It also frequently occurs fibrous, granular, or compact. It is softer than calcspar, and its specific gravity is about 2.3.*

Compact white gypsum is called alabaster; the transparent crystals are called selenite.

* The gypseous alabaster must not be confounded with the true or Oriental alabaster, which is a species of stalactitic carbonate of lime.—W. K. S.

10. *Anhydrite* is sulphate of lime without water, its formula being Ca O, S O^3, which gives—

Lime	41.18
Sulphuric acid	58.82
	100.00

It is harder and heavier than true gypsum.

Silicates.—The combinations of lime and magnesia with gaseous carbonic acid may take place at the ordinary temperatures of the air, either directly from the atmosphere or through the medium of water, and that of lime with liquid sulphuric acid at any ordinary temperature.

In order to induce the solid silicic acid, or Silica, however, to enter into combination with any of the bases, it is, in the majority of cases, necessary that the two be mingled together in a fine state of division, and be subjected to a very high temperature.

For the production of the artificial silicates, glass and porcelain, the heat of a furnace is necessary. It is useful to remember this fact when examining the great group of the natural silicates.

SILICATES OF POTASH AND SODA

Which are the bases of artificial glass, do not occur alone as natural minerals, though they enter into the composition of many.

SILICATE OF LIME

However occurs both as a detached simple mineral and as a constituent of other minerals.

11. *Wollastonite*, or *Tabular Spar*, is a mono-silicate of lime. Its normal formula is Ca O, Si O^2, giving the percentage—

Lime	47.46
Silica	52.54
	100.00

O in a : O in b : : 2 : 1.*

It crystallizes in the 5th system. It is white, translucent, fusing

* Oxygen in Acid : Oxygen in Base : : 2 : 1.
This relation, for the explanation of which see ante Table IV., will be noted in many of the following minerals.

with difficulty before the blow-pipe, having a specific gravity of about 2.7, and a hardness greater than that of calcite, but less than feldspar.

Okenite is a bi-silicate of lime with two equivalents of water.

Datolite is a borate and silicate of lime with one equivalent of water.

Botryolite is the same, with two equivalents of water.

Apophyllite is a silicate of lime and potash.

Pectolite is silicate of lime and soda.

SILICATES OF MAGNESIA.

Of these we have first the anhydrous, di-silicate (bi-basic silicate) forming the mineral.

12. *Chrysolite and Olivine*, consisting of two equivalents of magnesia to one of silica, having the normal formula 2 Mg O, Si O^2, which gives the percentage—

Magnesia	56.34
Silica	43.66
	100.00

O in a : O in b :: 2 : 2 = 1 : 1.

The crystalline system is the 4th or right prismatic. The specific gravity about 3.4, harder than felspar, transparent, generally of a yellowish-green colour. It is infusible before the blow-pipe. Some of the magnesia is commonly replaced by iron, sometimes as much as 15 per cent.

13. *Serpentine* (noble serpentine) has three equivalents of magnesia to two of silica and two of water, having the normal formula 3 Mg O, 2 Si O^2 + 2 H O, or 2 (Mg O Si O^2) + (Mg O, 2 H O), giving the proportions—

Magnesia	42.86
Silica	44.28
Water	12.86
	100.00

O in a : O in b : : 4 : 3 (exclusive of water.)

Specific gravity 2.55, hard as calcspar, translucent, generally of a green colour and waxy lustre. Fuses at the edges before the blow-pipe to a white enamel.

Variegated Asbestos has the same composition.

Schillerspar and Picrosmine have nearly the same composition as Serpentine.

Talc & Serpentine are Silicates of magnesia with water, Soft, greasy. Talc in plates

14. *Talc* is formed of five equivalents of silica with four of magnesia. Its normal formula may be stated as 2 (Mg O Si O^2) + (2 Mg O, 3 Si O^2), giving the following percentage—

Magnesia	34.04
Silica	65.96
	100.00

O in a : O in b :: 10 : 4 = 5 : 2; or, 2 (2 : 1) + (6 : 2 = 3 : 1.)

It occurs in rhombic and six-sided tabular crystals belonging to the 3d system; specific gravity about 2.7, softer than gypsum, translucent, pearly lustre, unctuous touch. Splits into laminæ before blow-pipe, and hardens without fusing.

15. *Steatite*, or *Soapstone*, has four equivalents of silica to three of magnesia, or Mg O, Si O^2 + 2 Mg O, 3 Si O^2, giving—

Magnesia	32.61
Silica	67.39
	100.00

O in a : O in b :: 8 : 3; or, 2 : 1 + (6 : 2 = 3 : 1.)

Specific gravity 2.6, soft, unctuous, slightly translucent. Before blow-pipe fuses at edges to white enamel.

SILICATES OF MAGNESIA AND LIME.

16. *Augite*, or *Pyroxene*, is most probably a monosilicate of magnesia and lime—that is, it contains two equivalents of silica to one of magnesia and one of lime, having the normal formula Ca O, Si O^2 + Mg O, Si O^2, which would give the percentage—

Magnesia	18.18*
Lime	25.46
Silica	56.36
	100.00

O in a : O in b :: 4 : 2 = 2 : 1; or, 2 : 1 + 2 : 1.

* Analyses by Wackenroder, Bonsdorf, and Rose, come sufficiently near to this normal formula to warrant us in stating it as a good theoretical idea of augite. In fact, both lime and magnesia are variously replaced by oxides of manganese and iron. Many augites also contain alumina, and may then be looked on as mixtures of (say) 5 atoms of true augite with one of some kind of garnet.

Its crystalline system is the 5th or oblique prismatic. Specific gravity about 3.4, hardness rather less than felspar. Fuses with various degrees of facility according to composition, the magnesia being often replaced to a large extent by protoxide of iron.

Diallage, or *Bronzite*, has a similar composition, but the bases are more numerous and variable, and there is generally present 1 to 4 per cent of alumina, and from $\frac{1}{4}$ to 4 per cent of water.

Hypersthene is also like *Augite* in its chemical composition, but has commonly less lime.

18. *Hornblende*, or *Amphibole*, is a compound of 6 equivalents of silica to 5 equivalents of base; having the formula $3\,(Mo, Si\,O^2), + 2\,Mo, 3\,Si\,O^2$, where the base Mo denotes a variable mixture of magnesia and lime, and the protoxides of iron and manganese.

Alumina is often present either as an aluminate of magnesia, or an aluminate of iron; not unfrequently fluoride of calcium also occurs. The composition varies much, within certain limits, as may be seen from the following:—

Lime .	13.19	9.82	14.41
Magnesia .	18.84	12.85	15.44
Iron, protox.	7.77	19.19	9.05
Silica .	46.53	50.71	47.86
Alumina .	12.10	7.01	13.24
Fluoric acid	1.57	0.42	
	100.00	100.00	100.00

O in a : O in b : : 12 : 5, or 3 (2 : 1) + 6 : 2 = 3 : 1.

Crystalline system the fifth or oblique prismatic. Specific gravity about 3.2. Hardness less than felspar. Colour dark green, almost black sometimes. Before blowpipe, readily swelling up, and fusing to a dark glass.

Tremolite has a similar composition; a specific gravity of 2.93, and fuses with difficulty to a colourless glass.

Actinolite, similar composition; specific gravity 3.03; coloured green by chromium and iron.

Anthophyllite, similar composition; specific gravity 3.2; fuses with great difficulty to a blackish grey glass.

Ordinary Asbestos, *Amianthus*, *Wood-asbestos*, *Petrified Cork*, *Byssolite*, etc., consist of tremolite, actynolite, or common hornblende, in a very fine fibrous state.

"When one atom of lime is fused with one atom of magnesia and two atoms of silica, or one atom of lime with two atoms of magnesia and six of silica, and the mass very slowly cooled, it crystallizes in the form of augite. The first mixture yields a mass resembling ordinary augite; the latter a mass like augite from Finland. In the cavities of a slag from an iron furnace, fed with a hot air blast, Nöggerath found artificial crystals of augite."—*Gmelin*, vol. iii. p. 402.

"G. Rose (Pogg. 22, 321) considers that augite and hornblende belong to the same class, and for the following reasons:—the angles of either of these minerals may be reduced to those of the other; crystals are found in the form of augite with the cleavage of hornblende; when crystals of hornblende and augite have grown together, their axes are parallel; the specific gravity and composition of the two minerals are identical; if the fused mass is rapidly cooled, it assumes the appearance of augite, and if cooled slowly, it seems to crystallize in the form of hornblende. When, therefore, both are found together, the hornblende surrounds the crystals of augite, which are the first produced. From this cause, hornblende is accompanied by quartz, felspar, albite, and other minerals which are formed by the slow cooling of molten masses; augite, on the contrary, is found with olivine, which crystallizes by rapid cooling. For the same reason, slags, from being too quickly cooled, yield only crystals of augite. According to Mitscherlich and Berthier, also the fusing together of lime, magnesia, and silica, yields white crystals of augite, but none of hornblende; and even *tremolite*, fused by Mitscherlich and Berthier in a charcoal crucible, or *actynolite*, by G. Rose, in a platinum crucible in a potter's furnace, solidified to a mass consisting of distinct crystals of *augite*.—(G. Rose). It is remarkable that hornblende is always richer in silica than augite."—*Gmelin*, H. 6, vol. iii. p. 408.

Uralite.—"Scheerer has used the law of paramorphic pseudomorphism to explain the structure of this mineral, which, with the composition of hornblende, has the external form of augite, and very often a crystal of true augite within it, while the external layer exhibits the cleavage, and all other properties of hornblende."
—W. K. S.

The silicates of alumina are a still more important and numerous class than those of magnesia, especially those which are combined with silicates of potash, soda, lime, magnesia, etc.

A.—SILICATES OF ALUMINA ONLY.

Collyrite and *Opaline Allophane* are hydrated silicates of alumina, in which there is one equivalent of silica to two of alumina.

O in a : O in b : : 2 : 6 = 1 : 3, (exclusive of water.)

20. *Andalusite* and *Chiastolite* are anhydrous silicates of alumina, andalusite having the normal formula $Al^2 O^3$, $Si O^2$, and the percentage of—

Alumina	62.38
Silica	37.62
	100.00

O in a : O in b : : 2 : 3.

Crystals right rhombic prisms of the fourth system. Specific gravity, andalusite, about 3.1; chiastolite, about 3.0. Andalusite harder than quartz; chiastolite softer than felspar. Infusible.

Cyanite has a similar composition, (O in a : O in b : : 2 : 3), but has a specific gravity of about 3.6. Transparent, generally blue.

Miloschine and *Allophane* are hydrated silicates of alumina, with the same relation of O in a : O in b : : 2 : 3.

21. *Staurolite* has two equivalents of silica to three of alumina; one of the latter, however, being generally replaced by one of peroxide of iron. Its normal formula is $2\ Al^2 O^3,\ Fe^2 O^3 + 2\ Si O^2$, giving the percentage of—

Sesquioxide of iron	17.6
Alumina	51.4
Silica	31.0
	100.0

O in a : O in b : : 4 : 9, or 2 : 3 + 1 : 3.

It belongs to the fourth, or right prismatic system of crystallization.

The crystals frequently intersect each other in the form of a cross, whence its name. Specific gravity 3.5 to 3.8; harder than quartz. Translucent; dark red, or brown. Fuses at the edges to a black slag.

Clay, when pure, is a hydrated bisilicate of alumina.

Bole is the same, with part of the alumina replaced by peroxide of iron.

B.—COMPOUNDS OF SILICATES OF ALUMINA WITH SILICATES OF THE OTHER BASES.

(*a*) *Compound Silicates in which there are a greater number of equivalents of the Protoxide Bases than of Alumina.*

We pass over several minerals which occur rarely or in unimportant quantities, and come to

22. *Chlorite*, which is a compound of 4 equivalents of silicate of magnesia with 1 of silicate of alumina and 3 of water. Its normal formula being $4\,MgO,\,SiO^2 + Al^2O^3,\,SiO^2 + 3\,HO$, giving

Magnesia	25.47
Protoxide of iron	14.94
Alumina	21.81
Silica	26.32
Water	11.46
	100.00

O in a : O in b :: 4 : 7, or 4 (2 : 4) + 2 : 3, exclusive of water.

Crystalline system third or rhombohedral. Specific gravity about 2.8; soft, dark green, nearly infusible.

23. *Biotite*, *Uniaxal* or *Magnesia Mica*, has a similar composition for its principal varieties. The following gives the composition deduced from some analyses—

Potash	8.44
Magnesia	16.14
Protoxide of iron	13.46
Peroxide of iron	6.67
Alumina	13.10
Silica	42.19
	100.00

O in a : O in b :: 8 : 7, or 2 (2 : 3) + 4 : 3. (?).

Crystalline system the third or rhombohedral. Specific gravity about 2.8; hardness between gypsum and calc-spar. Dark green or brown, inclining to black; translucent. Fuses pretty easily to a semi-opaque glass.

Orthite has a somewhat similar composition, but contains a very variable quantity of water. O in a : O in b :: 8 : 7, or 4 (4 : 1) + 4 : 3.

24. *Vesuvian*, or *Idocrase*, is a silicate of lime, combined with a silicate of alumina, having the formula $3\ Ca\ O, 2\ Si\ O^2 + Al^2\ O^3, Si\ O^2$, some of the lime being replaced by magnesia and protoxide of iron, giving the following analysis—

Lime	32.26
Magnesia	2.43
Protoxide of iron	3.80
Alumina	19.93
Silica	40.58
	99.00

O in a : O in b : : 6 : 6, or 1 : 1 = 4 : 3 + 2 : 3.

It belongs to the second, or square prismatic system. Specific gravity = 3.3 to 3.4; harder than felspar. Transparent, yellowish green, swells up and readily fuses before blow-pipe.

25. *Garnet* is similar in composition to Vesuvian, but is dimorphous to it, belonging to the first or regular system of crystallization. Both the lime and the alumina, however, in the formula for Vesuvian, may be replaced by magnesia, manganese, and iron, and the analyses varying accordingly. We have, therefore, *calcareous-alumina garnet*, which predominates in cinnamon stone; *magnesio-alumina garnet* in the black garnet of Arendal; *manganesio-alumina garnet* in a North American variety, and one from Brodbo; *ferruginous alumina garnet* in Oriental alamandine and other red varieties of precious garnet; and *calcareous iron garnet* in the ordinary yellow, brown, and black garnets, and in *melanite.*

Specific gravity varies from 3.4 to 4.3, rather harder than quartz, transparent, of various colours, fuses readily into a transparent glass.

26. *Epidote* has three equivalents of protoxide bases to two equivalents of alumina, having the formula $3\ (Ca\ O, Mg\ O, Mn\ O, Fe\ O), 2\ Si\ O^2 + 2\ (Al^2\ O^3, Si\ O^2.)$

O in a : O in b : : 8 : 9, or 4 : 3 + 2 (2 : 3).

The protoxide base is lime in *zoisite* or calcareous epidote, replaced in large measure by iron in *pistacite* or ferruginous epidote, and by protoxide of manganese in manganesian epidote. In the two latter, part of the alumina is also replaced by the peroxides of manganese and iron. Epidote has for its primary crystal a right rhomboidal prism, (fourth system). Its specific gravity is 3.0 to 3.5; harder than felspar; fusible before the blow-pipe.

27. *Prehnite* has two equivalents of a silicate of lime to one of a silicate of alumina and one of water, or 2 ($Ca\,O$, $Si\,O^2$) + $Al^2\,O^3$, $Si\,O^2$ + $H\,O$, giving

Lime	26.74
Alumina	24.55
Silica	44.41
Water	4.30
	100.00

O in a : O in b :: 6 : 5, or 2 (2 : 1) + 2 : 3, exclusive of water.

Crystalline system, the fourth or rhombic, specific gravity 2.92, harder than felspar, translucent, of a light colour, fuses to a blistered glass.

Many varieties of uniaxal or magnesia mica appear to have a somewhat similar composition, the protoxide bases being $Mg\,O$, $K\,O$, $Ca\,O$, $Fe\,O$. It has not been yet satisfactorily shown whether the water which mica contains, is an essential constituent; the same remark applies to the fluoride of calcium which this also contains.

(*b*) *Compound Silicates in which the number of equivalents of Protoxide Bases is equal to that of Alumina.*

28. *Scapolite*, or *Wernerite*, is $Ca\,O$, $Si\,O^2$ + $Al^2\,O^3$, $Si\,O^2$, that is, a silicate of alumina with a silicate of lime, giving the percentage—

Lime	19.80
Alumina	36.35
Silica	43.85
	100.00

O in a : O in b :: 4 : 4 = 1 : 1, or 2 : 1 + 2 : 3.

Crystalline system the second or square prismatic. Specific gravity 2.7; softer than felspar. Colourless and translucent. Fuses before blow-pipe.

Palagonite is an amorphous highly hydrated Scapolite.

Anorthite has a similar composition; small portions of the lime being replaced by potash, soda, and magnesia.

29. *Ryacolite* consists of one equivalent of silicate of

potash, soda, or lime, and one of a silicate of alumina; or (K O, Na O, Ca O) $Si O^2 + Al^2 O^3$, 2 $Si O^2$, giving the percentage—

Potash	6.58
Soda	11.60
Lime	1.30
Alumina	28.66
Silica	51.86
	100.00

O in a : O in b : : 6 : 4 = 3 : 2, or 2 : 1 + 4 : 3.

Its crystalline system is the fifth, or oblique prismatic. Specific gravity = 2.6. Before the blowpipe, fuses rather more readily than felspar (orthoclase).

a lime-soda felspar

30. *Labradorite* consists of one equivalent of silicate of soda, three of silicate of lime, and four of a silicate of alumina; or Na O, $Si O^2 + 3$ (Ca O, $Si O^2$) + 4 ($Al^2 O^3$, $Si O^2$), giving—

Soda	4.50
Lime	12.13
Alumina	29.68
Silica	53.69
	100.00

O in a : O in b : : 24 : 16 = 3 : 2, or 4 (2 : 1) + 4 (2 : 3.)

Crystalline system, the sixth or doubly oblique prismatic. Specific gravity about 2.7. Fuses rather more readily than orthoclase.

31. *Thomsonite*, or *Comptonite*, is likewise similar in composition, but containing a large proportion of water, so that its normal formula is given as Na O, $Si O^2$, + 3 (Ca O, Si^2 O) + 4 ($Al^2 O^3$, $Si O^2$) + 8 H O, that is, 1 equivalent of silicate of soda, 3 of silicate of lime, 4 of silicate of alumina, and 8 of water.

O in a : O in b : : 16 : 16 = 1 : 1, or 4 (2 : 1) + 4 (2 : 3), exclusive of water.

Fourth or rhombic system. Specific gravity 2.3. Harder than fluor-spar. Transparent. Swells up before blowpipe, becomes opaque, and fuses at edges to white enamel.

Cordierite, in which the protoxide base is magnesia, with small quantities of iron, water, or lime.

O in a : O in b :: 20 : 10 = 2 : 1, or 4 (2 : 3) + 2 (6 : 6 = 1 : 1).

Fourth or rhombic system. It is softer than quartz. Specific gravity = 2.58. Before the blowpipe, fuses with difficulty; has a blue colour when viewed parallel to its axis, but perpendicular to it, a yellowish grey.

32. *Pinite* has one equivalent of silicate of potash, or protoxide of iron, to one of bisilicate of alumina, and also contains water; or $(K\,O,\ Fe\,O)\ Si\,O^2 + Al^2\,O^3,\ 2\ Si\,O^2 + H\,O$, giving—

Potash	12.42
Protoxide of iron	9.26
Alumina	27.04
Silica	48.92
Water	2.36
	100.00

O in a : O in b :: 6 : 4 = 3 : 2, or 2 : 1 + 4 : 3.

Its crystalline system is the third or hexagonal. Specific gravity 2.8. Softer than orthoclase; slightly translucent. Becomes colourless before blowpipe, and fuses at edges to blistered glass.

33. *Sodalite*, or *Soda Mesotype*, has one equivalent of silicate of soda, one of a silicate of alumina, and two of water, or $Na\,O,\ Si\,O^2 + Al^2\,O^3,\ 2\ Si\,O^2 + 2\ H\,O$; gives—

Soda	16.12
Alumina	26.55
Silica	48.04
Water	9.29
	100.00

O in a : O in b :: 6 : 4 = 3 : 1, or 2 : 1 + 4 : 3, exclusive of water.

Belongs to the right prismatic system; has a specific gravity of about 2.2; is softer than orthoclase; before the blowpipe becomes turgid, and fuses to a transparent glass.

Scolezite, or *Calcareous Mesotype*, has one equivalent of hydrated silicate of lime, to one of a silicate of alumina, and two of water.

Mesolite may be considered as a mixture of one equivalent of Sodalite and two of Scolezite.

34. *Leucite* has one equivalent of silicate of potash, and

Nephelite, Chabasite, soda-potash felspar
Leucite & nephelite are closely allied to the felspars and often replace them in igneous rocks. (W.H.S.)

one of a silicate of alumina, or K O, Si O^2 + Al^2 O^3, 3 Si O^2, giving—

Potash	21.20
Alumina	23.09
Silica	55.71
	100.00

O in a : O in b :: 8 : 4 = 2 : 1, or 2 : 1 + 6 : 3 = 2 : 1.

It belongs to the first or regular system; has a specific gravity about 2.4; a hardness rather less than orthoclase; is transparent, and infusible.

35. *Andesine* has one equivalent of silicate of potash, soda, lime, or magnesia, and one of a silicate of alumina, or (K O, Na O, Ca O, Mg O) Si O^2 + Al^2 O^3, 3 Si O^2, giving—

Potash	1.00
Soda	6.58
Lime	5.91
Magnesia	0.84
Peroxide of iron	1.65
Alumina	23.86
Silica	60.16
	100.00

O in a : O in b :: 8 : 4 = 2 : 1, or 2 : 1 + 6 : 3 = 2 : 1.

Belongs to the sixth, or doubly oblique prismatic system. Specific gravity 2.7; fuses more readily than albite.

Analcime has one equivalent of silicate of soda, one of a silicate of alumina, and two of water. O in a : O in b :: 2 : 1 + 6 : 3, exclusive of water.

Chabasite has one equivalent of silicate of potash, soda, or lime, one of a silicate of alumina, and six of water. The variety richer in lime is true or calcareous Chabasite; that richer in soda is Gmelinite or Hydrolite. O in a : O in b :: 2 : 1 + 6 : 3.

36. *Orthoclase*, *Potash Feldspar*, or *Common Felspar*, has one equivalent of trisilicate of potash and one of monosilicate of alumina, or K O, 3 Si O^2 + Al^2 O^3, 3 Si O^2, giving—

Potash	16.59
Alumina	18.06
Silica	65.35
	100.00

O in a : O in b :: 12 : 4 = 3 : 1, or 6 : 1 + 6 : 3 = 2 : 1.

Its crystalline system is the fifth or oblique prismatic. Specific gravity 2.5 to 2.6, increasing according as potash is replaced by soda or lime. Softer than quartz. Colourless, or slight flesh or yellow coloured. Fuses with great difficulty to a blistered turbid glass.

Adularia, or Glassy Feldspar, is the same mineral as Orthoclase, but in the form of a clear transparent glass.

In the specimens of adularia from volcanic districts more than 4 per cent of soda is sometimes found, while in that from St. Gothard, according to Abich, there is not more than 1 per cent.

37. *Albite, Soda Feldspar*, has one equivalent of trisilicate of soda and one of monosilicate of alumina, or $Na\,O,\ 3\,Si\,O^2 + Al^2\,O^3,\ 3\,Si\,O^2$, giving—

Soda	11.62
Alumina	19.13
Silica	69.25
	100.00

O in a : O in b :: 12 : 4 = 3 : 1, or 6 : 1 + 6 : 3 = 2 : 1.

It belongs to the sixth or doubly oblique system of crystallization. Its specific gravity is 2.6, and before the blow-pipe behaves like Orthoclase.

Pericline is an albite, in which part of the soda has been replaced by potash. It fuses more readily than albite.

38. *Stilbite*, or *Desmine*, has one equivalent of trisilicate of lime, one of monosilicate of alumina, and six of water, or $Ca\,O,\ 3\,Si\,O^2 + Al^2\,O^3,\ 3\,Si^2 + 6\,H\,O$.

O in a : O in b :: 6 : 1 + 6 : 3, exclusive of water.

(*c*) *Compounds of Silicates in which the number of equivalents of Protoxide Bases is less than that of Alumina.*

39. *Oligoclase*, or *Soda Spodumene*, is probably composed of three equivalents of monosilicate of soda, and four of monosilicate of alumina, which would be expressed by the formula, $3\,(Na\,O,\ Si\,O^2) + 4\,(Al^2\,O^3,\ 3\,Si\,O^2)$, in which O in a : O in b :: 30 : 15 = 2 : 1, or 3 (2 : 1) + 4 (6 : 3 = 2 : 1), but there is a little uncertainty about its exact composition.

Crystalline system the sixth, or doubly oblique prismatic. Specific gravity 2.6. Hardness equal that of orthoclase; more or less translucent. Colour white, grey, or greenish. Fuses more easily than orthoclase or albite.

40. *Spodumene*, or *Triphane*, is composed of three equivalents of monosilicate of lithia with four of monosilicate of alumina, or 3 (Li O, Si O^2) + 4 (Al^2 O^3, 3 Si O^2), giving—

Lithia	6.05
Alumina	28.80
Silica	65.15
	100.00

O in a : O in b : : 30 : 15 = 2 : 1, or 3 (2 : 1) + 4 (6 : 3 = 2 : 1).

A portion of the lithia commonly replaced by soda. Specific gravity 3.2. Harder than felspar. Swells up and fuses rather easily to transparent glass.

Killinite is probably a decomposed spodumene.—*Nicol*, p. 132. Professor Haughton has since shown that the angles of spodumene and killinite are supplementary.—*Dub. Nat. Hist. Review*, vol. iii.

41. *Petalite* is a compound of one equivalent of bisilicate of soda, two of bisilicate of lithia, and four of bisilicate of alumina, or—

Soda	2.61
Lithia	2.41
Alumina	17.19
Silica	77.79
	100.00

O in a : O in b : : 60 : 15 = 4 : 1, or 3 (4 : 1) + 4 (12 : 3 = 4 : 1).

Specific gravity 2.4. Harder than felspar. Fuses readily to a turbid and blistered glass.

42. *Biaxal*, or *Potash Mica*, the composition of which is stated as one equivalent of trisilicate of potash to three of tribasic silicate of alumina = (K O, 3 Si O^2) + 3 (Al^2 O^3, Si O^2), part of the potash being replaced by lime and the protoxides of iron and manganese, and part of the alumina by sesquioxide of iron, manganese, or chromium. One analysis gives—

Muscovite is potash mica (old [illegible] glass) [illegible]
[illegible]
Biotite, a magnesia-iron mica; usually black. p. 34

Potash	10.09
Protoxide of iron	1.50
Sesquioxide of iron	3.35
Alumina	37.36
Silica	47.70
	100.00

O in a : O in b :: 12 : 10 = 6 : 5, or 6 : 1 + 3 (2 : 3).

Crystalline system the fifth or oblique prismatic. Specific gravity about 2.9. Hardness between gypsum and calc-spar. Transparent, colourless, or light-coloured with metallic pearly lustre. Fuses with various degrees of facility to a turbid glass.

Often contains fluorine.

This is the ordinary variety of mica. When it contains chrome it is known as Fuchsite.

Margarodite is said to be 12 $(3\,Al^2\,O^3,\ 2\,Si\,O^3) + 3\,(Mg\,O,\ 2\,Si\,O^3) + Fe^2\,O^3,\ 3\,Si\,O^3 + 6\,(Na\,O,\ Si\,O^3) + 9\,(K\,O,\ Si\,O^3)$, and is described as forming the matrix of the black tourmaline from the Zillerthal.

C.—COMBINATIONS OF A DOUBLE SILICATE OF ALUMINA AND ANOTHER BASE, WITH CARBONATES, BORATES, OR SULPHATES, OR WITH METALLIC SULPHIDES, CHLORIDES, OR FLUORIDES.

Of these we will take only the three minerals.

43. *Tourmaline*, or *Schorl*, which is a combination as above with a borate, but the analyses are so varied and indefinite as not to be reducible to a common formula. The following is an example—

Soda	4.99
Protoxide of magnesia . .	2.85
Protoxide of iron	2.81
Sesquioxide of iron	6.27
Alumina	39.72
Silica	39.65
Boracic acid	3.71
	100.00

Primary form an obtuse rhombohedron of the third system. Specific gravity 3. to 3.3. Softer than quartz. Every degree of transparency, from perfect clearness to complete opacity; and is variously coloûred. Before the blow-pipe swells up and fuses to a slag.

44. *Porcelain Spar*, a combination with a chloride, consists of four equivalents of the double silicate of lime and alumina with one of chloride of sodium.

45. *Lithia Mica*, or *Lepidolite*, a combination with a fluoride, consists of two equivalents of monosilicate of lithia, three of two-thirds silicate of alumina, and one of a combination of fluoride of potassium and terfluoride of silicon, the peroxides of iron and manganese partly replacing the alumina.

The following is the calculated analysis:—

Potash	8.72
Lithia	5.32
Alumina	28.48
Silica	51.55
Fluorine	5.93
	100.00

O in a : O in b : : 2 (2 : 1) + 3 (4 : 3) (exclusive of K Fl, $Si\,Fl_3$).

Specific gravity about 2.9; softer than calc-spar. Transparent or translucent. Fuses very readily.

The most important of the silicates may be conveniently grouped under four heads. 1. The Feldspars. 2. The Micas. 3. The Augites or Hornblendes. 4. The Zeolites. The principal species of each of these heads have been selected for the foregoing descriptions.

1. The Feldspars may be classed as

"*a.* The potash species (which often include some soda), common Feldspar or Orthoclase, and Leucite.

"*b.* The soda species, or *soda and potash*, are Albite, Ryacolite, Oligoclase, Hexoclase and Nepheline.

"*c.* The soda and lime species (containing also some potash), Andesine, Vosgite, Davyne.

"*d.* The lime species, Anorthite, Labradorite, Thiorsaurite.

"*e.* Lithia species, Petalite."

(*Dana's Mineralogy*, 2d edit. p. 322.)

According to Abich, potash, soda, and lime, and pro-

Mica consists of Silica with alumina, with potash, magnesia, or iron, manganese. Sometimes with fluorine.

bably also magnesia, play the part of isomorphous elements in all feldspars.—(*D'Archiac*, *Histoire de Géologie*, tom. iii. p. 589.) The crystallization of orthoclase, albite, and anorthite, requires that soda and potash be considered as dimorphous.—(*Nicol*, p. 130).

2. The Micas on which Gmelin has the following note, (vol. iii. p. 423).

"Schaffhäutl (Ann. Pharm. 44, 325) compares the compositions of the various micas with one another, by taking all the bases as one, and calculating them as ($Al^2 O^3$) alumina, and then combining them with the acid $Si O^3$ (silica).*

"The following micas are thus compared:—

	$Al^2 O^3$	$Si O^3$	Formula.
Talc	33.82	60.56	$Al^2 O^3 \; 2 Si O^3$
Lithia Mica . .	35.49	48.35	$2 Al^2 O^3 \; 3 Si O^3$
Biaxial Mica . .	39.66	45.03	$5 Al^2 O^3 \; 6 Si O^3$
Magnesia Mica .	43.92	41.91	$Al^2 O^3 \; Si O^3$
Chlorite	55.30	31.38	$5 Al^2 O^3 \; 3 Si O^3$
Ripidolite . . .	61.73	26.31	$2 Al\; O^3 \; Si O^3$

"From this it would appear, that the composition of the micas ranges between $M\,O,\ 2\ Si\ O^3$, and $5\ M\,O,\ 3\ Si\ O^3$." In these formulæ $M\,O$ stands as the symbol of magnesia, potash, lithia, and the other bases, including alumina.

In words the above expressions would mean that the different micas are intermediate between a composition having two equivalents of silica to one of base, and one having three equivalents of silica to five of base; the substance composing the base having likewise a great range of variation.

My colleague Dr. W. K. Sullivan has remarked to me, that it is possible, perhaps, that some of these micas are so by virtue rather of physical structure, such as a similar mechanical arrangement of their particles, giving them a flaky structure and a glistening metallic lustre, than of their having any definite chemical composition in common.

3. The Hornblendes, or Augites, are essentially silicates

* Schaffhäutl uses $Si O_3$ as the symbol of silica.

of magnesia combined with silicates of lime and other bases. They include the minerals Augite or Pyroxene, Diopside, Sahlite, Diallage, Hypersthene, Hornblende, Tremolite, Actinolite, Anthophyllite, Asbestos, Arfvedsonite, Wollastonite, Serpentine, &c.

4. The Zeolites, most of which might be described as highly hydrated feldspars, being silicates of alumina combined with silicates of the other bases, and a large quantity of water. Others of them, however, do not contain alumina, but consist of silicates of lime and soda, etc., with also a large amount of water. From this quantity of water causing them to intumesce and *boil* up before the blow-pipe the name *zeolite* is derived. They consist of the following minerals:—

Analcime, Natrolite or Mesotype, Thomsonite or Comptonite, Stilbite or Desmine, Scolezite, Damourite, Ædelforsite, Heulandite, Brewsterite, Epistilbite, Apophyllite, Okenite, Pectolite, Chabasite, Gmelinite, Levyne, Faujasite, Harmotome, Phillipsite, Zeagonite, Laumonite, Leonhardite, Glottalite, Edingtonite, and some other minor varieties.—(*Nicol's Mineralogy*).

CHAPTER II.

ON THE ORIGIN AND CLASSIFICATION OF ROCKS.

IF our object were simply the study of the science of mineralogy, we might take a purely natural history view of it. We might, that is, look upon minerals merely as natural objects, having certain external properties which enabled us to distinguish them from each other, and arrange them in a certain order, according to some principle. This arrangement might enable us to identify any particular mineral laid before us, and consequently to refer to what is known of its chemical composition, and other qualities. For this view of mineralogy, we must refer the student to the special works upon the science.

In order to apply mineralogy to geology, however, we must study rather the generic relations of minerals, that is to say, we must endeavour to discover their modes of production, and the circumstances which were necessary or conducive to their appearance in the positions and in the combinations in which we now find them. This is the object we have had in view in the brief abstract we have just given of a part of chemistry and mineralogy. For a larger and more complete, though sometimes, perhaps, rather a preconceived and not altogether trustworthy view of this subject, we must refer to Bischof's Chemical and Physical Geology, published by the Cavendish Society.

What has been here given, however, will enable the student to reason, to a certain extent, on the origin of rocks; and to draw certain conclusions as regards the relations of those mineral constituents, at all events, which are essential to their existence—those which so far enter into their mass as to make them what they are, and the abstraction of which would make them something different.

Crystallization.—One of the most obvious properties of minerals is their crystallization. All crystals are, as it were, built up of minute crystalline particles of like forms, and have been produced by the successive external additions of these minute particles.

It is clear, then, that these particles must have been free to move and arrange themselves; in other words, they must have been in a *fluid*, or *nearly fluid* state. But this fluidity may have been the result either of *solution* in water or other liquids, or of *fusion* by heat. Whenever, then, we find a crystal or a mineral particle that has an internal crystalline structure, we may feel assured that it has once been either *dissolved* or *melted.*

But if this be true as regards individual crystals or crystalline particles, it must be true also of rocks that are made up of such crystals or such particles.

Now we have seen that some minerals, as for instance carbonate of lime, are readily soluble in water containing carbonic acid gas, or in liquid acids; if, therefore, we meet with a rock composed of crystalline particles of carbonate of lime, we could easily believe that it had once been dissolved in water and deposited from that solution.

As regards the solid acid silica, it is also soluble in water containing carbonic acid gas or some other substances, and also when in certain chemical states, and in water at a high temperature. We can, therefore, easily understand the deposition of crystals of silica or quartz from aqueous solutions.

We have also seen, however, that for the production of many silicates (as, for instance, the artificial silicates porcelain, slag, and glass) great heat is necessary, and that consequent fusion takes place. We know also with regard to many, if not most of the natural silicates, that they are practically insoluble in water, or in any other fluids which are found abundantly in nature.

When, then, we meet with rocks composed altogether of crystals, or crystalline particles, of such silicates, we are compelled to conclude that those rocks were once in a state of fusion from heat.

But in each of these cases we should find gradations from some rocks in which the crystalline particles were large and distinct, through others where they became less and less, and were eventually only discernible with a lens, into some at last which appeared quite *compact* and homogeneous. The very fact of the gradation, however, would teach us that what was true of the crystalline rocks might also be true of *compact* rocks of the same mineral composition, and that, therefore, crystalline and compact limestone, quartz crystals and compact flints, might equally have been dissolved in water, and crystalline and compact silicates equally been melted by heat. In the latter case the artificial silicate glass again assists us, since we know that the very same mass which, if cooled under given circumstances, will form a perfectly homogeneous glass, will, if allowed to cool more slowly, become opaque, and stony, and that ultimately it will begin to granulate, that is, its constituents will begin to separate from each other and form distinct crystals in the mass.

Chemical Rocks.—These considerations at once prepare us for the belief that many rocks have been chemically formed, that is, have consolidated from fusion or solution in obedience to chemical laws. Those that have become consolidated from fusion we may call Igneous rocks; those that have consolidated from solution Aqueous rocks.

Chemically-formed aqueous rocks may be either crystalline or compact.

Chemically-formed igneous rocks may be either crystalline, compact, or glassy.

Both kinds may have occasionally concretionary, nodular, sparry, fibrous, or other textures, according to local modifying circumstances.

In chemical crystalline rocks, whether aqueous or igneous, the external forms of some of the crystals are often very imperfect and sometimes even irregular. Crystals of one mineral having been first formed prevented the regular formation of the crystals of the other minerals; or the whole mass having crystallized together, the crystals were mutually hindered from attaining their full development by the growth of their neighbours, and all became thus locked and interlaced together in a congeries of mutually imbedded and intertangled crystalline particles.*

These crystalline particles, although not perfect crystals, have yet some faces and angles of perfect crystals, being evidently formed in the position where we now find them. They are *innate* or *ingrown* crystalline granules.

Loaf-sugar, sugar candy, crystallized alum, are familiar examples of this structure, and will serve to explain what is meant by the *innate* crystalline structure of marble or of granite.

Mechanical Rocks.—When, however, we began to study rocks with a view to examine into their mineral constitution, we should soon become aware of another essential difference in them. We should find some rocks the particles of which were large and distinct, but not at all crystalline; or if crystalline internally, we should see that their external form was not regular like a crystal, but exhibited evident marks of mechanical fracture and attrition, of wearing away, or rounding.

The particles of the rocks which are now alluded to, whether internally crystalline or internally compact, are not mutually embedded and interlaced, like those of chemical rocks, and have no such appearance of having *grown* where we now find them, but have evidently been brought together from different places, and adhere to each other either in consequence of having been squeezed together by mechanical pressure, or because they are cemented by some other substance which serves to bind and unite them to each other.

In these rocks the particles are generally more or less rounded and smoothed externally, as if water-worn.

This water-worn form and derivative origin is very

* The paragenesis of minerals in chemically formed rocks is a subject that has not yet received the attention it deserves. The peculiar association of minerals, and the relative order of their crystallization, as shown by their mutual indentation and envelopment, would, if accurately observed and described, doubtless explain much that is still obscure as regards the formation of such rocks, as also that of the contents of mineral veins.

obvious with respect to some of these rocks which consist of *pebbles* or rounded fragments of other rocks, compacted together in *sand*, which is clearly the result of the rounding process.

In many cases the very rock from which the pebbles were derived can be pointed out, and the distance, therefore, which they have been carried is known. In other cases the fact of mechanical transport is equally obvious, though the original site may be unknown.

From those cases where the particles are large and their form distinctly visible, there is every gradation through those where they become less and less, till at length they are not discernible by the lens. We have, then, compact derivative rocks just as we have compact chemical ones.

To all such derivative rocks we may with great propriety assign the term Mechanical, as showing that their materials have been mechanically transported to their present sites.

The machinery employed in this transportation must clearly be either currents of water or currents of air, and the mechanical rocks, therefore, must be all either Aqueous or Aerial rocks, the latter being very few and unimportant compared with the former.

Even with regard to igneous rocks, which must in themselves be purely chemical compounds, they still may have their mechanical accompaniments whether they were formed in the air or in the water, as we see in the case of the ashes, cinders, and fragments blown from the mouths of volcanoes.

Organic Rocks.—There is yet another source from which some rocks are derived, inasmuch as some are found to be wholly or almost wholly composed of fragments of animals or plants. These rocks may be termed Organic, in the sense of organically-derived rocks.

The portions of the plants or animals may be either little altered from their original condition, or very much altered and altogether mineralized. In the first case, they belong perhaps more particularly to the mechanically; in the latter, to the chemically formed rocks.

Mixtures.—As, moreover, chemical precipitates are liable from many causes to be adulterated with mechanical impurities, and mechanical deposits to be impregnated with chemically acting gases or liquids, and as both mechanical admixtures and chemical actions and reactions may play a part in the formation of rocks made of organic materials, we can easily see how all three classes of rocks may occasionally be mingled together and pass into each other, and how many aqueous rocks may have been formed by the union of two or of the three agencies, and appear to belong to one, or the other class according to the point of view from which we observe them.

We have now arrived, then, at the conclusion that different rocks had an aqueous, an igneous, or an organic origin, solely from the consideration of the nature of the mineral particles composing them. This conclusion, however, by no means depends entirely on such considerations. The aqueous rocks are known to be so, not only from their being composed of soluble minerals, or of minerals that have been water-worn, or of parts of plants and animals that have either lived in water or been carried down into it, but also because their materials are arranged in regular layers and beds or *strata*, obviously the result of their having been regularly *strewed* out over the bottom of the seas and lakes in which they have been deposited. They are hence often called Sedimentary and Stratified rocks.

The igneous rocks, on the other hand, are many of them such as we see now to be poured forth from the mouths of volcanoes in the state of molten lava; others again are closely allied to these, and there is a regular chain of gradation from these through their whole series.

Those which least resemble actual lava are found sometimes to have been injected, in the form of veins and tortuous strings, into the cracks and crevices of other rocks, or to have cut through them in great wall-like masses called "dykes," just as lava does. In many of these cases they have exerted just such an influence on the rock they came in contact with as great heat would have exercised. The neighbouring rocks have in fact been burnt, and are sometimes greatly altered from their original state as seen at a distance from the igneous rocks.

Metamorphic Rocks.—This fact, together with the consideration of the chemical actions and reactions that may be set up in the mass of rocks by the percolation of various fluids or gases, and the mechanical or chemical forces that may be brought into play by the action of pressure and other agencies, naturally disposes us to ask the question, Whether many rocks as we now see them may not be in a very different state from that in which they were originally formed? We should ultimately find reason to answer this question in the affirmative, and introduce another class under the head of Metamorphic (or transformed) rocks, to include those which had by means of subsequent alteration acquired any essentially different characters from their original ones.

Guided by these considerations we may class all rocks whatever under the four great heads of Igneous, Aqueous, Aerial, and Metamorphic.

The Igneous are almost entirely chemically-formed rocks, but some of their varieties have their mechanical accompaniments.

The Aqueous rocks are either chemical, mechanical, or organic, those of mechanical origin being far the most abundant, although not the most important kinds.

The Aerial are all mechanical.

The Metamorphic are either those in which the original structure and composition are still obvious, or those in which those characters are altogether obscured and replaced by others produced either by heat, or pressure, or both conjoined.

We shall commence with the description of the igneous rocks, because these may be looked upon as those most essentially original and self-subsisting, or most independent of the others.

Before entering on the technical description of rocks, however, it will be as well, perhaps, to define exactly what we mean by the term rock.

A mineral is an inorganic substance that has a definite chemical composition, and a regular and symmetrical form; each of the particles of which it is made up exactly resembling all the other particles.

A rock is a mass of mineral matter consisting of many individual particles, either of one species of mineral, or of two or more species of minerals, or of fragments of such particles. These particles need not at all resemble each other either in size, form, or composition; while neither in its minute particles, nor in the external shape of the mass, need a rock have any regular symmetry of form.

Geologists are accustomed also to include under the term rock, all considerable accumulations of mineral matter, whether they be hard or soft, compacted or incoherent. In this sense soft clay, loam, or loose sand, may be called "a rock."

CHAPTER III.

IGNEOUS ROCKS.

THE igneous rocks are divided by Sir C. Lyell and others into two classes—the Volcanic and the Plutonic. Such a classification is theoretically correct, as separating those formed at the surface, in air or water, from those formed deep in the earth; but practically we often meet with rocks that it is difficult to place with certainty in either class. It is, moreover, often advisable to avoid terms that involve theoretical or foregone conclusions. For these reasons I should prefer, with Sir R. I. Murchison and others, to arrange the igneous rocks under three heads—Volcanic, Trappean, and Granitic; taking the middle term trappean as one of convenience only, to include some that are possibly volcanic, some that are more essentially granitic, with many intermediate or undetermined rocks between the two.

Igneous rocks differ among each other—

1st, As being made up of different minerals.

2dly, As having different textures.

The three principal varieties of textures are the crystalline (or granular), compact, and glassy.

When a rock is distinctly granular, so that the crystals of its mineral constituents are clearly discernible, they may be determined by simple inspection. In the compact and vitreous textures, however, the determination of the mineral constituents of a rock can only be arrived at by chemical analysis. This will enable us to find out of what substances the rock consists, and what are their proportions; and the consideration of these proportions, and the comparison of them with those forming different minerals, will enable us to determine with greater or less certainty of what minerals the rock is composed, or at all events, what minerals it would probably form if they were allowed to develope themselves.

It has been already shown from the processes of the manufacture of glass, that the very same molten mass of silicates would form transparent glass, opaque slag, or crystalline stone, according to circumstances. As these different conditions of texture receive different names, so may the different textures of natural substances receive different names, notwithstanding that in some cases they consist of essentially the same ingredients.

As some slags become porous, or vesicular, and thus pass into cinders, so some igneous rocks likewise assume a vesicular, or cindery texture.

When the pores or vesicles become filled with a crystalline nucleus or kernel of any mineral, either by subsequent infiltration, or during the process of consolidation, so that the dispersed crystalline patches look like almonds stuck into the mass, the rock is said to be amygdaloidal.

When single detached crystals are disseminated through a compact base, or large crystals through a fine grained base, the rock is said to be porphyritic. The term Porphyry then, which has been often used as a designation for a particular class of rocks, will here be used chiefly, or solely, to distinguish this variety of texture, which is one that may occur in every kind of igneous rock.

From what has been said before, it may be inferred that all igneous rocks without exception are composed of minerals which are silicates.

These minerals may be said to belong to two great classes, silicates of magnesia and silicates of alumina, the species or varieties of each resulting from their various mixtures with silicates of potash, soda, lime, iron, manganese, etc. The silicates of magnesia, etc., constitute the hornblendic, or pyroxenic or augitic minerals, the silicates of alumina, etc., forming the feldspathic ones. The micaceous minerals, which we may look on as resulting from mixtures of the two, or as holding an intermediate place between them, are in reality of minor importance so far as unaltered rocks are concerned.

The feldspars are the basis of all igneous rocks, those in which no feldspar of any kind is present being very few and unimportant, even if they exist at all. The hornblendic and augitic minerals hold the next most important place, and the volcanic and trappean rocks may be divided into two great series depending on the amount of those minerals which are mingled with the feldspars. Those rocks in which feldspar alone occurs, or in which it greatly predominates, may be called the feldspathic rocks; those in which the hornblendic or augitic minerals play a considerable part may be called hornblendic or pyroxenic rocks. It must, however, be clearly borne in mind that feldspar in some form or other is always the basis of the latter, while hornblende and augite in any form are often entirely absent from the former.

The Volcanic Rocks.

These are often spoken of under the general term of Lava. They include, however, some that would be more commonly described as trap rather than lava, and others, such as tuff and ashes, which could not strictly be called by either name.

The volcanic rocks have been classified by Abich under three heads:—

a, Trachyte; *b*, Dolerite; *c*, Trachy-dolerite. Bunsen, also, in his memoir on the volcanic rocks of Iceland, gives a similar classification, describing his *normal trachytic* rocks as one end of the series, and his *normal pyroxenic* rocks at the other end, with many intermediate varieties between the two.

Bunsen gives us the following as the mean value of the composition of his two normal rocks:—

	Normal Trachytic. Trachyte.	Normal Pyroxenic. Dolerite.
Silica	76.67	48.47
Alumina and protoxide of iron	14.23	30.16
Lime	1.44	11.87
Magnesia	0.28	6.89
Potash	3.20	0.65
Soda	4.18	1.96
	100.00	100.00

He then shows that by analysing any intermediate variety of rock, and determining the proportion of any one of these ingredients (taking the silica as the easiest and best), the proportion of the other ingredients may be calculated, and thus may be determined the quantities of these two normal substances which have been mixed together to form the rock in question.

In the following descriptions of the volcanic rocks I am largely indebted to Cotta's Gesteinslehre, to the introduction to Daubeny's Volcanoes, and to the last chapter of the third volume of D'Archiac's Histoire des Progrès de la Géologie.

The Trachytes are so called from the Greek word τραχὺς, rough, as they commonly have a rough prickly feel to the finger. They are usually light-coloured, pale grey, or white, but sometimes dark grey and nearly black. They are composed principally of feldspar, the feldspar being one of the varieties that is rich in silica, such as orthoclase, adularia, or albite, and not any of those in which the bases are more abundant, such as labradorite or anorthite.

As trachyte is made into a class as well as a species of rock, we may similarly elevate dolerite.

The Dolerites, so called, from the Greek δολερὸς, deceptive, are usually of a dark green or black colour, weathering brown externally. They are commonly heavier than the trachytes, as containing a less proportion of silica and a greater one of the heavier bases.

They are composed partly of a feldspathic and partly of an augitic or pyroxenic mineral, the feldspar being commonly, though not perhaps invariably, one of the more basic silicates, such as anorthite or labradorite.

The Trachytes, or Feldspathic Lavas.

1. *Trachyte*, properly so called, has either a fine grained, or quite compact texture, a harsh feel, and sometimes a cellular and scorified appearance. It varies in colour from a pale grey to dark iron grey, and is sometimes reddish from the presence of iron. It is composed of a confused aggregation of crystals of feldspar, often minute and needle-shaped, but with others larger and more distinct.

This feldspar is said to be commonly potash albite (or pericline), and glassy feldspar (or adularia), in which some of the potash is replaced by soda. Crystals of mica and hornblende are often present, and sometimes even of augite, the whole either confusedly united without cement, or embedded in a feldspathic paste, either cellular or compact.

2. *Trachytic Porphyry* has seldom a scorified aspect, looking often more like a plutonic than a volcanic rock, as that of the Pic de Sancy, and the Roc de Cacadogne, of Mont Dor, which at first sight resembles granite in external appearance.

Crystals of glassy feldspar, sometimes small, but sometimes as much as half an inch long, white or flesh-coloured, are set in a compact light-coloured feldspathic paste, with brown mica, and sometimes also with crystals of quartz.

"Many varieties of trachytic porphyry contain a number of very small globules, which seem to consist of melted feldspar, having often in their centre a little crystal either of quartz or mica. The assemblage of these globules leaving minute cells between them, sometimes gives to the rock a scorified aspect."—(Daubeny). Chalcedony occurs in small geodes,* and sometimes intimately mixed with the paste in which the crystals are imbedded.

Trachytic porphyry passes sometimes by insensible gradations into

3. *Pearlstone*, which is composed of a number of globules from the size of a nut to that of a grain of sand, of a vitreous, or enamelled aspect, and pearly lustre, adhering together without any paste.

* Geodes are rounded concretions, generally hollow, and containing crystals. They are sometimes called "potatoe stones" from their size and shape.

These sometimes lose their lustre and size, and pass into a compact stony mass, or change into globules of feldspar, compact, or radiated—the whole rock being composed of them. Many variations occur; the whole sometimes becoming fibrous, cellular, spongy, and passing gradually into pumice.

4. *Domite* is a greyish white, fine grained, compact, earthy, and often friable variety of trachyte. It frequently contains flakes of brown mica.

It appears to be a decomposed trachyte, in which the feldspar is affected, but the mica not. The passage of muriatic (hydrochloric) acid is, by some, supposed to have affected this transformation. It is a remarkable rock, but not one of general occurrence beyond the district of the Puy de Dome, in France.

5. *Andesite;* a trachytic rock, found at Chimborazo and other parts of the Andes; has white crystals resembling albite in a crystalline base of a dark colour. It has various degrees of compactness and consistency, and has a coarse conchoidal fracture.

Small crystals of glassy feldspar occur, though rarely, but those of hornblende are common; and augite is also present sometimes. From the predominance of hornblende it sometimes passes into a diorite or greenstone.

6. *Clinkstone, or Phonolite*, is a compact homogeneous rock, with a scaly or splintery fracture, sometimes conchoidal, of a greyish green, or ashy grey colour, both weathering white externally. It is often rendered porphyritic by scattered crystals of glassy feldspar, but these are commonly not very distinctly separable from it, appearing only as brilliant surfaces here and there in the mass. Hornblende, augite, and magnetic iron are rare in it. According to Gmelin it consists of a mixture of glassy feldspar, with a zeolite in variable proportions. It may, therefore, be formed from trachyte by the addition of sea water; the soda of which, combining with some of the orthoclase, would make glassy feldspar, while the water, combining with the other constituents, would form a zeolite.—(*Abich, in D'Archiac*, vol. iii. p. 604.)

Clinkstone commonly splits into thin slabs, and is often so finely laminated as to be used for roofing slate. The slabs give a metallic sound when struck with the hammer, whence its name. It is sometimes perfectly columnar; the columns splitting across into slabs, which are also used as slates. It may, however, perhaps be doubted, whether many of the so-called volcanic clinkstones really contain water according to the definition, and whether they are not a flaggy, or laminated variety of compact trachyte.

7. *Obsidian*, or *Volcanic Glass*, is the vitreous condition of a trachytic rock. It is said to be necessary for its natural production that the rock should be composed of minerals rich in silica, "or trisilicates;" the simple "silicates," or "bisilicates" of alumina, being incapable of forming obsidian.* (*Daubeny*, p. 16, 2d edition.)

8. *Pumice* is the cellular and filamentous form of obsidian, and the same remarks as to origin will apply to it.

Abich divides pumice into two groups; the cellular being dark green, poorer in silica and richer in alumina, derived from clinkstone, trachyte, or andesite; the filamentous white, containing more silica, and derived from trachytic porphyry.

The Dolerites, or Augitic Lavas.

9. *Dolerite.*—A crystalline, granular, distinct mixture of labradorite and augite with some titaniferous magnetic iron ore, and also often with some carbonate of iron and carbonate of lime. General colour dark grey.

The labradorite forms white or light grey tabular crystals, and the augite black columnar ones. Both can easily be distinguished by the naked eye, especially in the coarser varieties. The magnetic iron forms small octohedral scarcely visible grains, which can be recognised only by the magnet.—*Cotta.*

Cotta mentions a variety from Aulgasse near Liegfried, which contains 28 per cent of the carbonates, three-fourths of that being carbonate of iron.

10. *Anamesite* is properly only a fine-grained dolerite, so fine-grained that we can only distinguish the fact of the

* Without disputing the truth of the origin here assigned to all naturally formed obsidian, it is yet equally true, that basalt can be artificially converted into obsidian, by simple melting and rapid cooling. Messrs. Chance of Birmingham now melt the basalt of the Rowley Hills by simple heat without the addition of any foreign ingredient, and cast it into blocks and ornamental mouldings for architectural purposes. Portions which are allowed to cool rapidly, form obsidian, undistinguishable by any external character from that of volcanic districts. Specimens may be seen in the Museums of Jermyn Street, London, and Stephen's Green, Dublin.

granular texture, and no longer recognise the individual minerals. Its colour is dark grey or greenish or brownish black. It forms the intermediate step between dolerite and

11. *Basalt*, which is a compact, apparently homogeneous, nearly or altogether black rock, with a dull conchoidal fracture. It often contains crystals or grains of augite, olivine, or magnetic iron, and is sometimes vesicular or amygdaloidal.*

The knowledge of the composition of basalt dates from 1836, when Gmelin showed that it was like phonolite, an intimate mixture of one part that was decomposable in acid and another not decomposable. The decomposable portion is partly of the nature of a zeolite, partly of that of labradorite; the undecomposable portion is augite.—*Cotta.*

Basalt, therefore, as it contains water in its zeolitic portion, bears the same relation to dolerite that clinkstone does to trachyte.

The three rocks above mentioned differ rather in texture than in mineral composition. In the two following rocks another feldspathic mineral is substituted for the labradorite.

12. *Nepheline Dolerite* is a crystalline granular mixture of nepheline, augite, and some magnetic iron.—*Cotta*.

13. *Leucite Rock* is a crystalline, granular, porphyritic-like, or even a compact, aggregate of leucite, augite, and some magnetic iron; generally grey.—*Cotta.*

TRACHY-DOLERITE, OR INTERMEDIATE LAVAS.

These rocks, from their very nature, do not admit of any precise definition or nomenclature. The rocks already named and described are mixtures of various minerals. When those mixtures are in anything like definite proportions, and the minerals are well characterised, the rocks assume a particular character, and are capable of definition. When, however, the mixtures become indefinite, and the minerals begin to pass one into another, or are so intimately blended that they cannot be distinguished, attempts at definition only lead to

* According to Cotta, the rock of the Giant's Causeway, etc., in the north of Ireland, ought to be called anamesite rather than basalt.

confusion instead of order, and encumber the memory rather than assist it.

Instead of separating these blending rocks, then, and distinguishing them by different names, it is better to follow the example of Abich, and unite them under one term, such as that proposed by him of—14. Trachy-dolerite.

Neither is this a mere evasion of a difficulty, since the things themselves are so similar both in substance and in origin, that the creation of distinct names would be merely making distinctions where no real or essential difference exists.

It may be useful, here, perhaps, to give Abich's table of the specific gravity, and the percentage of silica of some of the above rocks, arranging them according to the latter character.

	Specific Gravity.	Percentage of Silica.
1. Porphyritic trachyte .	2.5783	69.46
2. Trachyte . . .	2.6821	65.85
3. Glassy andesite .	2.5851	65.55
4. Domite . . .	2.6334	65.50
5. Andesite . . .	3.7032	64.45
6. Phonolite . .	2.5770	57.66
7. Trachy-dolerite .	2.7812	57.66
8. Dolerite . . .	2.8613	53.09

From this it appears that the percentage of silica in porphyritic trachyte is equal to that of albite; in trachyte and andesite, equal to that of orthoclase; and in dolerite, equal to that of labradorite. Trachy-dolerite, intercalated among the rocks, as andesite and oligoclase are between potash albite, and labradorite among the feldspars, shows the passage from one to the other. Lastly, with only two exceptions, the above Table shows us that the specific gravity increases as the percentage of silica diminishes; and Abich, therefore, says that the determination of these two characters, joined to the observation of the mineralogical constituents, will suffice to determine with precision to which kind any volcanic rock belongs.

There is yet another variety of volcanic rocks to be considered, that, namely, called tuff or peperino.

15. *Tuff* (ash) is ordinarily the ashes, dust, and powder, mixed with little lapilli and coarser fragments, blown from a volcanic focus and falling either on to the land or into the sea. If it fall on the land it may become compacted into a rock either by the simple pressure of its own weight, or

in consequence of the percolation of water containing mineral matter in solution. This water may either be rain falling with the ashes, or rain or other water subsequently gaining access to them. If the ashes fall in the sea they become subject to the conditions under which all other mechanically-formed aqueous rocks are produced. In this case tuffs often contain fossil shells.

Abich describes the trachytic tuffs of the neighbourhood of Naples as of two sorts—one inferior, of a clear straw-colour, characterised by fragments of glassy feldspar, augite, and hornblende, the other, or upper tuff, being white, in thinner beds, and with much pumice.

Bunsen, in his description of the volcanic rocks of Iceland, seems inclined to attribute a metamorphic origin to tuffs, and to derive them from the decomposition or alteration of the pyroxenic rocks of that island. He calls them palagonitic tuffs, the mineral palagonite (a hydrated silicate of alumina and lime) being an essential constituent of these tuffs both in Iceland and in Etna, as shown by Walterhausen.

He refers to Darwin's observations on a basaltic lava which has flowed over limestone at Porto Praya (C. de Verde Ids.), and says that the lava, when in contact with the limestone, possesses all the characters of palagonite.

Without denying that some tuffs may have been formed from the decomposition *in situ* of actual lava, we are still inclined to look upon that as the exception rather than the rule, and to believe that tuff in general is a mass of volcanic "ash," deposited mechanically, however it may have been subsequently modified either by igneous or aqueous agencies.

Some geologists confine the term tuff to trachytic masses, and use the word "peperino" to designate those derived from pyroxenic (or augitic) rocks.

Tuff and peperino, from the nature of their origin, must have a great variety of character, from a fine-grained compact stone to a coarse breccia or conglomerate, and from a loose incoherent accumulation to a hard tough stone.

Immense piles of volcanic sand and gravel, and great breccias composed of large semi-angular fragments, also not unfrequently occur, which would hardly be called tuff, but which must not be altogether omitted in our enumeration of volcanic rocks.

II.—Trappean Rocks.

I have before said that I adopt this designation as a convenient one only, and for the same reason I would extend it. The word "trap" has hitherto been considered to be strictly applicable only to hornblendic or augitic rocks. It is derived from the Swedish *trappa*, a stair, those rocks being supposed usually to assume a step-like form. The term, as thus derived, is, however, no more exclusively applicable (except from custom) to the hornblendic than to the feldspathic igneous rocks, and has been often used vaguely to designate any igneous rocks which could not be said to be distinctly granitic on the one hand, or absolutely volcanic on the other. In this vague and general sense I shall here use it, its very vagueness being its recommendation as best adapted to receive a class of rocks that do not admit of any strict definition or circumscription.

As the volcanic rocks are divisible into three heads, feldspathic, augitic, and intermediate, so I think we may conveniently divide trappean rocks into three similar heads, feldspathic, hornblendic, and intermediate. For the two first of these the general designations, Felstone and Greenstone may be used—felstone corresponding to trachyte, and greenstone to dolerite. It is not easy to make a combination of words answering to Abich's trachy-dolerite, but the intermediate rocks exist in abundance which would be comprised under such a designation.

Felstone is a name taken from the German *Feldstein*, and proposed by Professor Sedgwick to designate a class of igneous rocks to which many titles have been given, but which have never, we believe, been yet properly examined and described. Compact feldspar, petrosilex, and cornean, are among these names, as well as the hornstone of some geologists, though that name has also been applied to chert.

Felstone or Feldspathic Traps.

16. *Felstone* is a compact, smooth, hard, flinty-looking rock. Felstone is of quartz & orthoclase: the quartz so intimately mixed that it

Felstones are plutonic: formed deep in ancient formations.

It has two principal varieties; the pale green passing into a greenish or yellowish white, and the blue or grey varying from pale to dark grey. The grey or blue variety weathers white, its external margin being white sometimes to the depth of a line, sometimes to that of an inch or two. Some blocks that appear wholly white have a small blue patch in the centre. The green, or greenish white variety is often very translucent at the edges; the grey is commonly opaque. The fracture is generally smooth and straight, seldom conchoidal, but in some of the blue or grey varieties it is rough and splintery. It often splits into small slabs, and sometimes, especially the green kinds, into laminæ.

The fragments sometimes ring with a metallic sound like clinkstone, and many so called clinkstones (such as those of the Roche Sanadoire and Tuilliere in the Mont Dor district, and those of the Velay) are undistinguishable by any external characters, from many of the felstones of Wales and Ireland.

In many felstones, both in North Wales and South Ireland, lines and striæ, resembling lines of lamination or deposition, of slightly different colours, can be traced through the mass of the rock, sometimes straight, sometimes more or less wavy and tortuous, like the variously hued lines and bands in a slag from an iron furnace, and resulting, probably, like them, from the motion of the mass when in a pasty and semi-fluid condition.

In the most smooth and compact varieties, the lens will often disclose small shining facets of crystals of feldspar, and these become larger and more numerous till we reach the completely granular and crystalline felstones. Small crystals or crystalline portions of quartz also are occasionally present in most varieties.*

Sometimes the rock becomes nodular and concretionary, the nodules varying in size from that of a pea to that of a man's fist, either scattered in a compact or powdery base, or touching each other and making up almost the whole mass of the rock. The substance of these nodules is sometimes the same as that of the base, but in some instances they are hollow, and contain crystals of quartz and other minerals, and also a soft, dark green earth. In this respect it seems to resemble the rock previously described as pearlstone, though it never has any pearly or other lustre.

* Felstone, as here described, is a very abundant rock among some of the older formations in the British Islands, making up whole mountain masses; but it appears to be little known or remarked on the Continent, as Cotta speaks of it as only rarely seen and in small quantity, and but two specimens of it occurred in a collection of 660 igneous and altered rocks purchased from Krantz of Bonn.

Felstone as thus described is probably a mixture of a feldspar with silica in a state of paste. We may look on it as a compact form of trachyte, more or less altered by pressure, or other agencies. It passes from that state to one in which the minerals are crystallized out more or less completely, becoming first a granular and crystalline felstone, and then a granular aggregate of crystals of feldspar and quartz, passing into a quartziferous porphyry.

This latter is the rock known in Cornwall as elvan, and I think, as a convenient designation, "elvanite" might be adopted as a name for it and its varieties.

17. *Pitchstone* appears to be a variety of felstone, having a more vitreous character, and a resinous lustre; whence it derives its name. It is of many colours, varying from black to green, grey, and yellow. The black varieties look, however, more like hornblendic or augitic mixtures than purely feldspathic rocks.

Clinkstone is frequently spoken of as a trappean as well as a volcanic rock, but it is probable that many of the rocks so described would not come within the definition of clinkstone given before, and are only platy, flaggy, and laminated (perhaps even "cleaved") varieties of felstone. Other true trappean clinkstones, however, are probably the hydrated varieties of felstone, just as volcanic clinkstone is a hydrated trachyte.

18. *Felstone porphyry*, or *feldspar porphyry*, is a rock consisting of a base of compact felstone, with distinct scattered crystals of feldspar embedded in it. The base is commonly either of a dull green, grey, or red colour, and the imbedded crystals are commonly white or flesh colour, or some other shade generally contrasted with the base by being of a paler hue.

19. *Quartziferous-Porphyry* (*Elvanite*) has the same base, or a granular one of the same materials, with disseminated crystals or crystalline grains of quartz.

Greenstone, or Hornblendic Trap.

Greenstone is an old and well-known name for a numerous and important class of trappean rocks. It is a translation of the German *Grunstein*, and synonymous with the French *Diorite*.

20. *Greenstone*, or *Diorite*, consists of a mixture of feldspar (orthoclase) and hornblende, varying in texture from a fine-grained compact rock, in which the crystalline state of the minerals is barely discernible with a lens, to a coarsely crystalline aggregate. Its colour is generally a dull green, varying from light to dark green, sometimes almost black. In some varieties, on the other hand, where the feldspar is very white and in great quantity, the rock might almost be described as white speckled with dark green spots. It weathers to a dull dark-coloured brown, the weathered blocks being generally massive and well rounded, and covered with patches of white lichen. On breaking open the weathered part of a greenstone and testing the rock with acid, we almost invariably find that it will effervesce along the inner border of the weathered portion. Many greenstones, also, even when apparently unweathered, effervesce with acids along the minute cracks and pores in the mass.

The feldspar of greenstones is commonly presumed to be orthoclase, but is, perhaps, often albite; and in some of the rocks which come under this head augite or hypersthene is substituted for hornblende. Mica, of a dark brown colour, sometimes occurs (as in some of the Wicklow greenstones), either in distinct plates, or as coating the surfaces of small crevices or those of the other crystals.

M. Delesse says that many rocks hitherto classed as greenstone contain no hornblende, their green colour being the result of the greenness of some of the feldspar composing them. These, then, would probably come under the head of one of our crystalline felstones.

Greenstone, like felstone, becomes sometimes porphyritic, in consequence of one or other of its constituents forming distinct crystals in a compact mixture of the rest, or larger disseminated crystals in a granular crystalline base. When the greenstone is quite compact and dark coloured, it is not, perhaps, very easy to distinguish it from basalt by any external characters.

21. *Melaphyre* is a name for a black porphyritic rock, containing crystals of augite or oligoclase, in a base of augite and labradorite or oligoclase.

Under the general head of Greenstones and Melaphyres, Cotta describes the following rocks:—

22. *Diabase.*—A crystalline granular, sometimes porphyritic, or even a slaty, mixture of augite and labradorite or oligoclase, mostly with some chlorite.

23. *Calc-diabase.*—A finer-grained, or entirely compact diabase, with round grains of calcspar.

24. *Gabbro, Euphotide, Diallage Rock.*—A crystalline granular mixture of labradorite or saussurite, and diallage or smaragdite.

25. *Hypersthenite, and Hypersthene Rock.*—A crystalline granular mixture of labradorite and hypersthene.*

26. *Augite Rock, Lherzolite.*—A coarse-grained to compact rock, consisting essentially of augite alone. Rare. Lheherz in the Pyrenees.

27. *Norite* is a name of Esmark's for a rock yet undetermined; some of its characters seem to belong to diorite and some to gabbro.

28. *Diorite.*—A crystalline granular mixture of hornblende and albite; sometimes even slaty or porphyritic.

29. *Globular Diorite, Orbicular Greenstone, Corsican Granite.*—A crystalline granular mixture of greyish white feldspar (anorthite), dark grey hornblende, and some quartz, in which alternating concentric layers of hornblende and feldspar form globular concretions from one to three inches in diameter.

30. *Micaceous Diorite.*—A crystalline granular mixture of hornblende and oligoclase, orthoclase, quartz, and mica. Mostly dark, or quite black.

31. *Hornblende Rock, Amphibolite,* consists essentially of hornblende alone, which forms sometimes a crystalline granular, sometimes a quite compact aggregate.

32. *Kersanton.*—A crystalline mixture composed essentially of hornblende and mica, in which, however, some feldspar is often mingled. In the latter case it effervesces slightly with acids.

33. *Eclogite.*—A crystalline mixture of green smaragdite and red garnet. The garnet occurs as porphyritic crystals in the fine-grained base of smaragdite.

34. *Disthene Rock.*—Principally composed of disthene, with which, however, some garnet, mica, or smaragdite is mingled.

35. *Aphanite, Melaphyr.*—A compact or fine-grained, dark grey, brown, or black rock, which apparently consists principally of a feldspathic mineral intimately mixed with

* A magnificent mass of this rock, with crystals two or three inches wide, forms a hill at the head of St. George's Bay, Newfoundland.

augite, hornblende, magnetic iron, and the like. Its exact mineralogical composition is not yet determined. It is sometimes vesicular, amygdaloidal, or porphyritic, and is even said to be sometimes slaty.

36. *Serpentine.**—A compact, mostly green or brown rock, consisting essentially of the mineral serpentine only. Fracture splintery and dull, easily workable and unctuous to the touch. A variety of serpentine is Schiller rock, which contains crystals of Schillerspar.

37. *Garnet Rock.*—A crystalline granular, but very unequal mixture of garnet, hornblende, and magnetic iron.

38. *Eulisite.*—A mixture of olivine-like oxide of iron, green augite, and brownish-red garnet.

39. *Epidote Rock.*—A granular, compact, or variolitic mixture of pistacite (green epidote) and quartz.

40. *Labradore Rock.*—A crystalline aggregate of labradorite, with interspersed crystals or crystalline particles of dark hornblende. As a rule, it also contains small crystals of iron pyrites.

Basalt, like clinkstone, must also be enumerated among the traps as well as among the lavas, since it may be very difficult to say, with respect to some masses of basalt, that they were ejected from what might be truly described as a volcano.

Claystone, or *Wacke*, is sometimes spoken of as a trappean rock. It is probably either a compact basalt or greenstone, in a decomposed and earthy state, or an ash partially hardened and consolidated.

The traps, both felstone and greenstone, are accompanied, like the volcanic rocks, by their respective ashes or tuffs.

41. *Feldspathic Ash* † is usually a rather coarse-grained flaky-looking rock, of a pale green, pale grey, or white colour. It has often a soapy feel to the touch, and would be then called chlorite-schist by many persons. It is com-

* I have included serpentine among the trappean rocks, as there may doubtless be injected masses entitled to the name. Many serpentines, however, are only metamorphosed magnesian limestones, a fact which was confirmed to me by Sir W. Logan in 1854, from his observations in Canada.

† Professor Sedgwick uses the term "schaalstein" to designate these ashes, translating it by "trap shales" instead of ash. If, however, we use the term "ash" in a technical sense as the translation of tuff, there does not appear any valid objection to it. The specimens of German "schaalstein" which I have seen are not the same as any of the British "ashes" I am acquainted with.

monly to be easily detached in flakes, which are quite translucent, and can be as easily ground down into powder. Other varieties are much harder and more compact, and there is, in fact, every gradation from a soft ash into a compact felstone, undistinguishable from solid trap.

Some of these solid-looking traps, however, show casts of fossils, and contain angular fragments of slate and other rocks, clearly betraying their mechanical origin. Some even contain crystals of feldspar, making the rock look like a porphyry, until closely examined, when the crystals are found to have their angles worn, and to have been more or less weathered and rounded before they were included in the base.

Along with these also, there generally occur angular or rounded fragments of felstone, slate, or other rocks, of every size up to blocks of 6 or 8 inches in diameter; the rock then becoming a trappean breccia or conglomerate, with either a hard and compact or a loose and flaky base.

Sand is sometimes mingled with this base; and there is then a passage from ash, through sandy ash and ashy sandstone, into pure sandstone.

It is rare to find a genuine ash that will not effervesce slightly with acids. The nodular concretionary structure, which I have previously mentioned as occasionally to be seen in some felstones, likewise occurs, I believe, in felstone ash. At least, the base in which the nodules lie is often of that flaky slightly coherent character which is characteristic of ash.

42. *Greenstone Ash* is perhaps still more various in composition than that of felstone.

One well marked variety is a quite compact rock, of a pale greenish brown hue, speckled with small black spots.

Another is a flaky coarse-grained ash, like that of felstone, but of a darker green or olive colour. This sometimes contains embedded crystals of hornblende* that have had their edges rounded and worn, together with angular or rounded fragments of other rocks.

Another variety of greenstone ash is a dark hornblende

* Near Black Ball Head, county Cork, is a cliff of such a greenstone ash, in which crystals of hornblende, 3 inches wide, have been seen. They are dull and worn externally, but internally quite bright and glistening.

slate, passing into hornblende schist; and it is very possible that many hornblende schists, actinolite schists, etc., are metamorphosed ash-beds.

It is obvious that rocks thus made chiefly or entirely of igneous materials would more easily be metamorphosed than purely siliceous, argillaceous, or calcareous rocks, and would then be converted into rocks having all the appearance of trap. If they contained crystals of feldspar or hornblende, such altered rocks could not be separated from porphyries.

Greenstone ash often effervesces with acids as well as felstone ash.

The Granitic Rocks.

I have before said that all igneous rocks were composed of silicates, and pointed out that the varieties of the volcanic and trappean rocks were characterised by the relative amounts of hornblendic or augitic minerals (silicates of magnesia, etc.) which were mingled with their feldspathic constituents (silicates of alumina, etc.) These silicates are, in the volcanic and trappean rocks, generally one of the more basic varieties. The bases, then, in the compound, just previous to consolidation, must have been in comparatively great proportion to the acid (silica), so that none of the latter was left unused or uncombined, and consequently none was allowed to crystallize out separately as quartz. The granitic rocks, on the other hand, are distinguished by the relative abundance of silica which they contain. Not only are all the minerals composing them as highly silicated as possible, but there seems to have been a superabundance of silicic acid (or silica) beyond that which could be taken up by the basic substances present in the mass. This silica, therefore, has been left uncombined, and on the cooling and consolidation of the rock was compelled to crystallize out by itself as quartz.

So long as granite was looked upon as necessarily the most ancient of rocks, this superabundance of silica and occurrence of quartz was considered to indicate a difference in the proportion or distribution of the constituents of the globe, in the more ancient geological periods, from that which exists at extremity of large masses. It differs from Trachyte & Felstone by having mica, & by having quartz in grains of varying size.

when the igneous mass has solidified deep in the earth granite has been the result (with local variations Felstone.)

present. The mineral character of rocks was supposed to depend upon age. I shall touch upon this subject presently.

In the meantime, I would observe that we have already seen that some felstones contain distinct crystals of quartz, and pass into quartziferous porphyry. Now, if a rock consisting of granular crystals of quartz and feldspar, in anything like equal proportion, began to contain flakes of chlorite, talc, or mica, it would then pass into a granite; if, instead of a micaceous mineral, it were to acquire any hornblendic one, it would then become a syenite.

Again, if a greenstone containing granular crystals of feldspar and hornblende were likewise to exhibit crystals of quartz, it would pass into a syenite; and should the hornblende give way to a mica, this also becomes a granite.

These transitions are not merely hypothetical, but have been observed and described; and we have, therefore, existing in nature, every kind of gradation, from a trachytic or doleritic lava, through a feldspathic or hornblendic trap, into genuine granite.

43. *Granite.*—True granite in its most ordinary form is one of the most easily described and certainly recognised of all rocks. It is a granular, crystalline aggregate of the three minerals feldspar, mica, and quartz. Its name is sometimes said to be derived from its granular structure, but Jameson derives it from "*geranites*," a term used by Pliny to designate a particular kind of stone.

Ordinary granite varies according to the composition of the feldspar and mica composing it, according to the relative proportions of those minerals to each other and to the quartz, and according to the size of the crystals, and the state of aggregation of the several constituents.

The feldspar of granite may be either orthoclase or potash feldspar, frequently flesh-coloured, but sometimes white; albite or soda feldspar, generally dead white; an intermixture of those two minerals; or lastly, a feldspar containing both potash and soda, which may be called soda-orthoclase or potash-albite, as the case may be. Other varieties of feldspar, except, perhaps in some instances, oligoclase, are never found in granite as constituents of the mass.

Granites when exposed to view are usually

The mica of granite varies greatly in colour and lustre, being sometimes dark, coppery-brown, passing into black, sometimes green, sometimes golden yellow, and sometimes a pure silvery white. Whether its chemical constitution be equally various is perhaps hardly yet sufficiently ascertained. The quartz is commonly colourless or white, but sometimes dark grey or brown.

The proportions of the three constituents vary indefinitely, with this limitation, that the feldspar is always an essential ingredient, and never forms less than a third, rarely less than half of the mass, and generally a still larger proportion.* Sometimes the mica, sometimes the quartz, becomes so minute as to be barely perceptible.

The state of aggregation of the mass varies also greatly, some granites being very close and fine grained, others largely and coarsely crystalline. The colours of the rock are generally either red, grey, or white; the first when the feldspar is flesh-coloured, the latter when it is pure white, the inter-

* Professor Haughton, in his paper on the Granites of Ireland (Geol. Journal, London, vol. xii. p. 180), gives the following as the proportions of the Dublin and Wicklow granite:—

Mica	13.87
Feldspar	61.18
Quartz	24.98
	99.53

A detached granite boss, near Enniscorthy, had

Mica	3.60
Feldspar	89.69
Quartz	6.44
	99.73

In the Newry and Mourne mountain district he found three granites having the following proportions:—

	1. Wellington Inn.	2. S. of Newry.	3. Carlingford.
Mica	14.59	13.67	22.86
Feldspar	61.98	64.17	50.76
Quartz	23.23	21.96	26.08
	99.80	99.80	99.70

Porphyritic granite, having the feldspar in large crystals in a finer crystalline ground-mass. p. 71.

mediate grey tints depending chiefly on the abundance and colour of the mica, but sometimes on that of the quartz.

Large and distinct crystal of feldspar sometimes occur, disseminated at intervals through the mass, giving the rock a porphyritic texture. It is then called porphyritic granite.

Other minerals besides the three mentioned above, sometimes occur in granite. Among these are hornblende, actinolite, tourmaline, schorl, chlorite, and steatite.

When hornblende is abundant in rock, and the mica becomes scarce, or altogether disappears, it becomes a syenite.

44. *Syenite*, in its true form, is a granitic rock. It is named from the city of Syene, in Egypt, where it is formed of a crystalline aggregate of the four minerals feldspar, hornblende, mica, and quartz; the mica being in small and uncertain quantity. We have already, however, had occasion to remark, that syenite may be formed from either felstone or greenstone, and we may look upon it therefore either as a local variety of granite, or as a passage or transition rock between granite and the traps.

45. *Protogine.*—When talc occurs instead of mica, the granite has been called Protogine, from an erroneous supposition of its being always more ancient than granite.

The name, however, may be retained for the mineralogical variety, independently of any foregone conclusion to be drawn from it.

Instead of talc, chlorite sometimes occurs, as at Camaross, County Wexford, either in regular flakes or as a greenish coating to the surface of other crystals, but I am not aware of any name having been proposed for this variety. The granites of Cornwall and Devon sometimes contain so much schorl as to merit the name of schorl-rock, and would doubtless have been christened with two or three different designations by continental geologists.

46. *Eurite* is a term applied to a fine grained crystalline aggregate of quartz and feldspar, where the mica is either absent or occurs in such minute flakes as to be invisible.

It generally occurs as veins or as local masses in other granites, and rarely, I believe, as veins traversing other rocks at a distance from granite. These, therefore, are probably veins of segregation or of injection during consolidation, and not of subsequent formation.

47. *Minette* again is a name for a fine grained rock, con-

sisting principally of mica, but not having a schistose texture like mica schist.

48. *Pegmatite* is a crystalline aggregate of quartz and feldspar, in which the crystals are arranged as if with a design to produce a certain pattern, more or less resembling letters or characters (from πηγμα, a coagulation).

49. *Granulite* is a similar composition, in which the quartz occurs in thin flakes, so as to give almost a schistose texture to the mass.

50. *Elvan* or *Elvanite*.—Elvan is a Cornish term for a crystalline granular mixture of quartz and feldspar, forming veins that are either seen to proceed from granite or occur in its neighbourhood, and may thus be readily supposed to proceed from it.

It has three varieties :—

(*a.*) An equably crystalline mixture of quartz and feldspar, generally fine grained. This may either be considered as a granite destitute of mica, or as a granular felstone.

(*b.*) A compact felstone base with dispersed crystals, or crystalline particles of quartz, sometimes angular, sometimes rounded, and amygdaloidal. This may be considered as a quartziferous felstone porphyry.

(*c.*) A crystalline granular base of quartz and feldspar, with dispersed crystals of either quartz or feldspar.

The feldspathic portion of these rocks is often earthy, probably from decomposition.

I would propose *Elvanite* as a good euphonious term, and as being less cumbersome than the term of Quartziferous Porphyry, for these rocks which differ in texture from Eurite, or Pegmatite, or Granulite.

Professor Haughton, in his paper in the Geological Journal before quoted, gives the following as the composition of some rocks, which I should consider *Elvanites*.

Croghan Kinshela, Wicklow.	
Albite	62
Quartz	38
	100

Mourne Mountains.	
Albite	27.8
Orthoclase	44.2
Quartz	28.0
	100.0

The composition of the Carnsore granite is similar, being—

Felspar	78.5
Quartz	21.5
	100.0

but this, by its texture and coarsely crystalline grain, deserves to be considered as a true granite; and it, moreover, does contain occasionally a small proportion of mica.

As the granite rocks are all hypogenous or nether-formed, that is, have all been consolidated before reaching the surface of the earth, they are necessarily devoid of "ash," or of any mechanically derived accompaniments whatever.

We have remarked above, that the relative quantity of silica had a marked effect upon the nature of the rock; that among the lavas, quartz only appeared in these trachyte porphyries which were beginning to resemble granite; and that among the traps it only appeared among those feldspar porphyries, which were closely allied to, and passing into, granite, while from the true granites it is never absent. It has been attempted from this to prove that the more siliceous an igneous rock was, the more ancient it must be. Even Abich says that we may, perhaps, thus deduce a scale for the history of the formation of the earth—those rocks which contain, as essential constituents, "trisilicates" of both their protoxide and peroxide bases being "primitive," while those which contain quartz are called "primitive Plutonic," and those without quartz, "primitive volcanic."

M. Riviere also supposes orthoclase to be confined to the older, labradorite to the more recent rocks. The other bases, too, as magnesia and lime, have been supposed to characterise newer rocks than those of soda and potash, and soda itself to be newer than potash.

I would venture to suggest that these mineralogical differences depend upon space or locality rather than upon time; that the proportionate quantity of silica is referable to the depth at which an igneous rock has been cooled or consolidated, or to the nature of those it penetrated, rather than to the time at which it was formed. At great depths in the earth, pure silica itself may possibly be fused by the intense heat there to be met with, and the most refractory silicates may be equally molten at a somewhat less depth, and consolidate or crystallize on becoming cooler a little higher, while those portions of molten matter containing a greater quantity or variety of bases which act as more perfect fluxes, may be kept fluid till they reach the surface, and thus consolidate only in the air or in the water.

Whether the whole quantity and variety of the more fusible bases formed part of the original deepest-seated molten mass, and were separated from it on the first cooling and crystallization of the simple minerals, or whether a larger proportion of those bases was acquired during the passage of the molten rock through the higher part of the earth's crust, and thus the quantity of "flux" increased in proportion as the heat and pressure diminished, may be matter for speculation. We will not now stop to consider it farther, than to warn the student not to take it for granted that the mineralogical and lithological composition or structure of any rock whatever has any necessary and determinate relation to its geological age. Granite might become solid at a temperature that would keep felstone or trachyte still fluid; and these might solidify at temperatures which would keep molten all greenstones, basalts, and dolerites, so that from the very same stream of igneous matter proceeding from the interior to the surface of the earth, the more readily fusible portions might be successively squeezed out, as it were, as the infusible ones solidified, and contracted in consequence of that solidification.* This action might take place in spite of the greater specific gravity of the more fusible minerals, since the difference in the specific gravities would probably be small compared with the power of the eruptive force.

It is true, indeed, that actual subaerial volcanoes, with cones and craters and *coulées*, or *streams* of lava, are only known as recent geological phenomena—as either now active or as having been so during a recent geological period. But we shall see hereafter reason to believe that the preservation of any volcanic cones belonging to the more ancient periods was not to be expected. The parts preserved from destruction and denudation are the more deeply-seated portions only, the *roots*, as it were, of the volcano, the very parts which we do not see while the volcano is active or entire, but which we do see in some (such as those of the Mont Dor) that are half

* The chemist is reminded of the fact, that if a mixture of metals, as for instance tin, bismuth, and lead, be melted, they will, as the mixture cools, have a tendency to solidify and crystallize separately as the temperature of the mass reaches their respective melting points. This constitutes a great difficulty in large bronze castings.

ruined, and we then find these old lava roots to be essentially the same as the traps; and we have already seen that deeply formed trap is not to be separated by any hard line from granite. If, therefore, we could follow any actual lava stream to its source in the bowels of the earth, we should, in all probability, be able to mark in its course every gradation, from cinder or pumice to actual granite.

That this change of state from a granite into a trappean rock does actually occur is well known, and has been proved in a most interesting manner in Professor Haughton's paper before quoted. Near Carlingford (Ireland), a syenite, having the following composition:—

Hornblende	15.40
Orthoclase	67.18
Quartz	17.16
	99.74

comes in contact with, and sends veins into, a large district of limestone. The dykes proceeding from this syenite are converted into a kind of greenstone or dolerite by taking up a large quantity of lime from the adjacent limestone, which enters into combination with the silica and lets the potash go free, so that their mineral composition becomes—

Hornblende	14.16
Anorthite	85.84
	100.00

Anorthite, or a lime feldspar, is thus formed by the combination of lime with the silica existing in the mass, which in parts not reached by the lime can only form orthoclase and quartz. Anorthite had not been previously mentioned as a constituent of any other rock than a lava, and yet we see it here occurring in a mass proceeding from a granitic syenite, and therefore we may well suppose lava in many cases to have similarly proceeded from a granitic compound.

M. Delesse, in the *Annales des Mines*, 1849, has some interesting observations on the magnetic power of the igneous rocks, and some of their constituent minerals, as also of some of the glasses formed from melting the rocks. No practical results, however, being yet arrived at, we shall confine ourselves to this mention of the subject. (D'Archiac, vol. iii. p. 595.)

Bischof has some very important observations on the contraction of igneous rocks, as they pass from a fluid to a solid or crystalline state. (D'Archiac, p. 598.)

He experimented on basalt, trachyte, and granite, and found the following results:—

	Volume in the state of Glass.	In Crystalline state.
Basalt . . .	1	0.9298
Trachyte . . .	1	0.9214
Granite . . .	1	0.8420
	In the Fluid state.	**In Crystalline state.**
Basalt . . .	1	0.896
Trachyte . . .	1	0.8187
Granite . . .	1	0.7481

From this we see that granite contracts 25 per cent, or a quarter of its volume, in passing from a fluid to a crystalline state, and 16 per cent in passing from a glassy to a crystalline state. These effects must have had a great importance "when the primary granites were first cooling," says M. D'Archiac; but their importance seems to me still greater to geologists who are examining the broken and contorted rocks on the flanks of existing granite chains,* and the phenomena of intrusion which we shall hereafter meet with in such situations. M. Deville and M. Delesse arrive at results rather different from Bischof's, and the latter gives the following table as comprising the limits within which the several rocks mentioned contract on passing from a fluid to a solid state.

Granite, leptynites, quartziferous porphyries, etc.	9 to 10 per cent.
Syenitic granite, and syenite	8 to 9 "
Porphyry, red, brown, or green, with or without quartz, having a base of orthose, oligoclase, or andesite	8 to 10 "
Diorites and porphyritic diorites (greenstones) .	6 to 8 "
Melaphyres	5 to 7 "
Basalts and trachytes (old volcanic rocks) .	3 to 5 "
Lavas (volcanic and vitreous rocks) . .	0 to 4 "

M. Delesse sums up his results as follows:—

When rocks pass from a crystalline to a glassy state, they suffer a diminution of density which, all things being equal, appears to be greater in proportion to the quantity of silica and alcali, and, on the contrary, less in proportion to that of iron, lime, and alumina which they contain. In arranging

* I would just warn the student here, that, without altogether denying that there may have been such a rock as primitive granite, none of the granites now known at the surface can be shown to have an antiquity greater than that of some of the aqueous rocks with which they are associated.

the rocks in the order of their diminution of density, those which we regard as the more *ancient* are generally among the *first*, while the more *modern* are the *latter;* and in each case their order of diminution of density is almost exactly the inverse of their order of fusibility."

On this we would remark as before, that for "ancient" and "modern" might be substituted "deeply formed" and "superficially formed;" the most infusible and the most contractible rocks being those produced at the greatest depth and under the greatest pressure, while the highly fusible compounds escape to the surface, and suffer little contraction or solidification.

M. D'Archiac remarks that if granite contracts on cooling only 10 per cent, and that there be a thickness of 40,000 metres of it in the crust of the globe, crystallisation alone would diminish the terrestrial radius at least 1430 metres, and consequently alter the form and rapidity of rotation of the earth. Such speculations are practically useful only in a negative sense, as showing the great improbability of anything like a shell of 40,000 metres having cooled and consolidated at once in the crust of the earth during any of the known geological epochs.

CHAPTER IV.

AQUEOUS ROCKS.

WE are compelled to look upon the purely igneous rocks as original productions. We can only speculate, and that very vaguely, on what was the condition of the materials which compose them previously to their being placed, in a molten state, in the positions where they subsequently consolidated.

In our examination of the aqueous rocks, however, we can go a step farther back, and learn, either accurately or approximately, whence the materials composing them were derived, and what was their previous condition. This is true of all aqueous rocks, whether chemically, organically, or mechanically formed.

We will examine the mechanically formed rocks first.

1. Mechanically Formed Rocks.

Preliminary Remarks on their Origin.

The instruments used by nature in the production of these rocks are, moving water, whether fluid or solid (ice), and moving air.

The Sea.—The sea is probably never and nowhere stagnant. Currents, moving with greater or less rapidity, keep the whole mass in circulation; so that we may look upon the ocean, through all its depths, and in all its gulfs, bays, and recesses, as one great slowly moving whirlpool.*

It is probable, however, that no currents produce any marked or appreciable effects upon solid rock at great depths of water. The mechanical powers of the sea are principally brought into action by the motion of its surface along the shores of all lands, and in its narrower and shallower channels. Sea-breakers along beaches, and at the foot of cliffs, act like ever-moving jaws constantly gnawing at the land. The currents caused by the ebb and flow of the tides along shallow shores remove some of the eroded materials; the great oceanic currents of circulation, where they strike upon coasts, carry off others, and transport all, either mediately or immediately, to greater distances. Sometimes the breakers, after exerting a certain amount of destructive action, seem to raise a rampart against themselves out of the very ruins they have caused, by the fall of the blocks and masses they have undermined; but the materials thus accumulated are themselves then attacked, and ultimately removed. Great accumulations of pebble beaches are common along many coasts, and seem to remain stationary, since there are always piles of pebbles to be found in the same places. If, however, these are watched, the accumulations will often be found to consist of different pebbles from day to day, each pebble being in its turn washed from its place, which is occupied by another like it. The great Chesil Bank, connecting the island of Portland with the mainland, and sixteen miles in length, is a remarkable example of such a formidable accumulation of large pebbles.

Sometimes waves and currents bring and deposit materials on shores, and thus seem to produce rather than to destroy; but those matters have been themselves acquired by the destruction of land at other localities, and are often eventually removed again by a change in the direction of the currents, or other circumstances.

In looking at the destructive action of water, indeed, we must never forget that by *destruction* we do not mean *annihilation*, but only *re-arrangement*. Rock forming "land," that

* See Maury's Physical Geography of the Sea, and Johnstone's Physical Atlas, etc.

is, rock above the level of the sea, is destroyed; but its materials are carried off and deposited, either in similar or in different combinations, to form rock below the level of the sea.

Where the range of tide is considerable, some of these materials may be deposited and form rock between high and low-water mark.

Where the heave of the breakers is great, some of them may be even cast up to a slight distance above high-water mark, and rock may be thus produced.

For instances of the erosive and destructive action of the breakers, and the abrading and transporting power of currents, during historic times, we must refer the student to Sir C. Lyell's Principles of Geology, chapters 20, 21.

Along the eastern coasts of Scotland and England, as is proved by old records, land existed far outside the present shore, the sites even of important towns of the twelfth or fifteenth centuries being now under the sea. Even still in many places whole acres are annually consumed, and the total known destruction of the last few centuries is to be measured sometimes even by miles.* Speaking generally for the whole world, and dismissing historic testimony, we may always assuredly look upon all sea cliffs, crags, and pinnacles of rock, as caused by the erosion and destruction of the formerly more widely extended land, by the moving surface of the sea; and the height and extent of the cliff, together with the hardness and durability of the rock composing it, will give us a means of estimating the power of this action, and the time consumed in it.

The estimate thus formed will never exceed, but may often fall far short of the truth, inasmuch as the ultimate result of this agency is to bury and conceal from our sight the monuments of its action. Land, such as any island, may at last be completely worn away and destroyed; all that was once above the level of the sea being carried off and strewed over its bed, leaving to us no visible record of the event.

* While walking on the cliffs near Barton, in Hampshire, in company with Sir Charles Lyell, in the spring of 1856, as we were looking down upon the shattered slope of fragmentary and broken masses that stretch between their summit and the beach, we were assured by a farmer of the neighbourhood that they commonly reckoned their average loss per annum at a yard of land all along the coast.

Just as actual sea cliffs are proofs of the erosive action of the sea now in operation, so, in almost all cases, inland cliffs, crags, scars, and precipices, as well as all valleys and ravines, gorges and mountain passes, are proofs of the former erosive action of the sea, in times when the land stood at a lower level with respect to it; and the dimensions of the gaps and portions removed, combined with the strength and durability of the materials, give us a measure of the power of the eroding forces, and the time during which they were in action. But a still more wonderful example of this agency is frequently afforded us in a low and gently undulating district, from which the very mountains themselves, that we can prove once covered it, have been removed, and an amount of solid rock, that formerly existed over it, utterly destroyed by erosion, and swept off, that would far exceed in bulk the most gigantic of our existing mountain masses.

To such agency we can only allude here in brief and general terms, so as to prepare the student to estimate rightly the forces and the actions which we shall have to consider in their proper place.

Rain.—The sea, however, is not the sole agent of the destruction of that portion of rock at or above its level, which we call land. All rain falling upon land, and either running over its surface or draining through its interior, is constantly abrading and carrying off particles of pre-existing rock in the shape of mud, silt, and sand. From the gutters and the ditches, from the rills, the streams, and the brooks, these materials for the building of mechanically formed rocks are almost unceasingly being carried into the rivers, and by them transported to the beds of lakes and seas. Rain soaking into ground, and issuing as springs on steep slopes or precipices, sometimes exerts a more wholesale destructive power, by gradually loosening and undermining very considerable masses of ground, and thus causing them to be *launched* forward, down the slope, producing what are called "landslips."

Ice and Snow.—When rain falls as snow, on the other hand, it exerts a conservative and protective effect as long as it retains its solid form, but, on melting, acts like rain, and even with greater intensity, inasmuch as a greater amount of water is often set loose and in motion over the land by the rapid melting of snow than would fall in the same space of time in the shape of rain directly from the clouds. The most extensive and powerful floods are those of the spring in mountainous districts, when the snows melt rapidly on the hills. If rain or other water soaks into rocks and fills up their interstices, either the small pores, or the crevices, joints, and fissures by which all rocks are traversed, and this water then freezes, this conversion into ice is accompanied by an expansion which exercises an almost irresistible mechanical force, the effect of which will be either the disintegration of the particles in the one case, or the breaking and rending asunder, and the displacement of the larger masses in the other. On mountain summits and sides subject to great vicissitudes of temperature, this agency exerts no mean effect. The hardest rocks will be broken up by it, and enormous blocks ultimately displaced and toppled over precipices, or set rolling down slopes to suffer still further fracture, and produce still greater ruin in their fall.

Few men live in situations enabling them to observe, and of those still fewer have the ability or the inclination to note and record the amount of this agency in the remote and inaccessible places where it is greatest. This amount, however, may be measured by the piles of angular fragments, large and small, lying at the foot of crags and precipices, or sometimes on the sharp peaks and steep summits of the mountains, where they are the ruins of formerly existing "tors" and pinnacles.

Glaciers.—When mountains are covered by perpetual snow, all the part so covered is protected by this envelope from all change. In such situations, however, the moving power of water takes another form, that of the glacier, or "river of ice." The lower border of the perpetual snow-mass passes into ice, from the alternation of melting and freezing temperatures, just as snow on the roof of a house forms icicles at its lower edge, when partly melted and refrozen. This ice accumulates in the valleys, and is frozen into a solid or nearly solid mass, called a glacier. Glaciers sometimes fill up a valley twenty miles long, by three or four wide, to the depth of 600 feet.

Although apparently solid and stationary, they really move slowly down the valley, and carry with them, either on the surface, frozen into their mass, or grinding and rubbing along the bottom, all the fragments, large and small, from blocks many tons in weight, down to the finest sand and mud, that rain, and ice, and the friction of the moving glacier itself, detach from the adjacent rocks. The cause of this motion is now generally believed to be that attributed to it by Professor J. Forbes, namely, a slight degree of plasticity, a *demi-semi-fluidity*, in the ice mass, by which it is enabled to actually flow down the valley, just as a viscous substance, such as partially melted pitch, would flow.*

The glaciers of the Alps, and probably those of other parts of the world, descend to a vertical depth of nearly 4000 feet below the line of perpetual snow, before they finally melt away, and leap forth as rivers of running water. The confused pile of materials, of all sorts and sizes, which they there deposit, is called the "moraine." This word is also applied to the lines of blocks that are being carried along on the surface of the glacier.† The river of water that proceeds from the end of a glacier is of course quite unable to move the large blocks which had been carried with ease by that of ice, and only transports the finer particles, as mud and sand.

Icebergs.—If, however, it so happen that a glacier come down into a lake, or into the sea, before it melt away, large fragments of it (icebergs) will be frequently floated off, with all their freight of rock-fragments of all kinds; and these loaded icebergs may then be carried great distances before they entirely dissolve. In this manner, large unworn angular blocks of rock may sometimes be dropped on the bed of the sea even hundreds of miles from their original site. The terminal moraine, instead of a pile at the foot of the glacier, is disseminated far and wide over the bottom of the surrounding seas.

* Professors Tyndel and Huxley have recently disputed this idea of Professor J. Forbes's, and shown the motion of glaciers to be the result of the minute, almost molecular, *fracture* and *regelation* of the ice particles, which move as if they were sand continually thawing and re-freezing.—(*Philosophical Magazine*, 1856).

† See Professor J. Forbes's work on the Glaciers of the Alps, and also Johnstone's Physical Atlas; also the works of Agassiz, Charpentier, etc.

***River Valleys.*—Rivers are not the producers of their own valleys; they are the results of those valleys, but they are their immediate results. The river could not be formed till after the valley, with all its tributary branches, had been marked out; but the valley could not even be marked out without the river, in most cases, instantly springing into existence, and commencing to modify, and deepen, and complete the valley.**

If we watch the tide receding from a flat muddy coast, we should see that the mud flat, even where no fresh water drains over it from the land, is frequently traversed by a number of little branching systems of channels, opening one into the other, and tending to one general embouchure on the margin of the mud flat, at low-water mark. The surface of the mud is not a geometrical plane, but slightly undulating; and the sea, as it recedes, carries off some of the lighter and looser surface matter from some parts, thus making additional hollows, and forming and giving direction to currents, which acquire more and more force, and are drawn into narrower limits, as the water falls. Deeper channels are thus eroded, and canals supplied for the drainage of the whole surface, which is immediately directed into them. First two, and then more, of these little systems of drainage unite, until at dead low-water we often have the miniature representation of the river system of a great continent, wanting of course the mountain chains, produced before our eyes in the course of a single tide, in the very manner and by the very agent by which all river systems on all islands and continents have been produced.

The difference between them is this only, that our islands and continents are now above the sea, not in consequence of the gradual fall of the water, but in consequence of the gradual rise of the land.

It may be said, moreover, that this little drainage system thus set up in a mud flat is not the result of the action of one tide, that it is not obliterated every time it is covered at high-water, and reproduced again afresh, but is the final result of many elevations and depressions, and many successions of drainage action, all combining to produce the same effect in the same lines, wherever nothing has happened, in the meanwhile to direct them into different ones.

Just so, however, it is with the river systems of our dry lands. The present form and contour of our lands, and their partition into basins of drainage or river systems, each divided from the other by lines of "watershed," is the result of many elevations above the sea, and depressions below its level. The internal forces of elevation and depression have acted not once only, but many times; and accordingly the whole surface of our land has been, *not once only*, but often subjected to the graving tools and gouges, the planes and chisels, so to speak, of the upper surface of the sea; the hollows and excavations thus caused not having been obliterated, but generally deepened and intensified on each occasion.

Action of Rivers.—This re-direction of draining water into old channels will be more certain and frequent in proportion to the steepness of the ground and consequent rapidity of the flow of water; and channels once selected will there be more rapidly deepened, and more completely and permanently formed. Such deep valleys (ravines, as we should then call them) are scarcely to be obliterated, or otherwise altered than from deepening and enlargement, by any number or amount of changes, short of the removal of the mass of high ground which they traverse. As long as the mountains remain undestroyed, the valleys and ravines must obviously be continually enlarged, either vertically or laterally, by the action of the waters which traverse them.

The erosive action of mountain torrents can hardly fail to be perceived by any one who visits them. In their narrow channels, smooth grooves and cuts, obviously water-worn, may often be observed, even in the hardest rocks; while holes of several feet in depth and width are often formed in such rock by the whirling action of water keeping in perpetual circular motion a few pebbles or a little sand. Cascades and waterfalls dig deep holes and black pools below the ledges over which they fall, and often undermine those ledges, and thus break them away, block by block, much faster than the abrasion of mere water friction could remove them. Cataracts cut their way back in all rivers, whether in the ravines of mountains, or when they fall from one plain or one table-land to another, as in the case of the Falls of Niagara and others. The ravine that the river St. Lawrence has excavated for itself by the recession of its Falls is 7 miles long, 200 to 400 yards wide, and 200 to 300 feet deep, and would require something like 35,000 years for its production, at the present rate of progress.—(*Lyell's Principles of Geology*, chap. xiv.)

The temporary damming up of rivers, and subsequent breaking down of the barrier and escape of the lake formed above it, produces sometimes the most remarkable instances of the power of moving water. Rocks as big as houses are thus set in motion, and carried sometimes for very considerable distances down the valleys.—(See *Lyell*, as above; also *Jameson's Mineralogy*, vol. 3, where all these causes of mechanical destruction, including that of ice and icebergs, are distinctly pointed out.)

The blocks accumulated in mountain torrents give us likewise a measure of the eroding power of water, since these are frequently crags that have been gradually loosened by the weathering action of the spray, or undermined by the abrasion of the water, and then fallen into the bed of the river. These blocks, arresting the force of the stream, are immediately attacked by it, and very soon become smooth and rounded by attrition, either of the mere water, or of water charged with sand and gravel. When sufficiently lightened, and sufficiently rounded and polished, some greater flood than usual sets them in motion, to receive still further rough treatment themselves, and become converted into tools for the breaking up and grinding of others, till at length the massive and shapeless crag that once fell into the bed of the torrent is rolled forward into the brook in the form of a quantity of small round pebbles. Here they undergo a continuation of the same mechanical operation as before, till they are delivered by the brook into the river in the shape of grains of sand, and are thus swept onward towards the sea; and if the river be very large, long before they reach the sea the sand is ground down, or dissolved, into mud of the finest and most impalpable description.* Clouds of such mud discolour the sea off the mouths of great rivers, such as the Amazon and Orinoco, even for many scores of miles out of sight of land; and the great ocean currents may carry it on, still slowly sinking through greater depths, even for many hundred miles further, before it finally settles to rest in some tranquil hollow of the bed of the ocean.

We shall be able better to understand how rapidly the size of water-borne fragments increases in proportion to the velocity of the moving water, when we learn from Mr. W. Hopkins, *that the power of water to move bodies that are in*

* For a description of these facts as observed in the bed of the Ganges and its tributaries, see Hooker's admirable Himalayan Journals, vol. i. p. 378.

it increases as the sixth power of the velocity of the current. Thus if we *double* the velocity of a current, its motive power is increased *sixty-four times;* if its velocity be multiplied by 3, its motive power will be increased 729 times; if by 4, 2048 times; and so on.

In studying the mechanical force of water upon rock, also, it is necessary to bear in mind that all earths and stones lose fully a third of their weight when suspended in water. These considerations enable us to understand more readily the fact of blocks of rock many tons in weight having been removed from breakwaters and jetties, and carried sometimes many yards during great storms, as also of still larger blocks hurried along by floods, etc.

The rolling power of water upon stones lying in its bed depends greatly on their shape also, the same current being easily able to roll along pieces of rock in the form of rounded pebbles, that it would be quite unable to move if they were in the shape of flat slabs; while, reversely, flat slabs or flakes would float more easily, or sink more slowly, than rounded or square-shaped fragments of the same weight and cubic contents. Flakes of mica, therefore, might be floated and transported onwards where grains of quartz, even though lighter than the mica, would sink; and, on the other hand, rounded quartz pebbles might be rolled forward where smaller and flatter pieces, in the shape of shingle, would be brought to rest.

Mr. Babbage has lately treated of this subject, in a paper of which an abstract appeared in the Journal of the Geological Society, November 1856.

He there supposes the case of a river, the mouth of which is 100 feet deep, delivering four varieties of fine detritus into a sea which has a uniform depth of 1000 feet over a great extent, which sea is traversed by one of the great ocean currents, moving with a certain given velocity.*

He takes for granted that the four varieties of detritus are such as, from their size, shape, and specific gravity, would fall through still water, the first 10 feet per hour, the second 8 feet, the third 5 feet, and the fourth 4 feet. The combined effect of the downward motion of the detritus, and the onward motion of the water, would

* The supposed velocity of the river and ocean current is not stated in the abstract.

then bring the first variety to the bottom of the sea, at a distance of 180 miles from the river's mouth, and strew it over a space 20 miles long; the second variety would only begin to reach the bottom 225 miles from the river's mouth, and would be spread over 25 miles, and so on, as in the following Table:—

No.	Velocity of fall per hour.	Nearest distance of deposit to river mouth.	Length of deposit.	Greatest distance of deposit from river mouth.
	Feet.	Miles.	Miles.	Miles.
1	10	180	20	200
2	8	225	25	250
3	5	360	40	400
4	4	450	50	500

We should thus have, proceeding from the same river, and poured into the sea either simultaneously or at different times, four different and widely separated patches of mud or clay formed on the sea bottom.

Mr. Babbage says, that this subject was suggested to him from his observing the *extreme slowness* with which a very fine powder, even of a very heavy substance, such as emery, subsides in water, and speaks of mud clouds being suspended in the depths of the ocean, where the density of the water increases, for vast periods of time.

The amount of mechanical work done by rivers can be estimated by examining their waters at different periods, and determining their solid contents. If this be done by simply evaporating the water, the result will be not only the mechanically suspended mineral matter, but also that which was chemically dissolved in the water. As the separation of these two, however, is rather troublesome, and not very important, it is not often attempted; neither, as a measure of the work done, would it be often necessary, since the chemical solution of mineral matter is perhaps more frequently than not the consequence of the mechanical erosion of it by the water.

Sir C. Lyell, in his *Principles*, gives the following as the results of various observations:—

The total mineral matter carried down by the Ganges into the sea, according to Everest, is 6,368,077,440 cubic feet per annum, part of which has been deposited at its mouth, forming a gentle submarine inclined plane of 100 miles long, and sloping from 4 fathoms to 60 fathoms in depth. Lyell says, that for the transport of this quantity, it would require a fleet of 2000 Indiamen, each of 1400 tons, to start every day throughout the year. This mass of matter would cover a square space 15 miles in the side every year with mud a foot deep, or would raise the whole surface of Ireland one foot in the space of 144 years. The Brahmapootra probably carries an equal quantity.

Mr. Barrow calculated that the Yellow River (Hoang Ho) in China, carried down into the Yellow Sea 48,000,000 of cubic feet of earth *daily*, so that, assuming the Yellow Sea to be 120 feet deep, an English square mile might be converted into dry land every seventy days, and supposing its area to be 125,000 square miles, the whole would be made into terra firma in 24,000 years.

Herodotus remarked that "Egypt was the gift of the Nile," and that the sea probably once flowed up to Memphis, the old gulf having been filled up by the Nile mud, as the Red Sea would be filled up if the Nile were turned into it. The edge of the present delta is, however, now swept by a powerful current, which carries off all detritus delivered into it, and thus future increase is prevented. Otherwise the Nile would by this time have formed a long tongue of land projecting into the Mediterranean, just as the Mississippi has projected a tongue of land 50 or 60 miles long into the Gulf of Mexico, having previously filled up the inlet which formerly penetrated from that sea deeply into North America, and received the rivers more than 100 miles inland from the present coast. According to Dr. Riddell, the solid matter contained in the Mississippi is about 80 parts in the 100,000 of water by weight, or about 33 by volume; and Sir C. Lyell calculates, that it brings down 3,702,758,400 cubic feet annually, and that the present delta has required 67,000 years for its formation.

If we turn to the European rivers, Bischof states that Chandellon, by daily experiments during December 1849, found in the Maes, at Liege, a maximum of 47.4 parts of suspended matter alone, a minimum of 1.4, and a mean of 10 parts, in the 100,000 of water.

In the Rhine, at Bonn, Mr. Leonard Horner found, August 1833, when it was unusually low and turbid, 31.02 of suspended and dissolved matter, and in November, when swollen, 51.45. Bischof found in March 1851, 20.5 of suspended matter alone, and at another time, when it was clear, only 1.73 of such parts; while Stiefensand, near Uerdingen, after a flood, found 78 parts of suspended matter in the 100,000 of water.

In the Danube, August 5, 1852, there were found 9.23 of suspended, and 14.14 of dissolved matter, total solids 23.37, in the 100,000; while in the Elbe at Hamburgh, there were in June 1852 only found 0.9 of suspended, and 12.7 of dissolved matter.

In these experiments much depends on the state of the river, and also on the part of the river where the water is taken from, whether far from the bank, at the surface, or near the bottom, and so on.

Whether the matter thus carried down by rivers is deposited at their mouths, and forms a delta, or is carried off to a greater or less distance, depends on the tidal or oceanic currents which are to be met with at the mouth of the river. In lakes, deltas or flats are almost invariably met with at the mouths of rivers. In sheltered bays and gulfs, where there is no great rise and fall of tide, and consequently no great scour of the river's mouth, deltas are also formed; witness the Po, the Rhone, Nile, Mississippi, Orinoco, Indus, Ganges, Brahmapootra, etc. Where, however, there are strong ebb tides, or where the river mouth is swept by a strong oceanic current, the detritus is carried off directly into the sea, as in the case of the Amazon, the Rio de la Plata, the St. Lawrence, and of most of the rivers of Britain and Western Europe.

In the same way the mud and sand washed from all coasts by the erosive action of the breakers, may be carried out by tides and currents far from the land, wherever the materials are fine enough to be held long in suspension, and the currents swift enough to move far in that time. The current that sweeps round the extremity of Africa from the Indian Ocean to the Atlantic, is at once distinguishable by its dirty olive green colour from the deep blue of the pure ocean water, even in a depth of 100 fathoms, and out of sight of land. Small pebbles were brought up from that depth by the lead, in H.M.S. Fly; and the change of colour in the water can hardly be due to any other source than the presence of minutely divided mineral matter held in suspension by the water.

Among coral reefs, where there is no mechanically suspended matter in the water, it is of crystalline clearness, and deep blue colour, even in such small depths as fifteen and twenty fathoms, and it is only on shoals of less than ten fathoms where the white or yellow bottom begins to appear through the water, that a green tint appears which becomes plainly visible, even at a distance of one or two miles, when the water shoals to four or five fathoms. This, however, is a bright grass green, very different from the dull green of the Agulhas current, and our own and other shallow seas.

Similar differences in the colour of the sea, arising from the same cause, may be seen on our own coasts. The sea on the west coasts of Ireland and Scotland, where the current sets upon the land from the Gulf Stream, is the deep clear ocean blue, even in the bays and harbours, and is very different from the dirty green water of the English Channel, the Irish Sea, or the German Ocean, which has become loaded with matter from the washing of our coasts and rivers. This difference may be seen on the small scale in the bays of the western coasts. I have often been struck with the appearance of Bantry Bay after a day's storm and rain, when a margin of green discoloured water may be seen extending some half mile in width all round the shores, singularly contrasted with the bright blue water of the bay. In dry calm weather, there is no discoloured margin; and the general blueness of the water is not affected by the bottom, which inclines very gradually and regularly from five or six fathoms at the head of the bay, to about twenty-five at its mouth, and consists of a fine-grained silt, principally composed of broken corallines and shells.

This discoloured margin, then, is nothing else than the washing of the land during heavy rains and storms, proceeding either directly from the cliffs or from the numberless little brooks and rivers, and must exist under the same circumstances round all lands. No small amount of earthy matter is thus annually conveyed into the sea, swept off by its currents, and deposited somewhere in its bed.

It results from even such a hasty and rapid glance as we have just thrown over the principal mechanical powers of moving water that are daily and hourly at work around us, that we begin to acquire the notion that we are living in a vast workshop, and that all the earthy matters we see about us, the mud, the clay, the soil, the dust, the sand, the gravel, and the boulders, are only so much raw material in process of manipulation. They may be likened to the refuse and the chips of some vast manufactory. They are the building materials of stratified rocks, which are being carried from the quarry to the place of construction, much being dropped and scattered by the way. Every pebble, every grain of sand, every atom of mud, is a fragment of a pre-existing rock, removed at some period of past time, and destined ultimately to enter into the structure of some other rock in the future.

This building metaphor might be carried still farther when we come to speak of the chemically-formed rocks, since many of the mechanical deposits are bound together by cements and mortars which are more or less identical in composition with those used in architecture.

Description of Mechanically-Formed Rocks.

51. *Conglomerate, Puddingstone, Breccia.*—In the preceding pages, we have mentioned the method of formation of pebbles, gravel, and shingle, in rivers and along sea-coasts. When those materials are compacted together into stone, they are called *conglomerate* or *puddingstone* if the pebbles are round, *breccia* if the fragments are sharp and angular.

The pebbles may consist of any substance whatever; but they are most commonly composed either of quartz, quartz rock, or some very siliceous mineral. This is partly the result of the greater abundance of siliceous over other mineral matters in the composition of rock generally; but it also arises from the greater durability of quartzose substances, and from their mode of fracture. Pure silica, or a highly siliceous mineral, is not easily acted on either by water or any other commonly occurring solvent; they are not, therefore, so easily disintegrated by chemical force as those which contain lime or other earthy or alkaline minerals. On the other hand, quartz and quartz rock, and similar substances, though very hard, are often rather brittle; and they break into squarish or cubical lumps, rather than into plates or slabs. These squarish lumps are soon converted by motion in water, and the consequent rounding of their angles, into more or less globular pebbles, and are therefore set in motion with comparative facility.

Hence it results that, by "conglomerate" alone we usually understand a mass of quartz pebbles bedded in quartzose sand, and that when the pebbles consist of limestone or of trap, of slate, schist, or other rock, the fact is denoted by calling them calcareous or trappean conglomerate, etc.

Not unfrequently we are able, from recognisable characters in the pebbles, to ascertain not only the general nature, but the particular variety, and sometimes the exact locality from which these pebbles were derived; and we hence learn what must have been the strength and direction of the breakers and currents that removed them from their parent rock, and brought them into their present position.

In some cases, conglomerates are found to contain blocks of other previously existing conglomerates, so that we get evidence of several successive actions—first, of the formation and consolidation of one rock (A); next of its partial wearing away by the action of water, and the rounding and transporting of fragments of it to another locality; then of the consolidation of those fragments into the second rock (B); and, lastly, of the partial or entire breaking up of that, the rounding and transporting of blocks of it without detaching the pebbles of which those blocks consist, and the consolidation of a third rock (C) with some of these blocks embedded in it.

This shows us proof of what would be *a priori* very probable, namely, that the materials of the mechanically-formed rocks which now exist are not necessarily derived directly from originally-formed rock, but may in many instances have entered again and again into combination as the materials of previously existing mechanical rocks, which have been alternately destroyed and re-formed.

The degree of induration or consolidation in conglomerates varies greatly. Some seem to have been consolidated by simple pressure; and from these the pebbles may often be removed by a slight blow with the hammer, or even by the knife, the form or mould of the pebble remaining in the little film of sand which fills up all the interstices between the larger fragments. Sometimes the conglomerate has been bound or cemented together by calcareous, ferruginous, or siliceous infiltrations, the matrix in which the pebbles lie being as hard and indestructible as the pebbles themselves, a blow with a hammer breaking the pebbles as easily as the mass of the rock in which they are embedded. The size of the fragments in conglomerates and breccias varies greatly. In some rarer cases, blocks of as much as two feet in diameter occur; but the more ordinary sizes are from that of a man's head to that of walnuts. Below that size, the rock begins to pass into the coarser varieties of sandstone.

52. *Sandstone and Gritstone.*—The remarks as to the usually quartzose character of conglomerates hold good also with respect to sandstones. The very process by which fragments of rock are rounded produces sand, as the waste resulting from their attrition. Pebbles themselves also are gradually broken or diminished into grains of sand. Sandstone is nothing else but sand, formerly loose and incoherent, subsequently compacted into solid stone. The grains both of sand and sandstone generally consist of quartz, sometimes clear and colourless, sometimes dull white, sometimes yellow, brown, red, or green. The red colours are usually the result of the covering of each little grain with peroxide of iron, which sometimes acts as a sort of cement to the stone, serving to bind the particles together. The green colours are commonly derived from silicate of iron; and the green and red are often intermingled, in consequence of the change of the iron from the condition of a silicate to that of an oxide or peroxide.

The size of the grains varies from that of a pea to the minutest particle visible to the naked eye, many sandstones and gritstones even requiring a lens in order to distinguish the particles of which they are composed.

The materials are equally various, as, along with grains of quartz, may occur grains and particles of any mineral substance whatever. Grains of feldspar, distinguishable by their dull white colour and peculiar appearance, occur abundantly in some sandstones, which may then be called feldspathic sandstones. Flakes and spangles of mica are rarely altogether absent; and in many sandstones they occur so abundantly, and in such regular seams, as to cause the rock surfaces to glitter, and the rock itself often to split into thin plates and slabs. These are called *micaceous sandstones*. When grains of limestone occur in any remarkable proportion, the rock may be called a *calcareous sandstone*, though this designation is often applied to sandstones the quartzose or other grains of which are bound together by a cement of carbonate of lime, either invisible to the eye or occurring as a network of little veins and strings of crystalline carbonate of lime running throughout the stone. Other varieties of sandstone are similarly named from the prominent character of some part of their contents.

Argillaceous sandstone is a term not often used, nor is it very often applicable, though many rocks contain various mixtures of sand and clay. In many sandstones, too, little flat rounded patches of clay, more or less indurated, often occur. Similar little patches of clay may be seen on sandy shores, either originally deposited there in little hollows, or rolled as clay pebbles from some bed of clay. In quarrying sandstone, these clay patches are commonly called "galls" by the workmen. In highly indurated grits, they sometimes assume the form of pebbles of *slate*, though the slaty structure may often have been assumed in consequence of the subsequent induration, and not before they were embedded in the sandstone.

Among sandstones derived from hard crystalline trap rocks, it is sometimes not easy, at first sight, to distinguish between the sandstones and the traps from which they are derived. If the crystals of the one, after being disintegrated, become compacted together again before their angles are much worn, and retain undiminished the lustre of some of their facets, and the sandstone or gritstone thus composed be very hard and intractable, pieces of it might easily pass for an actual molten trap rock. In most cases, however, the particles of the trap rock are much decomposed before they enter into the composition of the sandstones; and the only mistake that could then be made between them would result from a hasty glance at the weathered surfaces of the two. The *trappean sandstones*, or *volcanic grits*, thus composed of particles derived from the decomposition of greenstones and basalts, consist principally of grains of feldspar and hornblende, which have commonly lost all their external crystalline appearance. Quartzose grains and mica flakes derived from other sources are, however, often mingled with those substances in such sandstones, and serve, even in the most crystalline-looking varieties, to distinguish them from trap rocks.

In some cases, these "trappean sandstones," or "volcanic grits," put on the appearance of trappean or volcanic "ashes;" and it would then be impossible to distinguish between the two kinds of rock, and say which accompanied the igneous outburst, and which was derived from the subsequent abrasion of the cooled igneous rock. These instances, however, are more rare than they might be supposed to be.

The difference between sandstone and gritstone is a vague and indeterminate one, which must necessarily be the case when the things themselves are so various and often capricious in composition and texture. The term gritstone is perhaps most applicable to the harder sandstones, which consist most entirely of grains of quartz, most firmly compacted together by the most purely siliceous cement. The angularity of the particles cannot be taken as a character, since the rock commonly called "millstone grit," is generally composed of perfectly round grains, sometimes as large as peas, and even larger; the stone then commencing to pass into a conglomerate.

There are many local terms used by quarrymen and miners for different varieties of sandstones, such as—

Rock, used generally in South Staffordshire to denote any hard sandstone.

Rotch, or *roche*, is generally used for a softer and more friable stone.

Rubble, means either loose angular gravel, or a slightly compacted brecciated sandstone.

Hazel is a north of England term for a hard grit.

Post is a similar term for any bed of firm rock, and is generally applied to sandstone.

Peldon is a South Staffordshire term for a hard, smooth, flinty grit.

Calliard,* or *galliard*, is a northern term for a similar rock.

* Mr. Page, in his advanced Text-book, which on several accounts is well worthy of the student's perusal, opposes the introduction of these local

Freestone is a term in general use, which is often applied to sandstone, but sometimes to limestones, and even to granite, as in the counties of Dublin and Wicklow. It means any stone which works equally *freely* in every direction, or has no tendency to split in one direction more than another.

Flagstone, on the contrary, means a stone which splits more freely in one direction than any other, that direction being along the original lines of deposition of the rock. These stones are ordinarily sandstones, though often very argillaceous, and some flagstones are perhaps rather indurated clay in thin beds than sandstone. Thin-bedded limestones may likewise often be called flagstone.

Sandstones, like *conglomerates*, may have been consolidated either by simple pressure continued for a long period of time, by pressure combined with an elevation of temperature, by the infiltration of mineral matter in solution, or by the aqueous or igneous solution and subsequent reconsolidation of some of the particles composing it, or lastly, by a combination of two or more of these actions. Some of the loose tertiary sands of the north of France, such as the Sable de Fontainebleau, and the Sable de Beauchamp, exhibit these actions in a very remarkable way. The Sable de Fontainebleau is a pure white siliceous sand. It is covered in some places by beds of a freshwater limestone called the Calcaire de Beauce. Water containing carbonate of lime in solution, derived either from this limestone, or from other sources, percolates through the sand, and deposits the lime, binding the sand either into globular concretions, or even into rhombedral crystals, such as carbonate of lime ordinarily forms.

Besides these smaller concretions, other large parts of the sand have been compacted together, either at the time of deposition, or subsequently, into a very hard white gritstone, which is extensively used as a paving stone in the districts where it occurs. This grès de Fontainebleau forms picturesque crags and precipices, all the

terms. I would, on the contrary, recommend their wider and more general use, not only as facilitating the intercourse between scientific geologists and our working brethren of the hammer, but as being often in themselves more definite and precise in their shades of meaning, as well as shorter, than our cumbrous periphrases of Latin terms. Many good, short, clear, and genuine Saxon names for natural objects, have been most unadvisedly allowed to fall into desuetude. As an instance, we need only mention the following for forms of ground:—

Scar or *Scaur*, A long line of cliff.
Torr, A rocky pinnacle.
Lowe, A round bare hill,—the Welsh *moel*.
Cleugh, A roundish mountain glen, the termination surrounded by steep hills.
Strath, The alluvial flat in the bottom of a valley.
Fell, A flat topped range of hills, whether a ridge, or the edge of a table-land.
Tarn, A lake in a cleugh.

more striking perhaps, from the loose and easily removed sand in which the beds and other irregularly formed masses of the consolidated rock occur. The cementing substance of this sandstone may in some cases be carbonate of lime, equally diffused through the mass. In other cases, however, the quartzose grains appear to be bound together by a siliceous cement, as if the percolating water had contained dissolved silica. This is obviously the case in one variety, a glittering rock being produced, greatly resembling ordinary quartzite, only more white and lustrous; this variety is called "grès lustrée," or lustrous grit.

The grès de Beauchamp consists of similar locally consolidated and semi-concretionary lumps of sandstone, occurring here and there in loose sand. On the plains north of Meulan, these lumps of gritstone are discovered by "sounding" or piercing the loose sands with an iron rod, and they are then extracted and broken into square blocks, and used for forming the roads of the country.

These tertiary grits are often as hard and intractable, and break with as splintery a fracture under the hammer of the geologist, as the grits he is accustomed to meet with among the oldest rocks of the British mountains.

When among the materials of a sandstone there occur any containing a notable proportion of alumina, which may be known by the earthy odour given out when the rock is breathed upon, we have the constituents for the formation of clay, and it only remains for those materials to be ground down into fine powder and mixed with water, either naturally or artificially, for clay to be produced. While all or any considerable portion of the rock remains in the form of distinct grains, we might call it an *argillaceous sandstone;* the passage from that to a sandy clay, and then to a pure clay or shale, being often an insensible one.

53. *Clay.*—Perfectly pure clay has been already described as a hydrated silicate of alumina. This is the substance known as "kaolin," or "porcelain clay," derived from the decomposition of orthoclase, albite, or other feldspars, from which the silicates of potash, soda, etc., have been washed out. In some granitic districts, the granite being decomposed yields this substance, which is carried down by water, and deposited in hollows, the quartz and mica being often left behind in the state of loose sand.

The ingredients of pure porcelain clay are also sometimes derived from other rocks, as at Rostellan, in Cork Harbour, where the highly inclined bottom beds of the carboniferous limestone afford them in considerable abundance. The rock is probably a cherty, or siliceous and argillaceous limestone, (though no distinct nodules or seams of chert are visible in the adjacent beds), and over one small district the lime has been almost entirely removed, leaving the silica and alumina behind* in the state of a crumbling powdery mass, which is rather largely exported to the English potteries.

Common clay, however, is often largely coloured with oxide of iron, and mingled with many impurities, besides being mixed in variable proportions with sand. Any very finely divided mineral matter, which contains from ten to thirty per cent of alumina, and is consequently "plastic," or capable of retaining its shape on being moulded and pressed, would commonly be called clay.

These clays have a number of varieties, of which the following are the principal:—

Pipe clay, free from iron, white, nearly pure.

Fire clay, nearly free from iron, and from all alkalies, often containing carbon, but this does not prevent its forming bricks that will stand the heat of a furnace.

Shale, regularly laminated clay, more or less indurated, and splitting into thin layers along the original laminæ or planes of deposition of the rock. The colliers' and quarrymen's terms for shale are *Bind*, or *Bluebind*, *Metal*, *Plate*, etc. When very fine, and containing a large proportion of carbonaceous matter, the collier calls it *Batt*† or *Bass*, the geologist carbonaceous or (bituminous) shale, and the coal merchant often "slate." In Scotland the collier's term for shale appears to be "blaes," or "blues," the shales being often bluish grey. When lumpy, they are called "lipey blaes." Black, argillaceous shales (or batts) are called "dauks;" "fekes," or "grey fekes," seem to be sandy shales such as would be called "rock binds" in South Staffordshire.—(See *Williams's Mineral Kingdom.*) In the south of Ireland carbonaceous shale is called "kelve," and indurated slaty shale is termed "pinsill," or pencil," as it is used often for slate pencils.

Clunch is a common name for a tough, more or less indurated clay, often very sandy.

* The highly inclined bedding of the mass is still distinctly visible in the clay pits, and fossils are occasionally perceptible in the lines of bedding in a very friable and crumbling condition.

† This term of "batt" commonly applied in South Staffordshire to a lump of shaly coal, which will not continue to burn in the fire, and therefore soon becomes ash, and is consequently of little worth, has gone out of general use in the English language except in composition, where it is retained in the word "brick-bat" for the broken end of a brick.

Loam is a soft and friable mixture of clay and sand, enough of the latter being present for the mass to be permeable by water, and to have no plasticity.

Marl is properly calcareous clay, which, when dry, naturally breaks into small cubical or dice-like fragments. Many clays, however, are commonly but erroneously called marls, which do not contain lime.

Argillaceous flagstone is an indurated sandy clay or clayey sandstone, which splits naturally into thick slabs or flags.

Clay slate is a metamorphosed clay, differing from shale in having a superinduced tendency to split into thin plates, which may or may not coincide with the original lamination of the rock. It will be more particularly described among the metamorphic rocks.

2.—Chemical and Organic Rocks.

Preliminary Observations on their Origin.

Before entering on the description of these rocks, it will be useful briefly to consider the nature and action of the forces concerned in their production. I shall take as my principal guide in this examination Bischof's "Chemical and Physical Geology," as translated for and published by the Cavendish Society.

Carbonate of Lime.

When speaking of the mineral Calcite, it was mentioned that carbonate of lime is nearly insoluble in pure water, but that if the water contain carbonic acid gas, the mineral is easily dissolved by it, either in consequence of some special solvent power in water so impregnated, or in consequence of the carbonate being converted into a soluble salt (never yet seen in a solid state) in the form of a bicarbonate of lime.

Rain water and snow contain small quantities of carbonic acid derived from the atmosphere, and acquire more in sinking through the soil.

If water in sinking into the earth meets with carbonic acid gas, rising from the interior, it becomes saturated with it, and carbonated springs are produced. The waters of springs, rivers, and lakes, therefore, always contain some, and probably a very variable amount of carbonic acid gas. The waters of the European seas, according to Vogel and Bischof, contain from 7 to 23 parts by weight of carbonic acid gas in the 100,000 of water. But from experiments made in the French ship "Bonité," in the Indian Ocean, only from 0.4 to 3.0 parts by weight in the 100,000.—(*Bischof*, vol. i. p. 113, etc.)

The quantity of carbonate of lime thus held in solution by water containing carbonic acid gas is likewise very variable. In springs it may occasionally reach the point of saturation, which is about 105 parts in the hundred thousand.

In the rivers of Great Britain and Western Europe, the quantity of mineral matter held in solution varies from 4 to 55 parts in 100,000 parts of water, the mean quantity being 22. Of this mineral matter one half is commonly carbonate of lime, the least proportion, or 35 per cent, being found in the Loire, the greatest 82 to 94 per cent in the Rhone, at Lyons. The quantity of mineral matter in the Thames, near London, is 33 in the 100,000 parts of water, 15 of which, or 46 per cent, are carbonate of lime. Bischof calculates that if the mean quantity of carbonate of lime in the Rhine be assumed as 9.46 in 100,000 of water, which it is at Bonn, then, according to the quantity of water estimated by Hagen to flow at Emmerich, enough carbonate of lime is carried into the sea by the Rhine, for the yearly formation of three hundred and thirty-two thousand millions of oyster shells of the usual size.

Notwithstanding the vast quantity of carbonate of lime thus carried down into the sea, observation shows that the quantity to be found in sea water is commonly very small. In most analyses of sea water it is not mentioned at all. Sea water from Carlisle Bay, Barbadoes, contained 10 parts in 100,000; sea water from between England and Belgium, only 5.7 parts in 100,000. In the open sea, at a distance from any land, it is said to be rarely if ever discoverable by analysis.

The smallness of the quantity to be found in sea water, compared with that in almost all rivers, is doubtless owing to the quantity of carbonate of lime constantly abstracted from sea water by marine animals, in order to form their shells and other hard parts.

When we consider the vast number and variety of fish and of mollusca, crustacea, echinodermata, and polyps that inhabit the sea, and especially when we look at the enormous bulk of the coral-reefs that are found within the tropics, we shall be in no danger of under-estimating the vast amount of carbonate of lime annually abstracted from the ocean. That it is abstracted more in one part than another, and yet the ocean maintains a nearly equal average, will not be surprising when we reflect on the extent of the great currents that traverse the sea, and look upon the entire ocean as one vast, slowly circulating system of moving water.

Bischof states that the quantity of free carbonic acid gas contained in the sea, is five times as much as is necessary to keep in a fluid state the quantity of carbonate of lime to be found in it. He argues, therefore, that it is impossible for any carbonate of lime to be *precipitated in a solid form at the bottom of the sea by chemical action alone.*

Carbonate of lime is deposited on land by springs and rivers in consequence of the evaporation of the water, and the consequent extrication of a portion of the carbonic acid gas that previously held the carbonate of lime in solution.

But it is clearly impossible for any evaporation of water and gas to occur to a sufficient extent in the sea for this precipitation to take place. We are almost compelled, therefore, to conclude with Bischof, that all our marine limestones have been formed by the intervention of the powers of organic life, separating the little particles of carbonate of lime from the water and solidifying them, in order to enable them to form part of a solid rock.

There is of course the possibility that the sea once contained a much greater proportion of carbonate of lime than it does now, though this does not appear likely when we recollect that in the earliest and least fossiliferous of our formations, there is a much smaller proportion of limestone than in later and more fossiliferous rocks; and that even in the oldest* limestones, organic remains are to be found. The purely chemical processes now open to our observation, in which limestone is being formed, are the following:—

54. *Stalactites* and *Stalagmites*, *Travertine* and *Calc Sinter*, are formed in places where water containing carbonate of lime in solution suffers from evaporation, and deposits the carbonate in a solid form. Each drop of water loses by evaporation both water and carbonic acid gas, thus becoming more saturated with the carbonate of lime, at the same time that it loses some of its solvent power. It is therefore forced to part with some of this carbonate of lime, which adheres in a solid form to the nearest part of the solid substance over which the water passes. In the case of *stalactite* and *stalagmite*, a coating of solid matter is thus formed, with long icicle-like pendants hanging from the roof of caverns or arches, and columns rising from the floor wherever the water continues to drop long enough in one particular spot. Vertical sheets of it may even be formed when the water oozes from a long joint or crevice in the roof. The part hanging from the roof is called stalactite; that on the floor stalagmite. The limestone thus formed is commonly white or pale yellow, subcrystalline, often fibrous, and, when thin, semitransparent or translucent.

Stalactites may often be seen under the arches of bridges, vaults, or aqueducts, especially if the stone of which they are built be limestone. Sometimes they are even derived from the carbonate of lime contained in the mortar or cement used in their construction.

Travertine, or *calcareous tufa*, is deposited by exactly the same process on the margins of springs or on the banks of rivers and the sides of waterfalls, or wherever water containing carbonate of lime in solution is brought into circumstances where rapid evaporation can take place. Sticks and twigs hanging over brooks often become coated with it; and the incrustation of birds' nests, wigs, medallions, and other matters,

* In the highly altered limestones associated with gneiss and mica slate, we could hardly expect to find traces of fossils, even if they once contained them. Organic forms have, however, lately been discovered in altered limestone from the gneiss of Scotland.

by the action of what are called petrifying wells, is commonly known. In Italy, large masses of solid and beautiful travertine are deposited by some of the springs, so that it is used as a building stone. The Colosseum at Rome is built of stone thus formed. The name travertine is derived from the Tiber, meaning simply Tiber-stone.

Pipes to convey water, especially water from boilers, frequently become choked up by the deposition of limestone. Bischof says that there are fifty springs near Carlsbad giving out 800,000 cubic feet of water in twenty-four hours, from which, according to Walchner's calculation, a mass of stone weighing 200,000 pounds could be deposited in that time.

Marine Limestones.—The marine depositions of carbonate of lime now taking place are best studied in coral reefs. In almost all tropical seas, encrusting patches or small banks of living coral are to be found along the shores, wherever they consist of hard rock, and the water is quite clear. In the Indian and Pacific Oceans, however, far away from any land, huge masses of coral rock rise up from vast and often unknown depths just to the level of low-water. These masses are often unbroken for many miles in length and breadth; and groups of such masses, separated by small intervals, occur over spaces sometimes of 400 or 500 miles long, by 50 or 60 in width. The barrier reef along the north-east coast of Australia is composed of a chain of such masses, and is more than 1000 miles long, from 10 to 90 miles in width, and rises at its seaward edge from depths which in some places certainly exceed 1800 feet. These reef masses consist of living corals only at their upper and outer surface; all the interior is composed of dead corals and shells, either whole or in fragments, and the calcareous portions of other marine animals. The interstices of the mass are filled up and compacted together by calcareous sand and mud, derived from the waste and debris, the wear and tear of the corals and shells, and by countless myriads of minute organisms, mostly calcareous also. The surface of a reef, where exposed at low-water, is composed of solid-looking stone, which is often capable of being split up and lifted in slabs, bearing no small resemblance to some of our oldest limestones. These slabs and blocks, when broken open, are frequently found to have a semicrystalline structure internally, by which the forms and the organic structure of the corals and shells are more or less disguised and obliterated. The "bottom" in and among the reefs composing the great Australian Barrier, at a depth of some twenty fathoms, often looked, when brought up in the dredge, very like the unconsolidated mass of some of the coarse shelly limestones to be found among the oolites of Gloucestershire. At other times the dredge came up completely filled with the small round foraminiferous* shells called orbitolites, and these organisms seemed in some places to make up the whole sand of the beach either of the coral islets or of the neighbouring shores. In the deep sea around, and in all the neighbouring seas, from Torres Straits to the Straits of Malacca, wherever "bottom" was brought up by the lead, it was found to be a very fine-grained impalpable pale olive-green mud, which was wholly soluble in dilute hydrochloric acid. This substance, when dried, would therefore be scarcely different from chalk, though it commonly was of a greener tinge. Raised coral reefs, in the islands of Timor and Java, were often internally as white and friable as chalk, though they had frequently a rougher and grittier texture, and weathered black outside. The weathered surfaces of these limestones, often at a height of two or three hundred feet above the sea, with their embedded shells of all descriptions, including a tridacna of one or two feet in diameter, differed in no respect from some of the surfaces of the Great Barrier reef, where exposed at low-water.—(*Voyage of H.M.S. Fly.*)

On the upper surfaces of some of the existing coral reefs, small islands are formed; the coral sand being drifted by the winds and waves, till it forms a bank reaching above high-water mark. In some of these islands, the rounded calcareous grains are bound together into a solid stone by the action of rain-water, which, containing a small quantity of carbonic acid, dissolves some of the carbonate of lime as it falls, but, being shortly evaporated, redeposits it again in the form of

* See Dr. Carpenter's papers on these creatures in the *Philosophical Transactions*.

a calcareous cement. Some of this stone presented very distinct examples of the oolitic structure presently to be mentioned, little minute grains and particles being enveloped in one or two concentric coats, like the coats of an onion. That this stone was not consolidated under water was proved by nests of turtles' eggs being found embedded in it, evidently deposited by the animal when the sand was above water, and was loose and incoherent.

Guided by these facts and observations, we may form tolerably accurate notions of the mode of origin of all our marine limestones, and attribute to them an organic-chemical origin, taking into account, at the same time, how easily they may have been subsequently altered in texture by the metamorphic action either of water or of heat.

We must also bear in mind that, although the carbonate of lime may have been secreted and brought into a solid form from its aqueous solution by the action of animal life, yet that the original form it thus received has been retained in only a small part of it, the great mass having been subjected to the mechanical actions of erosion, trituration, and transport, to a greater or lesser extent, in the process of its conversion into calcareous mud, and deposition as beds of limestone.

Freshwater Limestones.—Those limestones which have been formed in fresh-water lakes, and are called fresh-water limestones, may more nearly resemble travertine in their mode of origin, since there is nothing to forbid the supposition of the waters of lakes becoming so highly impregnated with dissolved carbonate of lime as actually to deposit it as a chemical precipitate. At the same time, most fresh-water limestones look more like the result of the deposition of a highly calcareous, rather clayey mud, than of a precipitate of pure carbonate of lime. They become then the extreme term of marl or calcareous clay, and may be the result of either the disintegration of shells, etc., or of the mechanical action of rivers on previously existing calcareous rocks, the calcareous mud thence derived being perhaps mingled with the detritus of other rocks in greater or less quantity.

While, however, we depend upon the authority of the chemist, and look to him for instruction as to the mode of origin of naturally formed chemical compounds, we may perhaps, without presumption, doubt whether chemists are yet able to explain to us all the combinations to be found in nature. Among those not yet fully explained, we may perhaps place some of the varieties of limestone.

Dr. Lyon Playfair suggests two additional modes by which a chemical precipitation of carbonate of lime might in some places be formed on the bottom of the sea.

He says most rivers contain small quantities of silicate of potash; and when this is carried into the sea, some of the carbonic acid contained therein may unite with the potash, thus rendering possible a precipitation of carbonate of lime in a solid form, and also of silica.

Marine vegetables also, like terrestrial vegetation, require carbonic acid, and, by extracting it from the sea-water, may reduce the amount in particular localities below that which is necessary to keep all the carbonate of lime in a fluid state, and thus render a solid precipitation of that substance possible.—(*De la Beche's Geological Observer*, p. 102, 2d edition.)

Silica.—The aqueous deposition of silica is sometimes a purely chemical one, as in the case of the *siliceous sinter* deposited round the Geysers, or hot springs, of Iceland, and round the hot springs of St. Miguel and Terceira, in the Azores, and the chalcedony round those of New Zealand. Cold-water springs also, in some instances, deposit siliceous matter; but in these the silica is generally combined with alumina, oxide of iron, and other bases. In all these cases, evaporation of the water takes place; and Bischof attributes the formation of quartz crystals in cavities, and of compact quartz in veins, to the total evaporation of water containing silica in solution, and trickling down the sides of such cavities. He shows the impossibility of ascending springs depositing the quartz, inasmuch as those must be full of water, and therefore total evaporation of successive films of water could not take place. He attributes the formation of quartz crystals in drusy cavities to a similar evaporation of water containing silica, that has filtered through the adjoining rock. Agates, chalcedony, etc., show very distinctly the successive deposition of films of silica.

Marine Flints.—To account for the deposition of silica on the bed of the sea, where evaporation is not possible, we are compelled, as in the case of limestone, to call in the aid of the powers of animal life. The minute shells of many of the infusoria are almost entirely composed of silica, which they have extracted from the water of the sea. Some kinds of rock, such as the tripoli, or polishing slate, are entirely made up of these microscopic substances, some beds thus formed being many fathoms in thickness and many miles in extent.

All seas, from the equator to the poles, abound with these minute organisms. They have been found living even in ice. The phosphorescence of the sea, also, is due to the presence of organic beings, a large proportion of which are siliceous-cased animalcules. The bottom of the mid-Atlantic, at a depth of 2000 fathoms, was found, in some of the late hydrographic surveys of the United States, to be covered by what appeared to be a fine clay; but this, on examination, was discovered to be entirely composed of the siliceous shells of infusoria.* According to Ehrenberg, there are formed annually in the mud deposited in the harbour of Wismar, in the Baltic, 17,946 cubic feet of siliceous organisms. Although it takes a hundred millions of these animalcules to weigh a grain, Ehrenberg collected a pound-weight of them in an hour. So prolific are they, moreover, that "a single one of these animalcules can increase to such an extent during one month, that its entire descendants can form a bed of silica 25 square miles in extent, and $1\frac{3}{4}$ foot thick. As a parallel to Archimedes, who declared he could move the earth if he had a lever long enough, we may say:—Give us a mailed animalcule, and with it we will in a short time separate all the carbonate of lime and silica from the ocean." † The silica thus rendered solid may either be deposited alone, or may be

* Maury's Physical Geography of the Sea, p. 210. The student is reminded that this fine clay is not formed of the debris of these shells, but of the unbroken shells themselves. This will give him an idea of their minuteness.

† Bischof, p. 188.

associated, as will most probably be the case, with the debris of calcareous matter forming marine limestones, and having an equally organic derivation. When thus diffused in the finest particles, pretty equally perhaps through the mass of calcareous mud, it may either be consolidated in this equally diffused state, producing a more or less siliceous limestone, or it may, in obedience to certain chemical laws, segregate itself from the calcareous matter, and form either distinct layers and veins, or concretionary balls and nodules. The presence of a body, itself consisting largely of silica, such as many sponges, will facilitate and determine this process, affording a centre of attraction for the siliceous particles to collect around it from the adjacent matter.*

These views of the organic origin of most marine limestones and flints are corroborated by the fact, which we shall presently describe, of almost all great masses of limestone being accompanied by siliceous portions of a peculiar character, such as are not found in any other rocks except limestone.

Carbonate of Magnesia.—Magnesia occurs in sea-water in the form of chloride of magnesium and sulphate of magnesia. Of the solid salts dissolved in sea-water, 8 to 15 per cent consist of chloride of magnesium, and 6 to 16 per cent of sulphate of magnesia.—(*Bischof*, vol. i. p. 99 to 105.) From the quantity of free carbonic acid in the sea, it is plain that these might be converted into carbonate of magnesia, but that if so, it would be kept in solution as a bi-carbonate (sesqui-carbonate), as in the case of carbonate of lime. All that has been said, therefore, as to the necessity for calling in the aid of organic life to solidify carbonate of lime from the waters of the sea, "holds good in regard to carbonate of magnesia, and the more so, since this salt always separates later than carbonate of lime, even from fluids which have undergone a very high degree of evaporation."—(*Bischof*, vol. i. p. 117.)

There is, however, this difficulty in this view:—The carbonate of lime is largely separated from the sea-water by being made to enter into the composition of the hard parts of

* Mr. Bowerbank has proved the presence of sponge particles in many flints and cherts, and refers them all to that origin.

marine animals in overwhelming proportion, whereas the percentage of carbonate of magnesia to be found in the hard parts of corals and mollusca does not exceed 1 or 2 per cent.* Neither do we know any class of animals that secrete any much greater quantity of magnesia, as some of the infusorial animals secrete silica. Yet in many widely-spread magnesian limestones the quantity of magnesia is almost equal to that of lime, and the proportion is frequently as much as 20 to 30 per cent. According to Forchammer, the fucoid marine plants contain more than 1 per cent of magnesia; but the remains of such plants are rarely if ever found in magnesian limestones. Magnesian limestones are, moreover, generally poor in organic remains, though this may be the result of their more perfect crystallization and mineralization in various ways, by which the organic structure has been obliterated, rather than of the absence of organic beings from the original deposit.

In whatever way effected, it is true that magnesian limestones, containing various proportions of lime and magnesia, have been *deposited* originally as magnesian limestone at the bottom of the sea, sometimes in large quantities, and over considerable areas.

It is equally true that pure carbonate of lime has in many cases been subsequently converted into dolomite or magnesian limestone by chemical metamorphic action.

The resemblance which magnesian limestones, even where the carbonate of magnesia is in comparatively small proportion, bear to true dolomites, and their likeness to a chemical precipitate rather than to a mere sedimentary deposit, induce us to pause before denying altogether that such precipitation of carbonates, whether of lime or magnesia, have taken place on the bed of the sea without the intervention of organic life.

Sulphate of Lime and Rock-salt (*chloride of sodium*) are undoubtedly chemical precipitates, and we are here again met by the same difficulty as before, in assigning a proximate cause for that precipitation in the open sea. If we could

* It was stated by Professor Rogers, at the meeting of the British Association at Cheltenham, that Silliman junior had recently found a very large percentage of magnesia in the composition of corals.

imagine a portion of sea-water separated from the ocean, and left as a shallow lagoon to gradually dry up, there would be no difficulty in the case.

Bischof gives the following as the average composition of the salts of the sea-water, (vol. i. p. 379) :—

	Percentage.
Saline contents of sea water . .	3.527
Consisting of—	
Chloride of Sodium (common salt) .	75.786
Chloride of Magnesium . . .	9.159
Chloride of Potassium . . .	3.657
Bromide of Sodium . . .	1.184
Sulphate of Lime (gypsum) . .	4.617
Sulphate of Magnesia (Epsom salts)	5.597
	100.000

He tells us too, that when sea-water is evaporated, the point of saturation for sulphate of lime is much sooner reached than that for rock-salt; 37 per cent of the water being required to be removed in the one case, and 93 per cent in the other. Gypsum, therefore, must always be deposited before rock-salt, and it is possible for the point of saturation to be reached for gypsum in many cases without that for rock-salt being attained. This may be the reason why, although the sea contains sixteen times as much salt as it does gypsum, that the latter more frequently occurs as a mineral deposit than the former, though not often in such great masses.

It has been suggested that, in consequence of the greater specific gravity of sea water increasing with the quantity of salt it contains, and the evaporation at the surface causing a perpetual increase in the salt of the surface water, that a part of the water which holds a larger quantity of salt in solution than the rest, may sink to the bottom of the sea, and that this process may be continued until the lower strata be saturated with salt, and precipitation take place. The circulating currents of the ocean, however, keep up such a constant mixture of its waters, as would seem altogether to prevent this action; and even in deep hollows and basins, such as the Mediterranean, separated by a shallower bar (1320 feet at the deepest) from the bed of the ocean, the *traction* of the currents passing over this is sufficient, according to

Maury (Physical Geography of the Sea), to prevent any accumulation of denser and salter water at the bottom.

In isolated seas, such as the Dead Sea, where the water is entirely saturated with salt, evaporation doubtless causes a precipitation on its bed (*Bischof*, p. 400). Here, and in shallow lagoons, such as the limans of Bessarabia, south of Odessa, that dry up in summer, we have the formation of rock-salt going on before our eyes.

In fresh-water lakes, sulphate of lime may be deposited, either directly, the water becoming saturated with that substance, or in consequence of springs or rivers containing sulphuric acid, which convert into sulphates the carbonates of the marls and calcareous muds already deposited. In some instances chemical reactions, such as the oxidation of iron pyrites, (bisulphuret of iron), and that of sulphuretted hydrogen, may be supposed to take place, producing sulphuric acid, which immediately acts on any carbonate of lime that it can reach.

It may, however, as was said before, be reasonably doubted, with respect to all these chemical explanations of the formation of rock, whether we are yet in a position to decide absolutely on their completeness and exclusiveness. There may be other yet undiscovered chemical laws, or physical conditions affecting chemical forces, which may give a greater latitude to the chemical explanation of the formation of certain rocks. It has only been recently known, for instance, that gypsum, which is usually soluble in 480 parts of water, becomes absolutely insoluble under a certain amount of pressure and temperature.

Carbon may be looked upon as essentially an organic element. Wherever we find carbonaceous matter in rocks, therefore, we may suspect it to have been derived from organic substances. Even the diamond is now believed to be a ? crystallised gum, or other vegetable product, and graphite may in like manner be looked upon as a possible, if not a probable, result of the metamorphosis of either animal or vegetable substance into a mineral. Even the purest graphite contains traces of earthy matter, diminishing its claims to be considered an original independent substance.

Carbon enters into the composition of *animal* matter, but its most abundant source is the *vegetable* kingdom.

Again taking Bischof as a guide in the explanation of the conversion of the organic substance wood, into the rock which we call coal, I abstract some of his results in the following remarks:—

TABLE, No. VII.

Composition of Carbonaceous Substances.*

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Wood	49.1	6.3	44.6
Peat	54.1	5.6	40.1
Lignite	69.3	6.6	25.3
Coal	82.1	5.5	12.4
Anthracite	94.0	3.0	3.0

In addition to these elements, however, the four latter substances given above contain variable quantities of earthy impurities, which are given, as in

Peat	from	4.6	to	10.0	per cent.
Lignite	„	0.8	to	47.2	„
Coal	„	0.24	to	35.5	„
Anthracite	„	0.94	to	7.07	„

Looking on these earthy matters as accidental and unessential, we learn from the examination of the above table, that the rocks anthracite, coal, and lignite, and the intermediate substance peat, consist of the same constituents as the organic substance wood, the differences between them being in the proportions in which these constituents occur.

No other rocks except the coals have a composition at all similar to this.

If we abstract from wood some 30 per cent of its oxygen and nitrogen, and compress the remainder till it becomes more dense and compact, it must form coal.

* See also a very clear explanation of this subject in Ronald's and Richardson's *Chemical Technology*, vol. i p. 31.

If, therefore, we suppose wood (or vegetable matter) buried under accumulations of more or less porous rock, such as sandstone and shale, so that it might rot and decompose, and some of its elements enter into new combinations, either gaseous or liquid, those combinations always using up a greater quantity of oxygen and nitrogen than of carbon and hydrogen, or of oxygen and hydrogen than of carbon, we should have the exact conditions for the transformation of vegetable matter into coal.

This process might naturally take place in four ways:—

1st, By the separation of carbonic acid gas (consisting of two equivalents of oxygen and one of carbon = CO^2) and carburetted hydrogen (consisting of four equivalents of hydrogen to two of carbon = $C^2 H^4$) from the elements of the wood.

2d, By the separation of carbonic acid from the elements of the wood, and the oxidation of some of the hydrogen (*i.e.*, its conversion into water = HO) by combination with external oxygen.

3d, By the separation of both the carbonic acid and the water from the elements of the wood.

4th, By the separation of all three substances, carbonic acid, carburetted hydrogen, and water, from the elements of the wood.

The loss of carbon is greatest in the first case, and least in the third, being always greater in proportion to the quantity of carburetted hydrogen which is disengaged.

When wood or vegetable matter, then, is buried under circumstances which allow of the extrication of these substances from it, in the course of its decomposition, it *must* become converted into coal; the extreme result of the process being to give us first anthracite, containing perhaps 94 per cent of carbon, and finally graphite, which is either pure carbon itself, or that substance mingled with others which are here excluded from consideration as not being among the elements of wood, and which it may have acquired, during the process of conversion, from external sources.

The great quantities of carbonic acid gas (choke damp) and carburetted hydrogen (fire damp) met with in coal mines, shows the fact of the large extrication of these substances, and corroborates, if need were, this explanation. Reservoirs of these gases in a highly compressed state are often found to be pent up in the crevices and cavities of coal beds, and are the cause, when tapped, of many of the accidents which take place. Some beds of coal are so saturated with gas, that, when cut into, it may be heard oozing from every pore of the rock, and the coal is called "singing coal" by the colliers.

Bischof shows, that "under circumstances otherwise similar, the conversion of vegetable substances into coal takes place in the same way, whether they are mixed with much or little earthy matter." He also believes, from Kremer's and Taylor's investigations into the nature of the ash of coal, that there was an *intimate mixture* of vegetable and earthy substances, and that coal containing earthy matter could not be formed from compact wood without previous decay having taken place (vol. i. p. 269). He seems to suppose that, in many instances, this decay has gone so far as to convert the vegetables into "mould," which has been drifted as a kind of vegetable mud, and when mixed with earthy matter, deposited under water in the place where we now find it as coal.

From these preliminary considerations, we learn that plants living in the air extract from it the invisible carbonic acid and other gases, and by the hidden processes of life, compel them to enter as solid and visible substances into the composition of their own bodies; and that animals* living in the sea, in like manner extract from it the invisible solutions of lime and other substances, and similarly compel them to become solid and visible parts of their own bodies. In each case the substances thus rendered visible and solid by the action of organic laws, become, after the death of the organism, subject to the ordinary laws governing inorganic matter, and after undergoing more or less alteration, are used as materials for assisting in the construction of the external crust of our earth.

* Although coral reefs were dwelt on as the most obvious and abundant source of limestone at the present day, it was not intended to infer that they had always been so. The older limestones have none of the huge reef-making corals in them; the small corals they contain merely contributed to their formation, together with other animals that secreted carbonate of lime.

DESCRIPTION OF THE CHEMICALLY AND ORGANICALLY FORMED AQUEOUS ROCKS.

55. *Limestone* may be hard or soft, compact, concretionary, or crystalline, consisting of pure carbonate of lime, or containing silica, alumina, iron, etc., either as mechanical admixtures, or as chemical deposits along with it.

Different varieties of limestone occur in different localities, both geographical and geological, peculiar forms of it being often confined to particular geological formations over wide areas, so that it is much more frequently possible to say what geological formation a specimen was derived from, by the examination of its lithological characters, in the case of limestone, than in that of any other rock.*

Compact limestone is a hard, smooth, fine-grained rock, generally bluish grey, but sometimes yellow, black, red, white, or mottled. It has either a dull earthy fracture, or a sharp, splintery, and conchoidal one. It will frequently take a polish, and when the colour is a pleasing one, is used as an ornamental marble.

Crystalline limestone may be either coarse or fine-grained, varying from a rough granular rock of various colours, to a pure white, fine-grained one, resembling loaf sugar in texture. This latter variety is sometimes called *saccharine*, sometimes *statuary marble*. The crystalline structure of limestone is either original, when it is often found that each crystal is a fragment of a fossil, or it has been superinduced by metamorphic action on a limestone formerly compact.

Chalk is a white, fine-grained limestone, sometimes quite earthy and pulverulent, sometimes rather harder and more compact, as the chalk of the north of Ireland, and some of that of the north of France.

Oolite is a limestone in which the mineral has taken the form of little spheroidal concretions, and the rock looks like the roe of a fish, from which its name, signifying *egg*, or *roe-stone*, is derived. These little concretions have several concentric coats, sometimes hollow at the centre, sometimes enclosing a minute little grain of siliceous, or calcareous, or some other mineral substance. It is commonly of a dull, yellow colour, but grey oolitic limestone is not unfrequent. Its peculiar structure gives it the character of a freestone,

* No experienced British geologist would be likely to confound characteristic specimens of the limestones of the silurian, carboniferous, oolitic, and cretaceous formations of Britain and Western Europe, while any one might easily mistake the argillaceous or arenaceous rocks of those different formations.

working easily in any direction; whence its value as a building stone.

Bath stone, Portland stone, Caen stone, are well-known examples of oolitic limestone.†

Pisolite is a variety of oolite, in which the concretions become as large as *peas*. It is a structure not confined to limestone, however, as other rocks or minerals occasionally assume it.

Many limestones are named from their containing some peculiar variety of fossil, as *nummulite*, *clymenia*, *crinoidal* limestone, and *shell limestone*, or *muschelkalk*.

Others have local names given them, as the *calcaire grossier* of Paris, a coarse limestone, some beds of which are used for building, while others are a mass of broken shells.

Cipolino, a granular limestone containing mica; *majolica*, a white, compact limestone; *scaglia*, a red limestone in the Alps.—(Murchison and Nicol, in *Johnston's Physical Atlas*).

Ireland especially abounds in a great variety of limestones used for ornamental marbles, such as the green serpentine-marble of Ballynahinch in Galway, the black marble of Kilkenny, the brown, red, and dove-coloured marble of Cork and Armagh; and many others less known, and some of them unworked, but equally beautiful, with those that are. In Derbyshire and North Staffordshire, we have a similar abundance of ornamental marbles.

Freshwater limestones have commonly a peculiarity of aspect, from which their origin may sometimes be suspected, even before examining their palæontological contents, or petrological relations. They are generally of a very smooth texture, and either dull white or pale grey, their fracture only slightly conchoidal, rarely splintery, but often soft and earthy.

Flint and Chert.—The association of flints with chalk is well known. Chalk flints occur as rounded nodular masses, of very irregular, and sometimes fantastic shape, and of all sizes, up to a foot in diameter. They are commonly white outside, but internally are of various shades of black or brown, sometimes passing into white. They have sometimes

† This oolitic structure is by no means confined to what is known as the oolitic formation. We have already mentioned its occurrence in coral limestone. It occurs also largely in the carboniferous limestone of Ireland, and may recur in the limestones of any formation.

concentric bands of black and white colours internally, and exhibit markings derived from organic bodies round which they have often been formed. Flint occurs in chalk not only in nodules, but also in seams or layers, sometimes short and irregular, sometimes regular, over a distance of several yards. These seams vary from half an inch to two inches in thickness, and are commonly black in colour.

Almost all large masses of limestone have their flints or siliceous concretions. These are frequently called *chert*, as

Fig. 1.

in the carboniferous limestone, where the nodules and layers of chert exactly resemble the flints in chalk.

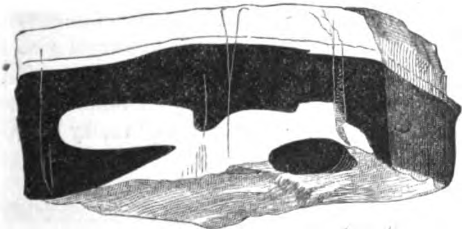

Fig. 2.

Fig. 1 is a sketch of some beds of limestone containing nodules of white chert, at Middleton Moor, in Derbyshire, in which the irregular and fantastic shapes assumed by these nodules are well exhibited, as also their likeness, to flints in chalk.

Fig. 2 represents part of a seam of black chert in the limestone, near Dublin. These seams, like those in chalk, are sometimes quite regular for some distance, and then either suddenly terminate, split up, or are subject to other irregularities like those in the figure.

Even the tertiary limestones around Paris have their flints, the melanite of that locality being nothing but a siliceous concretion, found in the Calcaire St. Ouen, and possibly other places.

Pure siliceous concretions occur even in the freshwater limestones and gypsum beds of Montmartre.

This invariable, or nearly invariable accompaniment of limestone and siliceous deposits, those siliceous parts having a chemical, and not a mechanical formation, strengthen the hypothesis of the organic origin of both, as previously described.

The silica diffused through the calcareous mud, of which the limestone was composed, has sometimes remained so diffused, instead of separating as nodules or layers, producing a *cherty* or *siliceous limestone.*

Clay, or argillaceous matter, has frequently been deposited with the calcareous, producing *argillaceous limestone*, which may be known by the earthy odour given out by it when breathed upon.

Carbonaceous matter, derived either from decaying vegetables, or perhaps more frequently from the decomposing animals of whose hard parts the rock is composed, produces in like manner the *black limestones*, which are in some instances called *bituminous limestones.* Little nests of pure anthracite, or other variety of carbonaceous matter, are sometimes found in the hollows of shells buried in limestone. The fetid smell, like that of sulphuretted hydrogen gas, given off by many limestones when struck with a hammer, is probably another result of the decomposition of animal matter, producing what is called "*fetid limestone*," or, by the Germans, "*stinkstein.*"

When the argillaceous has been mingled with the calcareous matter in very large proportion, a subsequent separation of the two has often taken place, the lime having segregated itself from the mass in this case, as the siliceous separated from the calcareous matter in the case of flints and chert. Nodular lumps of limestone are then produced, divided from each other by little, often irregular, seams and layers of shale or clay. These concretionary lumps of limestone are sometimes merely scattered through the clay, but they often form regular seams or beds, the upper, or under, or both surfaces being uneven and nodular. It is sometimes difficult to say whether the little parting films and small seams of clay which occur between the beds have been deposited at different times from the calcareous matter, or, having fallen together with it as an argillo-calcareous mud, have had their calcareous particles sucked out of them, as it were, by the segregating influence of chemical affinity.

It is by no means intended to infer that alternate deposits of thin layers of calcareous matter and purely argillaceous or arenaceous matter have not frequently occurred; we only wish to put the student on his guard against taking particular structures as proofs of original deposit, which, especially in so active and unstable a substance as carbonate of lime, may in many instances be the result of subsequent agency.

It is comparatively rare to find such a mingling of quartzose sand and lime as could be called *arenaceous limestone*, though we have already seen that *calcareous sandstones* are not uncommon. Scattered pebbles, however, are sometimes found in chalk and other limestones; and a curious instance, first noticed by Professor Haughton, occurred at Crumlin, near Dublin, of angular fragments of granite, several inches in diameter, accompanied by granitic sand, being found embedded in limestone, four or five miles from any known granitic mass *in situ*. Such fragments may perhaps have been floated in the roots of trees and other vegetables, just as in the present day pebbles of hard stone, highly valued by the natives, are found in the roots of trees cast up upon the shore of archipelagoes of coral islands in the Pacific, as mentioned by Chamisso and Darwin.

Magnesiăn Limestone.—Carbonate of magnesia is often found in marine limestones, mingled in various proportions with the carbonate of lime. Its occurrence in small quantity frequently gives a sandy appearance and gritty feel to an otherwise smooth and compact limestone. When examined with a lens, this apparent sand is found to be made up of minute dolomitic crystals, commonly of a yellowish brown colour, and with a pearly lustre.

In a true magnesian limestone, the crystallization and the pearly lustre is generally very distinct, though sometimes the crystals are minute. Its colour is commonly some shade of brown or yellow, occasionally tinged with red; grey and black varieties, however, occur sometimes over very large areas.

Magnesian limestone is very variable in lithological character. It is sometimes of a powdery, earthy, and friable texture; sometimes splits into thin slabs, some of which are flexible; sometimes forms singular concretionary masses, a number of balls touching each other, either like bunches of grapes, when it is called botryoidal, or like musket balls, or great piles of cannon shot. Many of these balls, on being broken open, are found to have a radiated structure. That all these curious forms have been produced subsequently to the deposition of the mass, is shown by the fact of the lines of deposition or stratification proceeding through them regularly, without regard to the spherical outlines or radiated structure of the balls.

Magnesian limestone occurs in two forms, original and metamorphic. In some limestones, the carbonate of magnesia has clearly been deposited together with the carbonate of lime, the whole having been originally formed as a magnesian limestone.

In other instances, it can be shown, from the geological conditions, that whether the rock originally contained magnesia or not, its present distribution and mode of occurrence, and its highly crystalline structure, are the result of agencies operating subsequently to the original formation of the rock, and affecting a number of different beds simultaneously, along certain narrow lines of fissure, to the neighbourhood of which the *dolomitized* condition of the rock is confined.

57. *Gypsum* occurs as a rock in various ways. It sometimes forms regular beds, sometimes irregular concretionary masses, sometimes veins and strings in the mass of other rocks.

Compact Gypsum or *Alabaster** is one variety; granular, finely crystalline gypsum another. The thin beds and the veins and strings of gypsum are commonly fibrous, the fibres being at right angles to the beds. The gypsum of Montmartre, from which plaster of Paris is derived, is chiefly granular gypsum, each bed being composed of many layers of little crystals, slightly differing in colour and texture, and thus assuming a regularly laminated appearance. This would

* Alabaster is derived from Alabastron, a town of Egypt, where it was manufactured into boxes for ointment. The term "alabaster" was then applied to carbonate of lime, as well as sulphate of lime.

lead us to suppose that this rock, which is associated with fresh-water limestones and marls, was formed by the periodical deposition of layers of small crystals of sulphate of lime at the bottom of the water.

In August 1855, I observed in the quarries north of Montmartre one or two beds, six or eight inches in thickness, of beautifully crystallised sulphate of lime, in large perpendicular plates, interstratified with these little layers of crystals. All the beds were horizontal; and the layers of small crystalline grains were quite parallel to the stratification; but in the beds above mentioned, large tabular crystals and broad flakes of selenite, of rather irregular form, had struck directly across the bed, more or less nearly at right angles to it, the original horizontal lamination not being obliterated, but being in some places waved, as if slightly disturbed by the formation of the crystalline plates, the angles of these waves having evident relation to the faces and angles of the superinduced crystalline plates.

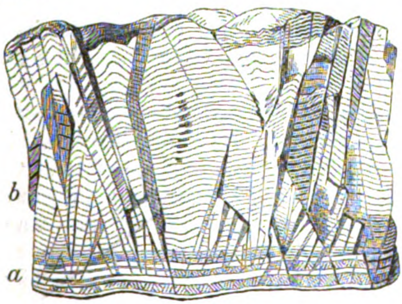

Fig. 3.

This formed a good case, like that before mentioned as occurring in the spheroidal concretions of magnesian limestone and other rocks, of a molecular change of structure having taken place in the mass of the rock subsequently to its formation. It yet remains for the chemist to explain to us the exact method of operation by which these changes are produced.

58. *Rock-salt* commonly occurs in Britain as a rudely crystalline, irregularly bedded mass, commonly stained of a

a, Layers of small crystalline granules of gypsum.
b, Crystalline plates of gypsum, traversed by the faintly seen and displaced original layers of granules. These lines are not sufficiently oblique in the woodcut; on the faces of some of the crystals they form angles of 35° with the plane of the beds.

dirty red by the mixture of ferruginous clay and other impurities. Perfect cubical and transparent crystals occasionally occur, and curious spheroidal bands, of a white colour, are sometimes observable in the roof of a salt mine. Bed-like masses of rock-salt are often 60 or 90 feet thick, thinning out probably in all directions, and thus taking the form of large cakes. In other countries, more numerous beds occur, but not making up larger masses. In some of these, the salt is perfectly pure and white; but in all countries, and in all geological formations, I believe I am correct in saying that the association of salt with gypsum, and with green, red, and variegated marls, is a frequent if not invariable occurrence. We have already seen how natural and almost inevitable is the occurrence of gypsum with rock-salt; but the accompaniment of red and variegated clays has not yet been explained. When it is, it will probably throw great light on the circumstances under which the rock-salt itself has been deposited. Dolomite is also often found in connection with rock-salt.

59. *Coal* is a rock the general aspect and nature of which is familiar to everybody. Its chemical composition has been spoken of above, and the resemblance of that composition to that of wood, and the way in which, by a slight alteration in the proportion of its component parts, and an accompanying physical consolidation, the one may be converted into the other. Coal is very commonly divided into bituminous and non-bituminous. Now bitumen is rather a vague term, including several combustible substances, such as asphalt or mineral pitch, elastic bitumen or mineral caoutchouc, naphtha, petroleum, etc. These bituminous substances are all either fluids, or are readily soluble in naphtha. It is, however, impossible to dissolve any appreciable portion of coal in naphtha, which shows that it does not contain any actual bitumen, though it may contan the constituents of it. The natural and artificial bitumens are the result of the decomposition of vegetable matter, and may be extracted also from coal by subjecting it to distillation. They always contain from 7 to 9½ per cent of hydrogen, combined with carbon and oxygen. The so-called bituminous coals, then, are those in which the

mineralizing process has only proceeded to a certain extent, leaving a considerable proportionate amount of hydrogen and oxygen in their composition; while those called non-bituminous are those from which a greater quantity of the latter substances have been extracted, and a larger proportion of carbon left behind. If the decomposition of wood results in the formation of carbonic acid gas, which takes away both carbon and oxygen, or of carburetted hydrogen, which takes away a large proportion of carbon, the carbon in the remainder will not be in such excessive proportion, and the constituents of the resulting coal will more nearly resemble those of bitumen. In this sense they may be called bituminous coals. If, however, a large portion of the oxygen and hydrogen be extracted, either as water or in any other form, the proportion of carbon in the remainder becomes excessive compared with that in the composition of bitumen; and hence the coals may be called *non*-bituminous.

Coals vary greatly, not only in the proportions of their essential constituents, carbon, hydrogen, and oxygen, but also in the amount of earthy matter (forming ash) which has been accidentally and mechanically mingled with those constituents. We have seen that the percentage of ash is sometimes as much as 35 per cent in coals that have been regularly analysed. In poorer varieties of coal, however, such as are never brought to market, but which are occasionally used in particular localities, this percentage is doubtless still greater; and we have in nature every gradation, from pure coal into a mere carbonaceous (commonly called bituminous) shale or "batt," which often contains enough inflammable matter to give out flame and support combustion for a time when burnt with better coals, but soon passes into a lump of ash, unaltered in form, and not retaining heat longer than a brickbat would under similar circumstances. These *batts*, shales, or slates, often accompany coal, being found not only either just above or just below it, but in it, in the form of thin seams, layers, or cakes, which are often not to be separated from it without some trouble.

Just as limestone is often mingled with clay, and passes through argillaceous limestone and calcareous clay (or marl) into clay itself, so coal passes through earthy or ashy coal, and carbonaceous shale, into common shale or clay, no very hard boundary line being to be drawn between the many minor graduating varieties of the different substances.

Discarding the impure or imperfect coals, the recognisable varieties of true coal are sufficiently numerous. They may be grouped under three heads:—Anthracite, ordinary or pit coal, and brown coal or lignite.

Brown coal or *lignite* sometimes shows the structure of the plants from which it is derived but little altered from their original condition; stems with woody fibre "crossing each other in all directions. It is of a more or less dark colour, soft and mellow in consistence when freshly quarried, but becoming brittle by exposure, the fracture following the direction of the fibre of the wood."—(*Chemical Technology, Ronalds and Richardson*, vol. i. p. 32.)

"Other kinds present only occasional distinct indications of vegetable structure, and appear throughout as a stratified mass of a dark, nearly black colour, with an earthy fracture; while in some varieties the structure is still more dense, and the fracture is conchoidal."—(*Ib.*)

The latter varieties, as in the case of the Bovey coal of Devonshire, are often scarcely distinguishable by any external characters from some varieties of ordinary coal.

Ordinary or *pit coal* has many varieties; indeed these are often as numerous as the different seams of a coal field, and even the different beds of a compound seam are readily distinguished from each other by the colliers, who give particular names to them; and even small blocks of these varieties can be recognised by them, and identified with the seam, or part of a seam, from which they are derived. Neither are these distinctions, which are only to be perceived after long practice, unimportant, since these varieties have distinct qualities, some of them being better adapted to smelting, and said to be "good furnace coal;" some of them to blacksmiths' work, or "good shop coal;" others to various uses; while only a few, comparatively, are best fitted for domestic purposes, and are brought to market by the coal-merchant.

Some idea of the immense varieties of coal may be gained from an inspection of the report of the Admiralty Coal Investigation (*Mems. Geolog. Survey*, vol. i.), as well as from the varying qualities of those which we are in the habit of using daily in our houses. "As many as seventy denominations of coal are said to be imported into London alone."—(*Chem. Tech.*)

All these minute varieties are commonly included under four principal heads:—1, Caking coal; 2, Splint or hard coal; 3, Cherry or soft coal, and 4, Cannel or parrot coal.

Caking coal is so named from its fusing or running together on the fire, so as to form clinkers, requiring frequent stirring to prevent the whole mass being welded together. It breaks commonly into small fragments with a short uneven fracture. The Newcastle coal, and many others from different localities, are caking coals. They leave many cinders and a dark dirty ash.

Splint or hard coal is well known in the Glasgow coal field. It is not easily broken, nor is it easily kindled, though when lighted it affords a clear lasting fire. It can be got in much larger blocks than the caking coals.

"*Cherry or soft coal* is an abundant and beautiful variety, velvet black in colour, with a slight intermixture of grey. It has a splendent or shining resinous lustre, does not cake when heated, has a clear shaly fracture, is easily frangible, and readily catches fire."—(*Chem. Tech.*) It leaves comparatively few cinders, and its ash is white and light. It requires little stirring, and gives out a cheerful flame and heat. The Staffordshire coals principally belong to this variety.

Cannel or parrot coal is called cannel from its burning with a clear flame like a candle, and parrot in Scotland from its crackling or chattering when burnt. Cannel coal varies much in appearance, from a dull earthy to a brilliant shiny and waxy lustre. It is always compact, and does not soil the fingers. Its fracture is sometimes shaly, sometimes compact. The bright shining varieties often burn away like wood, leaving scarcely any cinders and only a little white ash. The duller and more earthy kinds leave a white ash, retaining nearly the same size and shape as the original lumps of coal. Cannel coal often takes a good polish, and can be worked into boxes and other articles. *Jet* is an extreme variety of cannel coal in one direction, as *batt* or carbonaceous shale is in another.

Anthracite is heavier than common coal, with a glossy, often irridescent lustre, and a more completely mineralized appearance. It rarely soils the fingers, has a distinctly sharp-edged conchoidal fracture, or else breaks readily into small cubical lumps. It is not easily ignited, but when burning gives out an intense heat, so as to sometimes melt the bars of the grate or furnace in which it is used. It does not flame, and gives off but little smoke, being in this respect similar to coke or charcoal.

In many ordinary coals, little flakes of mineral charcoal occur, retaining that part of the vegetable structure called the vascular tissue. They are called "mother of coal" by the colliers in some places. "It is frequently seen in the form of a thin silky coating, covering some of the surfaces of the coal."—(Professor Harkness on Coal, *Edinburgh New Philosophical Journal*, July 1854.)

Microscopical examination exhibits not only the vascular but the cellular tissue of plants in the substance of many coals, as was shown by Mr. Witham in his work on the structure of fossil plants, and by many observers since. All coals have a peculiar structure, which bears a slight analogy to crystallization. They break or split not only along the bedding, but across it, along two set of planes at right angles to the bedding and to each other. The smooth clean faces produced by one of these cleavage planes are more marked and regular than that produced by the other, as may be seen by examining any lump of coal. The principal of these division planes are called by the colliers the *face* of the coal, the other being called the *back* or *end* of the coal. They preserve their parallelism sometimes over very wide areas; and the mode of working or getting the coal, and the direction of the galleries, is governed by the direction of the *face*.

It is a structure which is probably the result of the mineralizing process undergone in passing from an organic to an inorganic state, and may be likened perhaps to the "cleavage" of a mineral rather than to either the true "slaty cleavage of rocks, or to their "foliation" or "jointing" —structures that will be hereafter described.

Aerial Rocks.

Although the amount of rocks, or accumulations of earthy matter, formed of materials which were brought into their present situation by the action of the wind, is comparatively of small importance, it is not expedient wholly to overlook this action. Along all low sandy coasts, hills are formed of drift sand, which sometimes attain a considerable altitude, as much, for instance, as 200 or 300 feet. These hills are commonly called "dunes." They have been described as advancing on the low shores of France, in the Bay of Biscay, at the rate of sixty and seventy feet per annum, overwhelming houses and farms in their progress. Similar accumulations take place on the coast of Cornwall, where the sand, composed largely of fragments of shells and corals, becomes converted sometimes into a hard stone by carbonate of lime or oxide of iron.—(*De la Beche's Manual.*)

Lieut. Nelson has described similar aerial accumulations in the Bermuda Islands, giving them the name of œolian rocks.

Along the south coast of Wexford, as also in Smerwick harbour (county Kerry), and other parts of the British Islands, similar accumulations are in progress.

On the eastern coast of Australia, about Sandy Cape, this process is going on on a still larger scale. In Port Bowen, in the same neighbourhood, I once saw a very good instance of it. The rise and fall of tide there is as much as sixteen feet; and, at low-water, great sand-banks are exposed, derived from the shallow sea outside and the waste of the porphyritic rocks on the coast. These sand-banks rapidly dry under the hot sun; and the trade-wind, which blows home upon the shore, then drifts the sand up upon the beach, and piles it into hills 50 or 60 feet high. Behind these hills is a large mangrove swamp, which is being gradually buried under the advancing sand, some of the mangrove trees only just peering above it, others half covered, and so on. The drift of sand through the gaps of these dunes was exactly like a snow-drift in a heavy storm whenever the wind blew freshly.

Large districts, with hills of 200 or 300 feet in height, are found also on the coasts of Western Australia, stretching sometimes ten miles inland, formed of loose incoherent sand, once apparently drifted by the wind, though now brought to rest by the growth of a wide-spread forest of gum-trees. Parts of these sands, which consist greatly of grains of shells and corals, are compacted together into a stone, hard enough to be used for building, by the action of the rain-water dissolving some of the carb. lime, and re-depositing it on evaporation. Curious cylindrical stems, from one inch to eighteen inches in diameter, are there seen projecting from the soil, and have been taken for petrified trees, which they greatly resemble; but I observed, in 1842, a number of these supposed trees exposed in a little cove, south of the entrance of Swan River, ending downwards in tapering forms like stalactites; and I believe them, therefore, to have a stalactitic origin, due to the percolation of water down particular pipes and channels in the sand.

Nor is it along the coast only that such accumulations are taking place. In the interior of great dry continents, there are vast spaces covered with sand and sand-hills, which are shifted and carried about by the wind, just as some sand-banks are deposited now here now there, carried about by the water. We have but to recal to the mind of the reader the well-known stories of caravans crossing the desert being met and sometimes overwhelmed by moving columns of sand, and the way in which many of the temples of Egypt have been buried under such accumulations, for him to see that this action cannot be altogether overlooked. Egypt would probably have been long ago obliterated by drift-sand if it had not been for the Nile, and the strip of vegetation that accompanies and defends it. In the interior of Australia, Captain Sturt reports the existence of vast deserts of sand, with long lines of great sand-hills, 200 feet high, the base of one touching that of its neighbours, and all stretching in straight lines each way to the horizon.

It would be quite proper also to class among aerial rocks such accumulations of tuff as were derived from volcanic ashes falling on the land, and also the masses of pebbles, cinders, and fragments so derived, were it not more convenient to describe them in connection with the volcanic rocks, so as not to separate in our account those falling on the land from those deposited in water.

Soil.—The accumulation of decayed vegetable matter, mingled sometimes with animal, always with earthy mineral matter, which is called "soil" or "mould," is also an aerial process, deserving of more attention than it has yet received. Soils sometimes occur as distinct rocks, interstratified with other rocks.

CHAPTER V.

THE METAMORPHIC ROCKS.

Preliminary Observations.

IN the course of the foregoing descriptions we have mentioned the segregation, into concretionary lumps and nodules, of siliceous from calcareous matter, and of calcareous from argillaceous; and we have described the radiated and concretionary forms assumed sometimes by magnesian limestone and the re-arranged crystallized beds of gypsum. These, however, are not the only instances of such separation of parts, and assumption of new forms and combinations, by the particles of rock after their deposition, and after their more or less complete consolidation. Any mineral diffused in a state of minute division through a mass of different nature from itself, seems to have a tendency to segregate itself from the mass, and collect together upon certain points or centres. Iron, either in the form of iron pyrites (bi-sulphide of iron), or ironstone (carbonate of iron), or hæmatite (oxide of iron), frequently forms such concretionary lumps. Iron pyrites, either in cubical crystals, or in balls with an internal radiated structure, is frequent in all argillaceous and calcareous rocks, and in many trap rocks. Ironstone (clayey carbonate of iron) forms regular layers of round nodules, sometimes as much as a foot or eighteen inches in diameter, in many argillaceous rocks. These nodules, when broken open, are often found to be traversed by cracks in all directions, more or less filled up with crystalline spar (carbonate of lime, etc.), together with crystals of galena, blende, iron pyrites, and other minerals.

In other clays, carbonate of lime, mingled perhaps with iron, produces similar stones, called septaria or cement stones in some places. They often take a polish, and the sparry veins produce a variously ornamented appearance.

In these septaria and ironstone balls the external crust is generally smooth and compact, the internal cracks becoming larger and more numerous as they proceed towards the centre. As the cracks are obviously the result of desiccation and consequent contraction, and as the external crust would naturally be the first part to consolidate, it does not at first seem obvious why the cracks should not occur outside rather than in.

Professor Hennessey, however, remarked to me, that in the case of volcanic bombs, which have a similar structure, the fact of the preliminary consolidation of the external crust was the cause of the internal fissuring, since, when that was formed, no farther shrinking or contraction of the whole body could take place; and the internal parts being thus relieved from external pressure, would shrink and contract among themselves, being rather attracted towards the dense external crust than towards the centre. If consolidation commenced at the centre, the whole nodule would have contracted towards the centre, and thus have shrunk into a less size and a denser state, without the occurrence probably of either external or internal cracks.

Hæmatite, whether red or brown, affects a kidney-shaped concretionary form, often hollow, with a minutely radiated structure at right angles to the surface of the mass.

Other minerals, such as galena and blende (the sulphides of lead and zinc), occur in small balls or nests in some rocks, evidently formed as concretions, and not rolled fragments or pebbles.

This separation of one matter from another, and subsequent assumption of a condition more or less different from that possessed by rocks at the time of their original formation, leads us naturally to consider the next great division of our subject, the metamorphic or transformed rocks.

The mere physical force of pressure, as aqueous rocks after their formation become gradually covered by subsequent accumulations, must produce change in them in the way of consolidation and induration. This pressure may of itself be sufficient in some cases to cause the hitherto incoherent particles of sand or clay to cohere and be compacted into a solid stone. It will, however, be greatly assisted, either by the infiltration of water containing mineral matter in solution, or of pure water dissolving and re-arranging the soluble materials which it may find in the rocks.

Heat may, in like manner, modify the effects of pressure, either by its mechanical power of expansion producing pressure in every direction, and subjecting rocks to alternate expansions and contractions according to its own variations, or by setting in action chemical forces of decomposition and recomposition, and thus altering the chemical combinations in the materials of rocks.

Heat may also be joined with water, either raising it to various temperatures or actually converting it into steam, and we may thus get changes produced which neither cold water nor dry heat would be able or likely to effect of themselves. It has been stated that it is impossible to maintain the bulb of a thermometer in the boiler of a steamer at very high temperatures, since the glass is dissolved by the chemical action of water heated under pressure (*Sedgwick's Introduction to Synopsis of Classification*, etc., 3d Fasiculus, p. 29, note). Now, it may not unfrequently happen that we may have all the forces of pressure, heat, and the dissolving power of water combined in the interior of the earth.

The presence of water in rocks is known by experience, since no stone is ever quarried which will not part with some water on being dried, either naturally in the air or artificially. Bischof says, that he has observed, on breaking blocks of basalt, "wet patches, like rain drops, upon the fractures, and sometimes quite in the centre of the mass, affording positive evidence of the permeability even of so compact a rock as basalt." He says also, that almost all water contains both carbonic acid, and often a slight proportion of silica (silicic acid) in solution, that the silicates in which the silica is in its soluble modification are decomposed by weak acids, and that those also in which it is in its insoluble modifications are unable to resist the long continued action of acids.

This gives us the explanation of the brown spots and patches found in many rocks containing silicate of lime, such as basalt and greenstone, and also their brown and weathered surfaces. Along the internal margin of the brown part of basalt and greenstone a mineral acid will almost always cause effervescence, as also along the minute cracks and crevices and pores by which the water gains access to the interior. It is plain that the silicate of lime is converted into carbonate in the first place, and this being removed by subsequent solution from more carbonic acid and washed out, the protoxide of iron left behind is converted into peroxide, and the brown colour produced.

Limestone containing much silica or silicate of alumina, and some protoxide of iron diffused through its mass, is, in a similar way, converted into *rotten stone*, while pure limestone is wholly dissolved and washed away.

The decomposition of those rocks which do not contain any lime proceeds in the same way, though it is not so easy to detect it by the occurrence of effervescence with acids along the margin of the decomposed part. Feldspar rocks have their silicates of potash, soda, etc., converted first into carbonates and then into bi-carbonates, which are dissolved and washed away. Their decomposed portions are generally white rather than brown from the absence of iron, though shades or streaks of red and brown occasionally occur, showing its presence in small quantities.

In the examination of these changes, the study of pseudomorphic crystals of minerals is of great importance. A pseudomorph is one mineral occurring in the crystalline form of another. These are either "alteration pseudomorphs," in which the first mineral has been gradually changed into the other, or "displacement pseudomorphs," in which the first mineral having been gradually removed particle by particle, another has gradually, and particle by particle, taken its place. This action is a very important one, for it is precisely that of "petrifaction," as it is called — that by which organic remains are mineralized, and their external form, and more or less of their internal structure, preserved.

Animals and plants, by means of their fluids, take up and convert into their own substance certain minerals, such as silica, lime, magnesia, soda, potash, phosphorus, carbon, iron, etc. This they do in obedience to the organic forces, those chemico-biological actions, the assemblage of which we call *life*. When life no longer exists, and its forces cease to act, the substances of animals and plants become obedient to inorganic laws, and their mineral portions are acted on just in the same way that other mineral matters are affected. Wood may either, as we have already seen, lose certain *proportions* of its constituents and become more and more *carbonized;* or it may lose the whole of them particle by particle, and as each little molecule is removed, its place may be taken by a little molecule of another substance, as silica, or iron pyrites, and it may thus become entirely *silicified* or *pyritized.*

Bones and shells, and other hard parts of animals, consisting mainly of phosphate and carbonate of lime, may, in like manner, have the proportions or the state of aggregation of their constituents altered more or less completely, or may have their substance gradually but entirely replaced by another substance more or less different from the former.

Bischof combats the opinion that this pseudomorphous and petrifactive process is ever the result of dry heat or of sublimation, and shows, with what appears conclusive reasoning, with regard to many substances at all events, that whether it occur in the mass of rocks, or in veins and fissures, it must be the result of *water* (temperature uncertain) containing some acid, chiefly carbonic acid, in solution in the first place, and afterwards by means of that acid becoming impregnated with the solutions of other minerals.

Some of Bischof's remarks are so very instructive that we do not hesitate to quote several passages at length. "Stein converted a crystal of gypsum into carbonate of lime by leaving it for several weeks in contact with a solution of carbonate of soda, at a temperature of 122 F." The sulphuric acid of the gypsum uniting with the soda to form sulphate of soda, which was dissolved and carried away by the water, and the lime uniting with the carbonic acid. "All the striæ upon the curved surfaces of the crystal were perfectly retained, as well as the cleavage in the direction of the T-planes. In these artificial pseudomorphic processes, the form of the original substance is retained only under certain conditions, the most essential being slow action; and the same holds good in nature. If these conditions are not fulfilled, the original form is lost."

"In the analysis of a mineral in which changes have already commenced, especially by the addition of new constituents in very minute quantities, it is not unlikely that they may be considered as accidental and deducted. Since, however, alterations seldom take place merely by addition, but more frequently by loss of constituents, it is likewise requisite that the quantities lost should be added to the analytical results.

"There are sufficient grounds for considering andalusite to be a pure silicate of alumina, although previous analyses have pointed out, besides these two essential constituents, potash, lime, magnesia, oxides of iron, and manganese and water. Andalusite is converted into mica, in which change a part of the alumina is removed; potash, magnesia, and peroxide of iron, being introduced into its place. One of these bases is always found in andalusite, sometimes several of them together; and it may therefore be inferred that this mineral, as usually met with, is already in a state of incipient alteration. No other alteration of andalusite is known besides that into mica, except that into steatite. The latter change presupposes not only a partial but a complete disappearance of the alumina, and its replacement by magnesia. These examples will suffice to show the importance of the minute quantities of substances present in minerals, and generally considered as accidental. These substances, which are troublesome to the chemist, because he cannot introduce them into the chemical formula, acquire significance when compared with the constituents of the pseudomorphs resulting from the alteration of the mineral in question. They then no longer appear as accidental, but indicate the transition of one mineral into others, and lay before us clearly the greater part of the conversion process.

"It is possible that several changes may frequently have taken place before the last product was formed. In the alterations of complex minerals, especially silicates containing several bases, there are certainly transitions in most cases, and sometimes a long series. Thus Cordierite * is the starting point of a whole series of alterations, finally ending with Mica; while Fahlunite, Chlorophyllite, Bonsdorfite, Esmarkite, Weissite, Praseolite, Gigantolite, and Pinite, are remains of Cordierite in pseudomorphic conditions. Inasmuch as the minerals between Cordierite and Mica are only transition products, they cannot be regarded as individual species." † "As

* Cordierite is a mineral composed of a silicate of alumina, combined with two atoms of silicate of magnesia. See ante, p. 43.

† If farther well-considered researches establish these and similar conclusions, it will have a wonderful effect in simplifying the important science

petrifactions are important and in many cases indispensable aids in recognising the sedimentary formations, so likewise pseudomorphs are important, and frequently the only means of tracing the processes of alteration and displacement which have taken place and are still going on in the mineral kingdom.

"Pseudomorphs furnish us with a kind of knowledge which we have no opportunity of deriving from any other source. It will scarcely ever be possible to convert augite, olivine, or hornblende, etc., into serpentine in our laboratories. But when we find serpentine in the forms of these minerals, this fact is a sufficient evidence that such a conversion can take place; and if in any given instance there are geognostic reasons for the opinion that one or other of these minerals, or even several together, have furnished the materials for the formation of serpentine, there is a high degree of probability that such a change has actually taken place.

"If a crystalline mineral can, under certain conditions, be converted into another, whether with or without retention of form, then the same mineral in an amorphous state would certainly suffer the same change when placed in the same circumstances." From this he shows that amorphous masses of serpentine may be formed from amorphous masses of augite, etc., and also that in some instances the original form of a crystalline mineral may be destroyed together with its substance, and the new mineral occur in its own crystalline form. He concludes the subject thus:—

"The importance of the pseudomorphic processes, and the error of those who regard them as having but little connection with the changes of rocks, is sufficiently shown by the total disappearance of previously existing substances in veins. I consider that the entire removal of fluor and calc spar from a whole series of veins, and the introduction of an equal quantity of quartz in their place, is a matter of vast importance. To what enormous spaces of time do we come when we reflect upon the periods during which the fluor and calc spar were introduced into these fissures, and then the periods during which they were again removed by water, and quartz substituted in their place! And yet this happened after the formation of the rocks in which these fissures occur. If we imagine similar processes to have taken place in the rocks themselves, and extending over not only both these periods, but the entire space of time since their formation, we shall be compelled to admit that inconceivably stupendous changes have taken place. After such considerations, the conversion of extensive masses of rock by the action of water alone into steatite, talc, serpentine, kaolin, etc., cannot appear in the slightest degree strange."—(*Bischof*, chap. ii.)

of mineralogy, and thus give a greater attraction to a subject which has, on my mind at least, always exercised a most repulsive action, from the want of a clear, simple, and definite rule of classification.

If we allow so large an amount of metamorphic action to the infiltration of water, it becomes no longer difficult to understand the conversion of limestone into dolomite, subsequently to the deposition of the original carbonate of lime. Such cases as those described by Von Buch, and more recently by Mr. Andrew Wyley, in the journal of the Geological Society of Dublin (vol. vi. part 2), in his paper on the dolomitic rocks of Kilkenny, where dolomite is found traversing ordinary limestones in dyke-like masses running through a great number of beds in a straight line across the country, become explicable on the supposition of springs of water containing much carbonic acid and magnesia rising up through fissures, and the consequent solution of some of the carbonate of lime and its replacement by carbonate of magnesia.

If, again, such great changes as those just alluded to may be expected to result from the simple action of water, we may reasonably conclude still greater to be the consequence of the action of water combined with a high temperature, or of a still more intense heat, which first converts into steam the water contained in rocks, and effects great changes perhaps, or, at all events, prepares the way for great changes by that agent, and then proceeds to act upon the minerals contained in rocks with its own powers. We have already seen that some sandstones and gritstones may have probably been cemented by silica held in solution, either in the water in which they were deposited, or in that which subsequently gained access to them. We know that hot water can contain at least a tenth more silica in solution than cold water. If, therefore, a sandstone became penetrated by hot water, or still more by steam, a portion of the silica of which each grain was composed might be dissolved, and as the water ultimately evaporated, this silica would be re-deposited, and act as a siliceous cement to the mass. We should thus have a quartz rock or quartzite produced.

It would appear, however, that dry heat alone is able, under favourable conditions, to produce this effect, since the sandstones that have been used as the bottoms of iron furnaces are, in some cases, altered into a kind of quartz rock. It is true that bases, calculated to act as a flux to the quartz, may have gained access to the sandstone in the latter instance, but then they may, on the other hand, have been present in sufficient quantity for that purpose in many sandstones that have been naturally altered into quartz rock.

While we give full allowance to the importance and magnitude of the metamorphic effects produced by water at whatever temperature, there are yet still greater and more general changes which we must believe can only have been effected by the action of heat, too great to allow of the presence of water.

When we see whole mountain ranges, and whole districts of country, consisting of rocks that have more or less analogy in structure and constitution to rocks known to be of igneous origin, we cannot help feeling convinced that igneous action must in some way have been concerned in their production.

When we find that these rocks have every gradation, from such as might have been once molten, into rocks which we know to have been mechanically deposited under water, we are compelled to conclude with Lyell that these rocks are altered or metamorphosed by heat from their original aqueous and mechanical formation into a state more or less nearly approaching true igneous rocks.

Our belief in the truth of this metamorphism becomes certainty when we see these rocks always occurring on the flanks of masses of granite, and examine a district (such as Wicklow and Wexford) where both large and small masses of granite appear, and find these metamorphic rocks, not only always accompanying the granite, but occurring *no where else* except in the neighbourhood of granite or granitic rocks, and their extent always proportioned to the size and extent of the particular granite mass they mantle round.

It is by no means intended to assert that the neighbourhood of granite or igneous rock is the only source of heat from which this metamorphosis can arise. Should any mass of rock, capable of alteration, be so deeply buried in the earth as to be brought within the reach of any centre of heat whatever, the same effect would result; and it is quite possible that a far greater intensity and wider range of heat may be thus reached than could proceed from the mere intrusion of a more or less isolated mass of igneous matter into spaces which were naturally of a lower temperature. But as an intrusive mass of granite must be a source of great heat, and as the metamorphic effects in question are found always to accompany it, we are obliged to look upon heat as the cause of the effect.

This effect of intense heat may doubtless be variously modified by the previous presence or absence of water, and by the various mixtures of mineral matters occurring in the different rocks before alteration.

The very general appearance of mica, either in distinct flakes or crystals, or as a mere glaze upon the surfaces of laminæ,* may perhaps be explained by the very various composition of the different varieties of mica, and the consequent number of sources and combinations from which micaceous minerals could be derived. The remarks on the variable composition of the micas quoted from Gmelin, p. 49, and those just quoted from Bischof, show how naturally and readily other substances may be converted into mica either by water or by heat. Dr. W. K. Sullivan also has remarked to me the possibility of several different minerals, or at least many chemical combinations, putting on the micaceous form as a consequence of peculiarity in physical structure rather than of identity in chemical composition.

The metamorphic development of mica, then, offers no difficulties; and we may perhaps suppose that in mica schist, where there are alternate layers of mica and quartz, this development took place in such a way that the basic substances segregated themselves into alternate layers, leaving the silica of the intermediate layers free; these layers being determined by the original lamination or sedimentary layers of the mass, except where that mass was very homogeneous, or greatly affected by "transverse cleavage."

In gneiss, where we have the triple alternation of quartz, feldspar, and mica, a similar action similarly directed must be

* See *postea*, under the head of Petrology, remarks on the production of mica schist and gneiss on the flanks of the granite of Wicklow, etc.

supposed to have occurred under the modifying influence of a different composition in the original rock.

We shall have occasion, under the head of petrology, to recur to this subject in describing the "cleavage" and "foliation" of the metamorphic rocks. "Cleavage" is, indeed, a purely petrological structure, whatever may have been its origin, since it rarely, and only to a slight extent, produces any lithological change in a rock beyond that of simple induration. A highly indurated *shale* has no lithological difference from a true *clay slate*, it being often impossible, from an inspection of a mere hand specimen, to say whether it be one or the other.

Description of the Metamorphic Rocks.

The metamorphic rocks may be divided into two sub-groups, those in which the original mineral structure is still recognisable—the particles, however they may have altered their form and state, not having entered into new combinations—and those where such new combinations have been produced.

The former sub-group will accordingly consist of arenaceous, argillaceous, and calcareous rocks, while the members of the latter have a general similarity of structure and composition which enables us to speak of them under one general term, such as the *schistose rocks*.

Metamorphosed Arenaceous Rocks.

60. *Quartz rock or Quartzite* * is a compact, fine-grained, but distinctly granular rock, very hard, frequently brittle, and often so divided by joints as to split in all directions into

* The student must carefully distinguish between quartz rock or quartzite, as here described, and pure *vein quartz*, which occurs sometimes, as a white compact flint rock, in considerable mass. The "quartz rock," so often spoken of in Australia, is rarely, if ever, true quartz rock, but commonly vein-quartz; not an altered bed of sandstone contemporaneous with the rocks in which it lies, but a deposition in a vein or fissure produced subsequently to the consolidation of the rocks it traverses.

The Continental geologists seem frequently to fall into the same mistake, and confound two things essentially distinct. In a collection of European rocks purchased lately from Krantz of Bonn, among seven specimens of so-called quartzite, at least five were undoubtedly *vein quartz* and not *quartzite*.

small angular but more or less cuboidal fragments. Its colours are generally some shade of yellow, passing occasionally into red, and at other times into green. When examined with a lens it may be seen to be made of grains, which appear sometimes as if they had been slightly fused together at their edges or surfaces, and sometimes as if embedded in a purely siliceous cement. This cementation or semi-fusion of the grains shows at once that it is a sandstone which has been altered and indurated by the action either of heat alone or of heat and water. It has either been *baked* or *steam-boiled.*

Metamorphosed Argillaceous Rocks.

61. *Clay Slate* is a fine-grained fissile rock, differing from shale in being invariably highly indurated, and splitting into plates that are altogether independent of the original lamination or bedding of the rock, and frequently cross it at all angles. This fissile structure or "cleavage" is a superinduced or metamorphic one. The original bedding or lamination of the rock may frequently be traced, even in hand specimens, by means of parallel lines or bands of different colour and texture traversing the slate. These bands are called by Professor Sedgwick the "stripe" of the slate.

Clay slate is generally of a dull blue, grey, green, or black colour, sometimes "striped," sometimes irregularly mottled.

Metamorphosed Calcareous Rocks.

62. *Altered or Crystalline Limestone.*—This was formerly called *Primitive*, and is even at the present day often called *Primary Limestone.* Since, however, it is known that many crystalline limestones are not primary, that the statuary marbles of Italy and Greece, for instance, are even tertiary limestones in a metamorphosed state, it would seem better to disuse the term primary as a mere lithological designation.

It is probable that some limestones were originally formed as crystalline limestones, inasmuch as many parts of a coral reef are even now crystalline internally. Others, however, have certainly been only made to assume the crystalline structure at a period subsequent to their formation. In the well-known experiments of Sir James Hall, it was shown that even chalk could be converted into a hard crystalline marble, by being heated under such a pressure as should prevent the escape of the carbonic acid gas.

Saccharine or statuary marble is a white fine-grained rock resembling loaf-sugar in colour and texture, working freely in any direction, not liable to splinter, slightly translucent, and capable of taking a polish. Concealed flakes of mica or chlorite sometimes exist in it, as may be seen on examining the weathered surfaces of some of the ancient statuary in the British Museum and elsewhere.

Other varieties of altered limestone are variously coloured, and more largely and coarsely crystalline.

63. *Dolomite.* — Some magnesian limestones are clearly altered or metamorphic, forming a true dolomite or highly crystallized aggregate of nearly equal parts of carbonate of lime and carbonate of magnesia. Its metamorphic character, however, can only be certainly ascertained by its geological relations, and not by its lithological structure.

I had long suspected that some serpentines, or verde antique marbles, were nothing but highly altered magnesian limestones. This suspicion has been confirmed by Mr. Logan,* director of the Geological Survey of Canada, who assures me he has traced in that country serpentines ending gradually in unaltered beds of magnesian limestone.

The Schistose Metamorphic Rocks.

The term "schist" is used here in a restricted sense, as applicable to the fissile structure of "foliated" rocks.

"Foliation" is a term applied by Mr. Darwin† to those rocks which have had such a subsequent structure given to them as to split into plates of different mineral matter, either with the bedding or across it. "Cleavage" indefinitely

* Now Sir William Logan.

† The term "foliated," however, as applied to schistose rocks, such as *mica schist*, and distinguished from "cleaved" as applied to *slate*, was first suggested by Professor Sedgwick in his paper on the "Structure of large mineral masses."—*Geological Transactions*, vol. iii., pp. 479 and 480.

splits a rock, either with the beds or across them, without altering its mineral character, and thus produces "slate."

"Lamination" will then be the remaining term applicable to "shale," and signifying the splitting of a rock into the original layers of deposition.

When, therefore, we wish to be precise, we can speak of the *foliation* of *schist*, the *cleavage* of *slate*, and the *lamination* of *shale*.

64. *Mica schist* consists of alternate layers of mica and quartz, the mica generally consisting of a number of small flakes firmly compacted together, and the quartz more or less nearly resembling *vein* quartz. Many mica schists, however, contain comparatively little quartz, and seem scarcely to differ from clay slate or shale, except in the shining surfaces of their plates or folia.

Many mica schists have a minutely corrugated or crumpled structure, the layers being bent into sharp vandykes of one, two, or more inches in height and width. Others, however, are quite smooth and straight.

The separation into layers, or "foliation" of mica schist, sometimes coincides with the original bedding of the mass, and sometimes is independent of it. In the latter case, it may in some cases have taken the direction of a previously existing "cleavage."—(Prof. Ramsay, *Geological Journal*, vol. ix. p. 172).

Many soft highly micaceous sandstones require but induration to be called "mica schist." In parts of the new red sandstone of central England, the rock is so highly micaceous as to split into thin flags of a quarter of an inch in thickness and a foot in diameter; and these can be split by the nail into still finer flakes. The application of great or long continued heat would easily cause the peroxide of iron and the alumina present to form mica, in addition to that already existing, and the two might, perhaps, coalesce into layers, leaving the partially or entirely fused quartz grains of the sandstone in intermediate layers of quartz.

Instead of mica, other minerals are sometimes found, such as chlorite or talc, when the rock would be called *chloritic schist, or talcose schist.*

Hornblende schist, again, occurs, though we believe, in this case, the whole mass consists of flakes of that mineral without any alternation of quartzose layers. The same remark holds good with respect to the rarer rock called *actinolite schist.* As far, indeed, as my own observation goes, I should doubt the existence of these rocks in any other form than as the result of a partial metamorphosis of some hornblendic "ash," or of some other mechanically formed rock, derived from the wear and tear of a greenstone or a syenite.

65. *Gneiss* is probably of all others the most completely metamorphosed rock that retains any mark of its original mechanical structure.

Some gneiss can only be distinguished from granite by the regular arrangement of its component crystalline particles in a certain parallelism, so as to give it a slightly schistose structure, or "grain," as it is called by Professor Sedgwick. Other varieties of gneiss, again, can only be separated from mica schist by the occasional occurrence of little plates of feldspar in addition to the layers of mica and quartz. In hand specimens, indeed, it is often very difficult to draw any sharp line of separation between mica schist and gneiss, the more fissile specimens being called mica schist, while the firmer ones would be called gneiss. Even in the field they are often so blended together, and alternate with each other so frequently, that their separation is impossible. There is therefore almost every gradation from dull clay slate through glossy and so called talcose slate into mica schist and gneiss, and thus into actual granite.

Gneiss might, indeed, in its purest and most typical form, be termed schistose granite, consisting, like granite, of feldspar, mica, and quartz, but having those minerals arranged in layers or plates, rather than in a confused aggregation of crystals. In speaking of it as schistose granite, however, we must never forget that true gneiss was never really a granite, with a peculiar laminated structure, but that it was originally a laminated mechanically formed rock, a *sandstone* more or less argillaceous, containing, indeed, the elements of quartz, feldspar, and mica, but not exhibiting any more appearance of those minerals at its first deposition than is exhibited by any of the ordinary unaltered sandstones with which we are familiar. I by no means intend, however, to assert that all sandstones could be converted into gneiss, for it is obvious that purely siliceous sandstones could not, but *purely siliceous* sandstones are much more rare than is often supposed. The great mass of sandstones and of clays do contain the elements of feldspar and mica as well as quartz—that is to say, they contain alumina, iron, potash, soda, magnesia, etc., as well as silica.

We must also never forget that the extreme term of metamorphism by heat is actual fusion and reduction into the state of an igneous rock, and that it is possible therefore that some igneous rocks, nay, even some granites, may be metamorphosed rocks, aqueous rocks that have been completely melted down again. If we look upon *all* aqueous rocks as in some shape or other *derivative* rocks—and this is a conclusion from which we cannot escape—we must regard them as either mediately or immediately derived from igneous rocks. With regard to the mechanically formed aqueous rocks this is obviously true, because if we trace to their original source the silica and alumina, the quartz, the feldspar, and the mica of which they are comprised, we must eventually arrive at some igneous, most probably some granitic, rock as their parent.

But even as regards the lime and the soda and magnesia of all the chemically and organically formed aqueous rocks (setting aside the carbonaceous rocks), we are compelled to suppose that the water first derived those minerals from the decomposition of such igneous rocks as contained them. The carbonates of lime and magnesia, and the sulphates of lime, must have acquired their bases primarily from the decomposition of the silicates of lime and magnesia, which are to be found in the igneous rocks; carbon itself being the only element which does not seem primarily derivable from igneous rocks. Speaking generally, then, it need not surprise us to find materials that had once been fused reduced again to that condition. It is true, that in our purest sandstones and clays the matters that once acted as a flux to the silica and alumina may have been washed out and removed more or less completely from their former combinations; but these pure deposits of silica or silicate of alumina are, as just now said, comparatively rare and in small quantity, and if the rocks around them and enclosing them were once to be remelted, they would soon become mixed up and mingled with the rest, and reduced to the same condition.

There can therefore be nothing either unphilosophical or improbable in regarding, with Sir C. Lyell, the whole crust of our globe as consisting of materials passing through an endless cycle of mutations, existing at one time as igneous rocks, then gradually decomposed, broken up, separated out, sorted, and deposited as aqueous rocks, whether chemical, mechanical, or organic, at a subsequent period metamorphosed, and ultimately re-absorbed into igneous rocks.

In this view, the most highly metamorphosed rocks would be those most nearly hovering upon the brink of re-absorption,* and gneiss accordingly on the point of passing into granite, and in some cases almost undistinguishable from it.

One thing is quite certain, that many rocks which are now undistinguishable from true igneous rocks, may have been formed by a comparatively slight metamorphism of "ashes," or other mechanical accumulations of materials derived directly from igneous rock, and subsequently brought within the influence of heat. It is probable that many amygdaloids may be altered tuffs, and possible perhaps that some clinkstones, whether volcanic or trappean, may have a like origin. Some felstones, again, may be but baked and slightly altered feldspathic ash.

Some real and originally formed igneous rocks may in like manner undergo metamorphoses, more or less complex. Some felstone or greenstone porphyries, for instance, may have acquired their porphyritic structure by long-continued and comparatively gentle heat, acting on previously compact trap rocks. The same comparatively slight action of heat

* Such speculations as those in the text may be useless enough as far as any practical result to be derived from them, and may by many persons be thought uncalled for. The old ideas, however, of the original independent origin of mica schist and gneiss still linger in some men's minds, and are even, as I am informed, coming more and more into favour with some continental geologists.

may have caused many once compact or porphyritic igneous rocks to have become completely crystalline, and possibly may in some cases have generated new combinations, and produced mineral forms that did not exist in the original rock. Trappean rocks may thus have become granitic. These possibilities should be borne in mind when we are endeavouring to explain phenomena that otherwise are often difficult to understand.

It will perhaps be useful if we give here the foregoing classification of rocks in a tabular form.

IGNEOUS ROCKS.

Volcanic.

Essentially Feldspathic.		*Feldspar and Augite.*
Trachyte.	Trachydolerites, or intermediate varieties unnamed.	Dolerite.
Trachytic Porphyry.		Anamesite.
Pearlstone.		Basalt.
Andesite.		Nepheline Dolerite.
Clinkstone.		Leucite Rock.
Obsidian.		Amygdaloid.
Pumice.		Peperino.
Tuff.		

Trappean.

Siliceo-feldspathic.		*Feldspar and Hornblende, etc.*
Felstone.	Intermediate varieties unnamed.	Greenstone or Diorite.
Pitchstone.		Melaphyre.
Clinkstone.		Diabase.
Feldspar Porphyry.		Gabbro.
Feldspathic Ash.		Hypersthenite.
		Aphanite.
		Serpentine.
		etc. etc.

Granitic or Super-silicated Rocks.

Quartzo-feldspathic.	*Quartzo-feldspathic with Hornblende, or Mica, etc.*
Pegmatite.	Syenite.
Elvanite.	Protogine.
Eurite.	Granite.

AQUEOUS ROCKS.

MECHANICALLY FORMED.

Arenaceous .	Gravel or Rubble. Conglomerate or Puddingstone, and Breccia. Sand. Sandstone and Gritstone, and their varieties.
Argillaceous .	Clay and Mud. Clunch. Loam. Marl. Shale or Slaty Clay.

CHEMICALLY FORMED.

Calcareous .	Stalactite and Stalagmite, Travertine, etc. Some Dolomites.
Siliceous . .	Siliceous Sinter.
Gypseous . .	Gypsum.
Saline . . .	Rock Salt.

ORGANICALLY DERIVED.

Calcareous, mostly from animals	Limestone and its varieties, compact, crystalline, chalky, oolitic, pisolitic, some magnesian, etc.
Siliceous, probably from animals	Flint and Chert.
Carbonaceous, mostly from plants	Peat. Lignite. Coal. Anthracite. Graphite.

AERIAL OR EOLIAN ROCKS.

Blown Sand on coasts.
Sand-hills of deserts.
Calcareous Sands compacted by rain, etc.
Debris at foot of cliffs.
Volcanic Ashes, etc., falling on land.
Soil.

METAMORPHIC ROCKS.

THOSE IN WHICH THE ORIGINAL STRUCTURE IS STILL APPARENT.

Arenaceous . .	Quartzite or Quartz-rock.
Argillaceous . .	Clay Slate.
Calcareous . .	Primary, Crystalline, or Saccharine Limestone, or Statuary Marble. Serpentinous Limestone, Verde Antique, etc. Some Dolomites.

THOSE IN WHICH THE ORIGINAL STRUCTURE IS MORE OR LESS COMPLETELY OBSCURED OR OBLITERATED.

Schistose Rocks	Mica Schist. Chlorite do. Talc do. Hornblende do., etc. Gneiss.

Note.—The whole subject of lithology requires to be taken up and worked over again *ab initio*. This is especially requisite in the igneous and metamorphic rocks. Many of the simple minerals even appear to require re-determination, while their occurrence as constituents of rocks seems often to depend on very uncertain grounds.

Professor Haughton has lately been good enough to examine for me some specimens of clinkstone from the Velay, but finds that they contain no zeolites, or water in any shape, and are not, therefore, clinkstone, according to the definition, but compact laminated trachyte.

The same gentleman has recently analysed some specimens of Irish felstone, and has found in them such an amount of silica as confirms the view commonly entertained of this rock, that it is a mixture of feldspar and quartz. His results, as given to the Geological Society, Dublin, in a recent paper, are—

Felstone of Ballymurtagh, county Wicklow.

Quartz	45.54
Feldspar	54.16
	99.70

Felstone of Knockmahon, county Waterford.

Quartz	40.81
Feldspar	57.19
	98.00

Felstone of Benaunmore, near Killarney.

Quartz	20.51
Feldspar	77.85
	98.36

This superabundance of silica in these old igneous rocks, so far beyond that which is found in any trachyte, is certainly a very curious subject for speculation.

Could they ever have flowed at the surface with their present constitution? has their composition been changed, by aqueous metamorphosis or otherwise, since their formation?

PART I.

GEOGNOSY.

SECTION II.—PETROLOGY.

CHAPTER VI.

BY that division of geognosy here called petrology, we may understand the study of rock masses; that is to say, the examination of those characters, structures, and accidents of rocks which can only be studied on the large scale, and only be observed in "the field." This study will comprise the modes of stratification, of separation by divisional planes, those of fracture and disturbance, and those of denudation, as well as the composition of groups or "formations," and the relations of igneous to aqueous rocks.

Petrology of the Aqueous Rocks.

I. *Lamination and Stratification.*

The lamination and stratification of the aqueous rocks is the very foundation of geology, that on which all the more important deductions of the science are based. It is therefore necessary to describe these structures in some detail.

We have already mentioned the very fine laminæ (plates or layers) of which some beds of shale are made up.

Each of these little layers of earthy matter is obviously the result of a separate act of deposition. The whole bed of shale being formed by the gradual settlement of fine sediment, film after film, upon the bottom of some tranquil or very slowly moving water, we may suppose this sediment to have been carried into the water by successive tides bringing matter from some neighbouring shore, by frequent or periodical floods of some river, by the gradual action of some current, or any other agent by which we could imagine fresh materials to have been transported at different intervals into the water. Or we may perhaps suppose that the supply being continuous, and the water more or less turbid throughout, the act of settlement took place at intervals by little successive fits and starts. Whatever may have been the exact nature of the action, it was clearly a gradual, and not a sudden one; and some time must be allowed for the deposition of a bed even *one* foot thick, when we find it, as we often do, made up of distinct laminæ, fifty or a hundred of which do not exceed an inch in thickness.

Still, although some time was required, and although the acts of deposition were distinct, yet they were not so widely separated in time as to allow of any great consolidation of one layer before the next was deposited upon it.

The whole set of laminæ were made to cohere together so as ultimately to form *one* bed, which may be quarried and lifted in *single* blocks.

In some shales certainly the coherence between the laminæ is but slight; they may be pulled asunder by the hand; but in others it is more complete, and in some quite firm; and in some laminated fine-grained grits and sandstones it requires almost as much force to split them along the lines of lamination (*with the grain*, to use a common term) as it does to break them across. In such instances it is probable that the succession in the acts of deposition was a rapid one, so that the whole bed became consolidated about the same time after its deposition, and its parts adhered firmly together accordingly.

Now the planes of stratification differ in this respect from the planes of lamination, that they mark a total want of coherence between two contiguous layers of rock. It would be impossible to get a block consisting of a part of two beds; there would obviously be *two* blocks.

It follows from these facts, that as the coherence of the laminæ of a bed is the result of the comparative shortness of the intervals between their deposition, so the want of coherence between one bed and another is the result of the length of the interval between the deposition of the beds. Each bed had time to become consolidated, to a greater or less extent, before the next was deposited upon it, so that the latter could not at all coalesce with the former. The planes of stratification, then, mark an interruption in the act of deposition, a pause during which nothing was deposited; the duration of that pause being very considerably longer than that of the intervals between the successive laminæ.

It is true that in some rocks, the substance of which is throughout very fine grained and homogeneous, both the planes of lamination and those of stratification are not very distinct externally, and those of stratification are not to be in all cases distinguished from those of lamination; and it would then appear as if the whole mass had been deposited rapidly and consecutively without the occurrence of any such intervals as are here alluded to.

Such cases as these are, however, the exception, not the rule, and even apparent exceptions rather than real ones, since subsequent pressure or other influence may have obliterated structures such as the planes of stratification which they once possessed. Attentive observation, indeed, will frequently discover both lamination and stratification where either one or the other is not at first perceptible.

Laminæ or layers, then, are the parts of which a bed is made up. Strata or beds are the distinct sheets or wide tabular masses of aqueous rock which are completely and naturally separated from each other. The planes of lamination often refer only to the direction in which the laminæ are arranged, whether the laminæ are separable or not. The planes of stratification are actual planes of separation between one bed and another. When we look, indeed.

at the face of a cliff or quarry, we may speak of *lines* of lamination or stratification, but we must always recollect that these lines are the edges of planes, and that the layers and the beds are widely extended sheets of rock, and not mere strips.

If we are at a loss to estimate the length of the interval between the deposition of the successive laminæ of a bed, still less have we in general the means of calculating the time which elapsed between the formation of one bed and another. When two or more beds are of precisely similar character, as two beds of the same kind of shale or sandstone, we should naturally be led to suppose that the interval between bed and bed was not indefinitely greater than that between lamina and lamina. If we assigned hours to the one, we might assign days to the other; if days to the one, weeks to the other, and so on. Still we should have no certain grounds to go on, and the interval between bed and bed might be years or centuries for anything we could, in the majority of instances, show to the contrary. When, moreover, the two beds were of totally different characters, as, for instance, where a bed of sandstone or limestone rested on a bed of shale, or *vice versa*, we should generally be right in allowing a larger interval between their deposition than where the beds were similar. Some time must be required for a change to take place in the conditions of the neighbourhood. In the case of a bed of sandstone destitute of all argillaceous matter resting on a bed of shale, we should be obliged to suppose some alteration in the strength or direction of the currents, so that all the finer matter was swept away, and only the coarser or heavier deposited. In the case of a shale resting on a sandstone we should suppose that the current had diminished in velocity compared with that formerly acting. In either case the current might come from a new quarter where only one kind of material was to be got.

The same current of water charged with a mixture of gravel, sand, and mud, and having strength enough to carry it all on together, will, as its strength lessens, sort and separate the materials from each other, depositing them in the order of their coarseness, the pebbles first chiefly by themselves, next the sand by itself, and lastly, the mud by itself.* Three different kinds of rock, then, may be deposited at the same time by the same current; but in order that either sand or gravel may be thrown down at a subsequent period on the top of the mud, a fresh current either of greater velocity or from a nearer source will be required, while an interval will be necessary for the mud to consolidate so far as either not to be removed by the new current, or not to allow the fresh pebbles or sand to sink into it.

In the case of a limestone occurring either on shale or sandstone we are still more forcibly compelled to the supposition of a great change of conditions. If the limestone be a pure carbonate of lime without much admixture of mechanical detritus, it is obvious either that all currents had ceased in the water which had previously deposited the sandstone or the shale, or else that they were no longer able to get any earthy matter and transport it to that place. If, indeed, as seems necessary in the case of all marine limestones, we assign an organic origin to this rock, we are compelled to allow a period prior to its production sufficient for the animals from which it is derived to grow and to secrete their solid materials from the adjacent water.

It is possible, indeed, in some cases, by the aid of the remains of animals and plants found fossil in the rocks, to arrive at something like a rough approximation to the time which has elapsed between the formation of successive beds. There are cases, for instance, in which we find on the surface of a bed of limestone the roots or attachments of a particular class of marine animals, called encrinites, which when alive were fixed to the rock by a solid calcareous base. These attachments belong to animals of all ages, and are in great numbers; and in a bed of clay or shale which rests immediately on the limestone, there are found a multitude of the remains of the upper portions of these animals, likewise of all sizes and ages. Now it is plain that in this case, after the limestone was formed, there was an interval during which the sea was

* Just as was previously shown for mud of different degrees of coarseness in Mr. Babbage's observations, see p. 95.

quite clear and free from sediment, and therefore well adapted for the growth of these animals; that they, after a time, settled accordingly on the limestone at the bottom of the sea, and grew and flourished there for a sufficient period to allow of successive generations arriving at maturity undisturbed, before the time when a quantity of mud, having been carried into the water, was deposited upon them, and killed them, and at the same time buried their remains. Here, then, we have an interval of many years, if not of centuries, between the formation of two beds of clay and limestone which rest directly one upon the other. — (*Buckland's Bridgewater Treatise*, vol. i. p. 429.)

Many instances similar to this occur to the geologist when pursuing his investigations, although not often admitting of such clear illustration and description.—(See *Lyell's Elements* for other examples.)

On the other hand, we have instances of fossil trees passing through several beds of sandstone, in such a way as to show that the whole number of beds were accumulated after the tree had sunk, and before it had time to rot entirely away. These trees evidently became waterlogged, and sunk to the bottom, where they rested in an inclined position, anchored by their roots, while successive deposits of sand were accumulated round them. But a tree thus wholly buried in water will last many years before it is entirely decomposed, so that it might very well have become enclosed in several beds of sandstone, especially when we recollect that it forms an obstacle to the currents flowing by it, and checks their force, and thus causes the deposition of sand around it more rapidly than would otherwise take place. Still, whatever number of years we assign to the accumulation of the whole mass of sandstone, we cannot in this case suppose any great interval to have elapsed between the deposition of one bed and that which rests upon it.*

* I suffer the above to stand as it was written. Since then, however, I perceive, by a passage in Emmon's American Geology (p. 12), that the time even in such a case as this might be indefinitely extended. Speaking of the sounds, or shallow inland seas, along the coast of North Carolina, he says their bottoms are everywhere studded with the stumps of the pines of the country, which require removal before a net can be drawn. "At the

It is possible in some cases, even without the aid of organic remains, to discover that the interval between two adjacent beds was a comparatively long one. For instance, we not unfrequently find that two beds, which in one place are contiguous, do in another place let in one, two, or more separate beds between them, as in Fig. 4. It is obvious

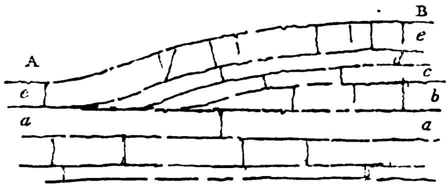

Fig. 4.

that if we observed the beds *a*, *e*, at the spot marked A, we should only suppose an ordinary interval to have elapsed between the times of their deposition; while on tracing the beds to B, we are compelled to enlarge that space of time sufficiently to allow for the formation of the beds *b*, *c*, and *d*, and the *intervals between them.* It appears, then, that while we are able to assign a sort of rough limit to the time required for the deposition of one bed, composed of a number of laminæ, we are rarely able to assign any approximate limit to the time required for the formation of a number of beds. Not only have we to multiply the first period by the number of the beds, but to allow for an equal number of intercalated intervals, of altogether uncertain duration, to represent the pauses that occurred between the formation of each two contiguous beds.

In some cases, if not in most, these intercalated intervals would be most probably *greater* than the periods of deposition, because we cannot very well imagine any set of circumstances that can keep up a continuous or rapid deposition of earthy matter, whether chemical or mechani-

first view, it might be inferred that the bottoms of the sounds were dry land very recently; but the stumps of pine, when immersed in water, are almost imperishable, lasting for centuries."

cal, for a very long and indefinite period of time, in any one particular locality. All we know, or can conceive, of the accumulation of earthy matters in the seas or lakes of the present day points to a discontinuous and interrupted action, a bed of sand being formed here, a patch of mud deposited there, a bank of pebbles accumulated in one place, a bed of oysters or other shells growing in another, so that the bottom of the sea becomes gradually covered by several unconnected and partial patches of deposition of different kinds, lying side by side. All our experience shows that for any great thickness or vertical succession of beds like these to be formed, in other words, for the depth of water to be materially diminished (except in narrow bays and inlets), a great length of time is required.

The soundings in shallow seas, such as those round the British islands, do not alter very rapidly, though they *do* alter; and the bottom at any one period is found to be very various, "mud," "sand," "sand and shells," "small stones," and similar terms, being scattered over the charts. These "bottoms" remain constant for a sufficient number of years to be used as a guide in navigation. In other words, great intervals commonly occur between the deposition of very different deposits at any particular spot on the bottom of the sea.

Moreover, if we take the whole earth generally, and limit ourselves to the consideration of any given instant of time, we must look upon the deposition of mineral matter as the exception, not the rule. Of many hundred thousands square miles of sea, only one perhaps is receiving, at any given instant, the accession of any mineral matter on to its bed. The next successive depositions may either be in adjacent or in widely separated localities; and a vast number of these partial and detached acts of formation will be required before the whole of any particular area will be covered with one or more beds of rock. In reasoning on the methods of production that have been concerned in the formation of our great series of stratified rocks, we are compelled to suppose a similar gradual, partial, and interrupted action to have taken place.

When we rise from the consideration of single beds to that of groups of beds, we find instances on a still larger scale of intervals having taken place in the deposition of rocks which at first appear perfectly continuous. Mr. Prestwich, in his paper on the "Correlation of the Eocene Tertiaries of England, France, and Belgium" (*Journal of the Geological Society*, August 1855), shows that on examining the rocks called tertiary above the chalk in France, they appear to have a regular continuous sequence of beds of sand and clay, etc., in which there is no sign of any interval having happened, while in reality a group of the English tertiaries, known as the London clay, having a thickness of 400 feet near London, was deposited in an interval between the formation of two of the French beds.* We cannot conceive the London clay to have required less than some thousands of years for its formation, and it may more probably have been many tens of thousands, during which interval no corresponding deposition was taking place over parts of the north of France, though deposition did take place both before and after this period, equally in the seas which covered what is now France and what is now England.

Such instances compel us to raise our estimate of the time required for the formation of a great series of stratified rocks to a perfectly illimitable extent.

These considerations, although they may appear somewhat speculative, are important, as leading us to a true interpretation of many of the appearances which the geologist meets with in his course of observation; and the student will do well if he accustom himself to look upon single beds of shale, etc., as the *possible* representative of a century or two, and upon small groups of beds as the product, perhaps, of thousands, or even millions of years.

* Mr. Prestwich's words are:—"It would nevertheless seem that there is a very important interval between the 'Lignites of the Soissonnais' and the 'Lits Coquilliers,' and that at so short a distance as from Kent to the Department of the Oise, there is introduced, wedge-shaped, between these two deposits, the large mass of the London clay, with its multitude of original organic remains. Yet there is not only no evidence either of the great lapse of time, or of the important physical changes which such a formation indicates, but there is even no cause for suspicion of such a fact in the apparently complete and continuous series of the 'Sables Inferieurs' of the north of France."

II. *Extent and Termination of Beds.*

In Figure 4 it is shown that, of a set of five beds at B, only two continue so far as A, the other three having thinned out and come to an end before reaching that part. This leads us to another conclusion respecting beds of stratified rock, namely, that although sometimes very widely spread, they are not of indefinite extent, but must end somewhere. This ending is generally a gradual one, the bed becoming thinner and thinner, till at last it disappears. Sometimes, however, though rarely, the termination is much more abrupt. Whether we reason from our own experience, or from the nature of the case, we should never be led to believe that the deposition of sediment in water, whether it be a chemical or a mechanical one, could, except in very rare instances, be co-extensive with the whole water. With respect to the sea, we cannot conceive any natural causes which could produce such an universal and simultaneous deposition, and should never expect to find a marine bed, the area of which at all approached in extent that of the water in which it was formed. The wonder perhaps is, that single beds sometimes extend over such very wide areas as we really find them to occupy.

The extent of single beds is most certainly ascertained in coal mining, in which the horizontal (or lateral) extension of beds is followed. Particular beds of coal, or of shale, or other rock having remarkable and recognisable characters, are sometimes known to spread throughout a whole district. For instance, in South Staffordshire a bed of smooth black shale, a little below the thick or ten-yard coal, is known as the "table batt." It has a thickness of from two to four feet, and extends over all the greater portion of the South Staffordshire coal field—places where it is known being ten or twelve miles apart from each other in straight lines and in different directions. Its original extension was probably much greater, since the beds now disappear in one direction by "cropping out," and are buried in others at too great a depth to be followed. Known beds of coal, with a particular designation, such as "Heathen coal," extend over still wider areas, and similar facts occur abundantly in most coal fields.

Neither is the great extension of single beds confined to those containing coal, but is found wherever there are beds of a sufficiently remarkable character to be noticed and recognised. A little bed called the bone bed, from its containing peculiar fragments of fossil bones, which lies just at the top of the new red sandstone of the south of England, is found both at Axmouth in Devonshire, and at Westbury and Aust in Gloucestershire—places full sixty miles apart—the bed itself never being more than two or three feet thick, and frequently only as many inches. It is even stated by Mr. Strickland, that he has identified this same bed in the form of a white micaceous sandstone up to Defford in Worcestershire, 104 miles from Axmouth, and at Golden Cliff and St. Hilary in Glamorganshire.—(*Proceedings of the Geological Society of London*, vol. iii. pp. 585 and 732). Similarly, a bone bed at the junction of the Ludlow rock and old red sandstone, never more than a foot thick, and frequently only one or two inches, has been traced at intervals over a space of forty-five miles from Pyrton Passage to the banks of the Teme near Ludlow.

Whether these beds be absolutely continuous or not over all the intervening spaces, these facts are sufficient to prove the uniformity of conditions over very large areas, so that wherever deposition took place, it was of precisely the same character. In the case of the bone beds mentioned above, the conditions under which they were deposited seem to have been so very peculiar that they may perhaps be looked upon as exceptions rather than as examples of a rule. It is useful, however, sometimes to know what is possible as well as what commonly occurs; neither, probably, would they be very uncommon if single beds were more frequently capable of being traced.

When from a single thin bed we come to the examination of a group of a few beds, the instances of mineral identity over very wide areas become still more frequent. This is especially observable when the group of beds is of a character quite different from the larger mass of rocks in which they lie; provided that difference points to a state of greater tranquillity or quietness of action, as would a bed of clay occurring in a group of sandstone beds, or a bed of limestone or coal occurring in others having a purely mechanical origin. We may take, as an example, what is called the Bala limestone in North Wales. This is a little group of a few beds, rarely exceeding twenty feet in thickness. The lowest bed is generally a black crystalline limestone, over which are several beds of hard crystalline concretionary and nodular limestone of a grey colour, alternating with more shaly or slaty beds. These contain small black nodules possibly of a coprolitic origin.* The softer argillaceous bands wear away more rapidly than the crystalline layers, which accordingly stand out in relief like a cornice moulding. By these characters the Bala limestone may often be perceived at the distance of half a mile on the side of a hill, and distinguished from the rocks of hard gritty slate above and below it. It extends from near Dinas Mowddwy on the south, to Cader Dinmael, on the north, a distance of 22 miles, and from near Llanrhaidr yn Mochnant, on the east, to the valley of Penmachno on the west, a distance of 24 miles; thus occupying an area of 400 or 500 square miles at least. It probably was once much more extensive; because, though we reach its apparent original termination in one direction near Dinas Mowddwy, where it dwindles to a thickness of two or three feet, in others its present "outcrop" shows no symptom of diminution of thickness or other sign of original termination.

On the other hand, some beds, even of a considerable thickness, have a remarkably small extension, being mere cakes, thick in the middle, and thinning out rapidly in every direction. This happens sometimes with all kinds of aqueous rocks; but is the more usual characteristic of the coarser mechanically formed rocks, being more common in sandstones than in clays and shales, and more frequent in conglomerates than in sandstones.

Beds of sandstone in the coal districts are sometimes found to thicken or thin out very rapidly. This is easily observable where sandstone beds are known to the colliers by specific names, and where the coal pits are near together. The miners are occasionally thrown out in their calculations

* By "coprolitic" is meant that they were the "droppings" of fish or other animals.

as to the depth at which particular coals will be found by these irregularities, which are sometimes so great and rapid, as to be called "faults" by men not accustomed to precision in the terms they use. Such an instance occurs near Wednesbury in South Staffordshire, where a bed of sandstone known by the name of the "new mine rock" thickens out from nine feet to seventy-eight feet in the course of a few yards' horizontal distance. In other parts of the district this sandstone varies from fifteen to sixty feet, and in some places is entirely wanting.

In examining sandstones and conglomerates, the conglomerates or old gravel beds are often found to be very partial and irregular, forming steep-sided banks and mounds enveloped in sand.

In these cases, although it was obviously a work of time for the pebbles to have been worn and ground down from their original large and angular condition to their present small rounded form, and although we may very well suppose them to have been washed about from place to place, and thus to have eventually travelled far from their original site, yet their final deposition in the place where we now find them was probably a rather rapid and sudden action.

Conglomerates, then, may be quoted as examples either of the *length* of time required for their formation or of its *shortness*, according as we look to the *preparation* of their materials or the actual *deposition* of them. This remark holds good, too, with respect to all other coarse mechanically formed rocks.

III.—*Irregular and Oblique Lamination and Stratification.*

In shales the laminæ are remarkably thin and regular, all parallel to each other, and parallel also to the planes of stratification. In many fine-grained, and in some coarse-grained sandstones, this regularity and parallelism likewise prevails. In other sandstones, however, great irregularity is observable in the laminæ of which the beds are made up, the layers of different coloured or different sized grains being oblique to the planes of stratification, and various sets of layers lying sometimes at various angles and inclining in different directions in the same bed, as in Fig. 5.

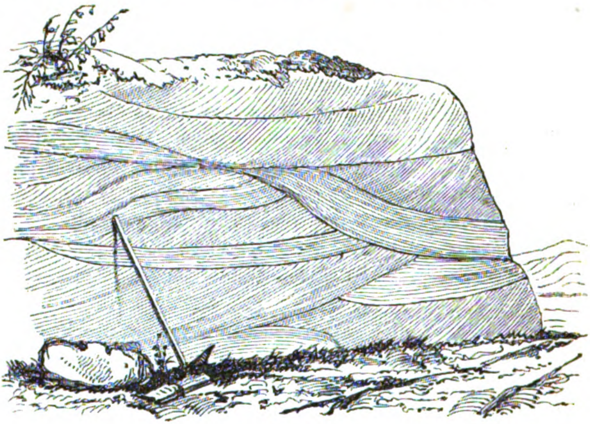

Fig. 5.

This structure is a proof of frequent change of direction, and probably of strength, in the currents which brought the sand into the water. If we suppose a current of water running over a surface which ends in a slope, as at *a*, in Fig. 6,

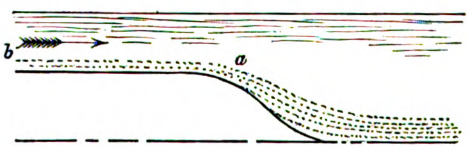

Fig. 6.

it is clear that any sand which is being drifted along the bottom from *b*, will, on reaching *a*, roll down into the comparatively still water of the deeper part, and remain there probably undisturbed. Layer after layer of sand may thus be deposited in an inclined position according to the slope of the bank.* On the other hand, if any obstacle arrests the

* A very pretty little machine has been invented by Mr. Sorby for producing this oblique lamination. Sand poured into a small trough is carried forwards by means of a screw, and falling down into a narrow space between

sand which is being drifted along the bottom of any water, some of it will be piled up into a heap, and a bank will be then formed having laminæ more or less inclined. If the current shifts its direction, another bank may be formed with its laminæ inclined at a different angle or in a different direction. Moreover, after one bank has been formed, a subsequent change in the velocity or the direction of the moving water may cut off and remove a portion of it, or excavate a channel through it, and this hollow or fresh surface may be again filled up or covered over by layers having a different form from the first. In this way water subject to changes of current, especially shallow water full of eddies, will throw down or heap up materials in a very confused and irregular manner.

It is a modification of this action probably which has produced what are called "rolls," swells," or "horses' backs," in the coal measures, and probably in other rocks where they remain less noticed.

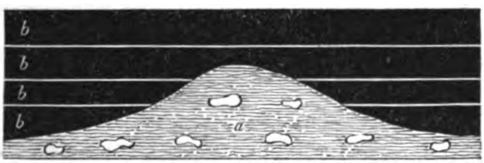

Fig. 7.

In this Fig. *a* is black clunch containing balls of ironstone; *b b*, beds of coal.

A long ridge, and sometimes one or two parallel ridges, of clay or shale are occasionally found rising from the floor through one or more beds of coal, "cutting them out" for a certain distance, to use the miners' terms. The crest of such a ridge is sometimes eight feet above the floor of the coal, with a very gentle inclination on either side, the beds of coal ending smoothly and gradually against it. (See *Records of School of Mines*, vol. i. p. 2). Its formation was obviously anterior to that of the coals which it "cuts out;" those coals and the "swell" itself being regularly covered either by a higher bed of coal, or by the "roof" of the seam, without any

a board and a sheet of glass, arranges itself in inclined layers according to the rapidity with which the screw is worked and the angle at which the instrument is held.

interruption or disturbance. The swells are sometimes 200 or 300 yards long, and 10 or 12 yards wide at the base. (See Fig. 7).

IV.—*Current Mark or Ripple.*

Another effect of current is to produce a "ripple" or "current mark" on the surface of a bed of sandstone or sandy shale. This rippled surface is exactly the same as that which is seen on the sands of the sea shore when left dry by the tide, and which may occasionally be seen at the bottom of any clear water where a current is moving over a sandy surface. It may be observed also sometimes on sand-hills on dry land, being produced by the drifting action of the wind. Either wind or water, as they roll before them the little grains of sand, tend to pile them into small ridges, which are perpetually advancing one on the other, in consequence of the little grains of sand being successively pushed up the windward or weather side of the ridge, and then rolling over and resting on the lee or sheltered side.

It is produced on the sea beach, not in consequence of the ripple of the wave impressing its own form on the sand below, which would be an impossibility, but because the moving current of water as the tide advances or recedes produces on the surface of the sand below the same form as the moving current of air produces on the surface of the water above. A rippled surface, therefore, to a rock is no proof of its having been necessarily formed in shallow water, though rippled surfaces are perhaps more frequently formed there, but simply a proof of a current in the water sufficient to move the sand at its bottom gently along, at whatever depth that bottom may be from the surface of the water.

Sandstones of all ages, from the oldest known rocks to the most modern, have occasionally rippled surfaces. Magnificent examples are sometimes shown in the cliffs of the south-west of Ireland, where highly inclined beds exhibit such markings over spaces frequently of 160 feet in each direction. The size of the ripple, or the distance from crest to crest of the ridges, varies from half an inch to eight or ten inches, with a proportionate variation in depth between them.

Mr. Sorby has lately shown that inferences may be drawn from the examination of these "current-marks" as to the strength and direction of the currents that caused them, and that we may thus reason back to some conclusions as to the physical geography of particular districts in former geological periods. One important conclusion certainly may be derived from these, as from other structures in rocks, namely, that the strength, velocity, and mode of action of moving water in the old geological periods was precisely of the same kind and intensity as those with which we are familiar at the present day.

In places where the current was troubled and confused, a modification of these rippled surfaces is sometimes produced, the bed being irregularly mammillated on its surface, which is pretty equally, although irregularly, divided into smaller hollows and protuberances of a few inches diameter. This surface structure may be seen in process of production now, on shores where spaces of sand are enclosed by rocks, so that as the tide falls it is made to run in different directions among the rock channels; but it would probably be caused at any depth at which a current could be similarly troubled and confused. It is not unfrequently seen among gritstones, even those of the very oldest rocks. It might be called "dimpled current mark."

V.—*Contemporaneous Erosion and Filling up.*

Instances are not unfrequent in which it appears that a bed, not only of sand, but of clay, coal, or other soft rock, after being formed, has had channels or hollows cut into it by currents of water, and these hollows have been filled up by a part of the bed next deposited.

In Fig. 8, taken from a road cutting in the New red sandstone at Shipley Common, near Wolverhampton, 1 is a bed of red and white marl or clay; 2 is a chocolate brown sandstone with irregular beds and patches of marl; 3 is a bed of red marl, like 1, but which seems at one time to have been thicker than it now is, and to have had some part of its upper surface carried off before the deposition of 4, which is a brown sandstone, that in like manner seems to have had its upper surface eroded and the hollows

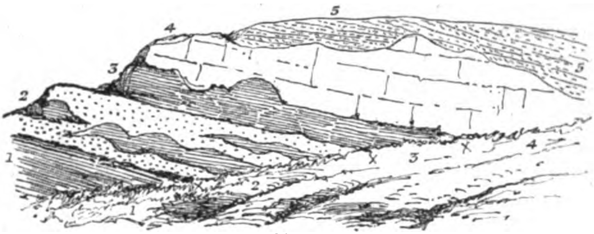

Fig. 8.

filled up by the deposition of 5, which is a mottled, red brown and white, calcareous sandstone, or cornstone.

In the tertiary beds near Paris, which are believed to have been deposited in a shallow bay or gulf, receiving rivers, and therefore traversed by currents, this structure is frequent. Two remarkable examples are observable in the large excavation near the terminus of the Rouen railway. In a cliff about 40 feet high in the fresh-water limestone formation called the Calcaire St. Ouen, two trough-like hollows may be seen about 50 yards apart; the beds previously formed having been excavated for a depth of 20 feet and a width of 15, and the hollows thus formed being filled up by irregular meniscus-shaped* expansions of the upper beds. (See Fig. 9).

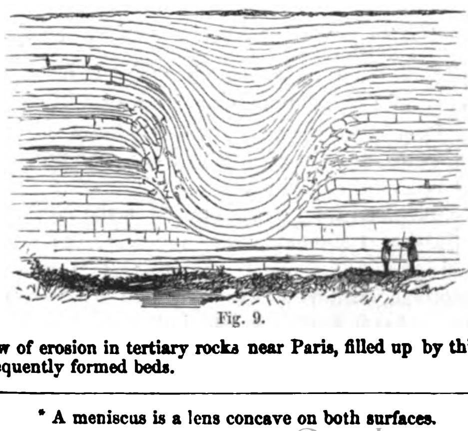

Fig. 9.

Hollow of erosion in tertiary rocks near Paris, filled up by thickening of the subsequently formed beds.

* A meniscus is a lens concave on both surfaces.

We are not aware how far the French geologists make a distinction in time between the beds thus eroded and those which fill up the hollows.

Similar trough-like hollows are met with in coal mining, traversing beds of coal, the coal being eaten away, and the hollows filled up by the matter which compose its roof, such as clay, shale, or sandstone. Mr. Buddle has described very fully one met with in the forest of Dean, where the miners gave the name of "the horse" to the stuff which thus seemed to come down and press out the coal. This trough was found to branch when traced, as in coal mining it was necessarily traced, over a considerable area, and to assume all the appearance of a little stream with small tributaries falling into it; the channels of the stream being afterwards filled up by the subsequently deposited materials that were spread over the whole coal.

Another modification of this erosive action is represented in Fig. 10, taken from a sketch made in a quarry in the

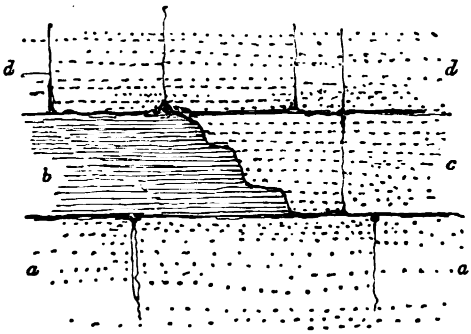

Fig. 10.

Eroded termination of bed of clay, with sandstone formed against it (Hobart Town, Tasmania).

neighbourhood of Hobart Town, Tasmania, where a bed of soft brown unctuous clay, about a foot thick (*b*), lying between two beds of hard white sandstone (*a* and *d*), suddenly ended, and its place was occupied by sandstone (*c*), similar in character to the beds above and below it. We must in this case suppose that after the formation of the bed of sandstone (*a a*), a bed of clay (*b*) was deposited over a certain portion of the area, and that then a current of water, bringing in sand, wore back the little bed of clay, eating into it so as to form a small cliff or step, and depositing the sand (*c*) afterwards against it, as represented in the diagram. The two beds, thus exactly on the same level, but *not exactly contemporaneous*, were finally covered by the bed of sandstone (*d d*), which spread equally over both of them.

We see in this case proof, that although the bed *c* is exactly on the same level as the bed *b*, both reposing on, and both covered by, the same beds, yet they are still not exactly of the same age, but that *c* was formed subsequently to *b*, inasmuch as *b* was not only formed, but partially destroyed, previously to the formation of *c*. Such facts give us farther proof of the length of the intervals which may elapse between the formation of two beds such as *a* and *d*, and also caution us not in all cases to infer strict synchronism from the fact of beds occupying the same geological horizon.

VI.—*Contemporaneity of Beds on same Horizon.*

If a group of beds, whether large or small, have the arrangement shown in Fig. 11, the order of the formation of the beds is clear enough as regards *a*, *b*, and *c*; but d^1 and

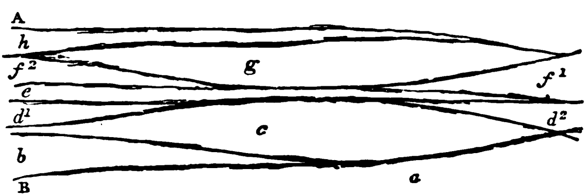

Fig. 11.

d^2 may either have been deposited contemporaneously, or one before the other; *e* is clearly subsequent to them both; but f^1 and f^2, again, are uncertain in relative age, while there is no doubt about that of *g* and *h*. If we wished to estimate the whole time consumed in the formation of such a set of beds, it would be obviously wrong merely to take their mean thickness, as shown at A B, for the measure of that time. The whole thickness of *a* had been deposited before *b* had been begun, and both were complete before *c* was formed. If, therefore, we assume thickness, or quantity of material deposited, as the measure of time occupied in deposition, it is clear that we should add together the maxima of *a*, *b*, *c*, and not take their mean. Similarly of the whole set, we ought to search out for the maximum thickness of each bed, and add those thicknesses together; and in doing this, we should feel some doubt as to whether we ought not to reckon d^1 and d^2, and similarly f^1 and f^2, as two separate and consecutive beds, instead of supposing them to have been formed at the same time. If in the set of beds under examination, we found many beds thus ending without overlapping, we should clearly be right in making allowance for the probably successive deposition of some of those which appeared to be contemporaneous.

We have already seen that this irregularity of deposition is most frequently met with in rocks that we supposed to be most hastily accumulated, while those which spread very regularly over extensive areas appeared to be most tranquilly and quietly, and therefore most slowly, deposited. We see now, however, that this very irregularity carries with it, in the long run, its own compensation, and that,—what with partial erosion and removal of some beds, and intervals of greater or less length between the formation of others, together with want of synchronism between beds that seem at first sight to possess it,—although any one bed, or small set of beds, may have been deposited in a comparatively hasty manner, yet the whole amount of time to be allowed for the accumulation of a great series of coarse beds would, if properly estimated, probably not be less than for an equal mass of more gradually and tranquilly formed rocks.

VII.—*Interstratification, Association, and Alternation of Beds.*

In studying the formation of aqueous rocks, we should soon be led to perceive that no general rule can be laid down as to their association with one another.

Limestones, sandstones, and clays occur either separately or interstratified one with the other in every imaginable variety of disposition.

We have sometimes a series of beds, many hundreds of feet in aggregate thickness, of pure limestone, with scarcely a single seam of mechanically deposited matter, even so much as an inch thick. Instances of this are shown in the chalk of the south-east of England, and the carboniferous limestone of Derbyshire, and of large portions of Ireland.

In the case of the chalk, there is in some places a thickness of as much as 1000 feet of soft, almost powdery, and nearly pure white carbonate of lime, that looks more like an artificial than a natural product. Its stratification even is occasionally indistinct, as if there had been almost a continuous deposit of this material with scarcely any interruption, though this is probably the result of the comparatively slight consolidation of the rock rather than of its rapid accumulation.

Series of beds of sandstone, almost entirely devoid of calcareous or argillaceous matter, and having a total thickness of many hundred feet, likewise frequently occur. Old gravel beds, now compacted into conglomerate, are often associated with these; and the sandstones exhibit every variety of texture, from lines of small pebbles to the finest possible grains. In such masses of sandstone, it is rare to find any foreign bodies, and mineral concretions or chemical deposits hardly ever occur in them.

Groups of beds of almost pure clay also occur, with a thickness of several hundred feet, with hardly a single bed of sandstone or limestone to be found in them.

While cases of this accumulation of one particular kind of matter, of great thickness, and therefore through long periods of time, are by no means rare, it is perhaps more usual to find different beds of rock alternating one with the other, sometimes so interstratified that there is never a greater accumulation than twenty or thirty feet of any one sort without others interposed between them.

Beds of limestone are frequently separated by beds of clay or shale, which is most commonly black or brown. These shales are themselves sometimes calcareous, and there seems occasionally to have been such an equal mingling of the two kinds of matter, that it is hard to say whether it would be most proper to call the rock a shale or a limestone. Such are some of the beds known as calp shale or calp limestone in the middle districts of Ireland.

Beds of sandstone, again, often alternate with such shales, so that we get a series of beds consisting of alternations of all these kinds. Beds of limestone sometimes alternate with sandstones, some of which may likewise be calcareous; but it is more rare to find pure limestone and pure sandstone interstratified with each other, than to have argillaceous beds alternating with either or with both. Speaking generally, indeed, we find, in examining the vertical succession of beds of rock, an approach to the same kind of passage or gradation that we sometimes perceive in their lateral extension. Beds of very fine and very coarse materials rarely rest directly one upon the other. Conglomerates are generally covered and underlaid by sandstones, and not by clays or shales. Coarse sandstone, in the same way, has usually a bed of finer material, either above or below, before shale or clay occurs.

The transition from the conditions favourable to the deposition of one kind of rock to those conducive to another has generally been gradual rather than abrupt. The tranquil water of the open sea, which seems to be the general producer of limestone, becomes first invaded by gentle currents, bringing in finely suspended mud, before it is traversed by those of sufficient strength to carry out the coarser material of sand. When a single bed varies in grain, we generally find the coarser part at the bottom, as we should expect; for when a quantity of variously sized detritus is delivered into any water, the larger and rounder grains or fragments will be the first to sink. Not unfrequently, however, alternations of finer and coarser grained laminæ occur in one bed, proving that the bed was formed by a succession of actions, and by as many different deliveries of matter into the water as there are sets of alternations.

We will give here a few instances of alternation of beds, taken from actual observation and measurement. The first is from Phillips's *Geology of Yorkshire*, vol. ii. p. 66.*

No.		Feet.
21.	Beds of sandstone, called millstone grit, together	87
20.	Beds of shale, taken together	30
19.	A bed of limestone	2
18.	Beds of shale	18
17.	A bed of limestone	3
16.	Beds of shale	6
15.	A bed of limestone	3
14.	Beds of shale, together	25
13.	Flinty chert (a compact siliceous rock)	16
12.	A bed of shale	1
11.	Crow chert. (Crow is a local term)	6
10.	Shale	9
9.	Second crow chert	12
8.	Crow limestone (probably in several beds)	12
7.	Sandstone or gritstone	6
6.	Coal	1
5.	Sandstone or gritstone	7
4.	Shale	8
3.	Gritstone in several beds	88
2.	Girdles (a kind of sandstone)	10
1.	Shale	18
		368

These beds are grouped together, with some others, under the name of the "millstone grit series," by Professor Phillips, it being often necessary to supply some one designation to a complicated series consisting of all kinds of rock.

In coal mining, abundance of alternations of arenaceous and argillaceous rocks, the latter often containing ironstones, with different varieties of coal, are almost invariably met with. The following is an example derived from the Bristol coal-fields (*Mem. Geol. Survey*, vol. i. p. 210).

No.		Feet.	In.
23.	Argillaceous shale	185	0
22.	Sandstone	4	0
21.	Coal	1	6

* In all tabular lists of beds or formations in this work, the series will be arranged on the page in their order of superposition, but they will be numbered in order of age, beginning with the oldest or first formed.

No.		Feet.	In.
20.	Underclay	2	0
19.	Argillaceous shale	64	0
18.	Coal and shale	4	0
17.	Coal	1	0
16.	Underclay	4	0
15.	Argillaceous shale	4	0
14.	Sandstone	2	0
13.	Argillaceous shale	23	0
12.	Coal	9	0
11.	Underclay	3	6
10.	Coal	0	6
9.	Underclay	2	0
8.	Argillaceous shale	7	0
7.	Sandstone	1	0
6.	Argillaceous shale	2	0
5.	Sandstone	6	0
4.	Argillaceous shale	4	0
3.	Coal	2	4
2.	Underclay	2	0
1.	Sandstone	3	0

The whole section of which this is a portion, enumerates 294 similar alternations, having a total thickness of 5084 feet, below which is a series of beds, 1200 feet thick, principally composed of hard sandstone.

It is to be specially noted, as regards the occurrence of coal, that it almost invariably rests on a fine argillaceous bed, often what is called "fireclay." This fact is familiar even to the miners, so that it has received the name of "underclay" in the South Welsh district, and in others is called "coal *seat.*" The general order of superposition (or of time of formation, for these are convertible terms), is 1. Sandstone; 2. Clay; 3. Coal; 4. Clay. If we disregard the minor alternations, we should see this rule carried out in almost all sections of Coal measures, the clay above the coal (the roof) being generally thinner and stronger (more shaly) than that immediately below. In some few instances the coal seat is arenaceous, and still more frequently a sandstone or "rock" roof may be found.

The following section, supplied by Mr. G. V. Dunoyer, represents the top beds of the upper limestone (Carboniferous), where they are observed to pass into the lower Coal measures, in county Carlow, from a quarry close to Old Loughlin.*

No.		Feet.	In.
1.	Hard earthy black splintery shale . .	3	0
2.	Earthy rotten black shale	2	0
3.	Hard black shale	0	2
4.	Brown earthy layer	0	5
5.	Crystalline grey crinoidal limestone . .	3	4
6.	Soft brown earthy shale, containing abundance of fossils, and very numerous layers of black chert	11	6
7.	Hard grey shale, encrinite stems, and shells .	0	9
8.	Grey compact limestone	3	6
9.	Chert layer, black	0	4
10.	Grey compact limestone	1	0
11.	Thin irregularly bedded shaly limestone, with grey shale on top	1	9
12.	Compact limestone	0	9
13.	Light grey compact limestone	4	8
14.	Black chert layers in hard black shale . .	1	0
15	Grey compact limestone, forming floor of quarry.		

See Fig. 12, at end of volume.

It will be useful to add one more section from a totally different set of rocks, but still exhibiting the same facts as to the alternation of various kinds of beds. It was taken at Catsgrove Hill, near Reading (Connybeare and Phillips, p. 43).

		Feet.
12.	Soft loam	11
11.	Dark red clay, mottled with grey . . .	4
10.	Light ash-coloured clay, mixed with fine sand	7
9.	Fine micaceous sand, laminated, partially mixed with clay	4
8.	Fine ash-coloured sand	5
7.	Dark red clay, mottled with blue . .	6
6.	Light grey clay, mixed with fine sand, .	5
5.	White sand	4
4.	Fuller's earth	3
3.	Yellowish quartzose sand	5
2.	Siliceous sand, with rolled and angular chalk flints	3
1.	Chalk to an unknown depth.	

* In this section the rule as to numbering is not observed, as the numbers refer to the woodcut at the end of the volume.

VIII.—*Nomenclature of Groups of Stratified Rock.*

From a study of the foregoing sections, we derive a knowledge of the way in which beds of aqueous rocks are frequently interstratified one with another, and we see how minute are sometimes the subdivisions of the beds, and how frequent and rapid are their changes, when we examine them in vertical succession.

It is obviously impossible to speak of such groups of beds collectively by any name that shall be comprehensively descriptive of these varieties, and yet, as we must often speak of such a series as one group or assemblage, and treat them as one mass, it is necessary we should fix upon some one name for them. In doing this we may either give them the name of the place where they were first observed and described, or we may select some mineral character of importance which some of the beds possess, and apply that to the whole; or we may give them a name derived from some local term or accidental circumstance. In either case we must be careful to recollect that the name will in many cases be a mere name and not a description, since its original meaning can never be universally applicable.

Just as we find Mr. White and Mr. Black, Mr. Long and Mr. Short, with persons the very reverse, perhaps, of what their names would imply, so we may in geology have the name of "red" or "green sandstone" affixed to rocks which in some places are neither red nor green, nor even sandstone. So we may have "coal measures" which in some places contain no coal, and "chalk" or "cretaceous" rocks which consist of black marble or dark clay-slate.

This will become still more strikingly obvious when, having gained an idea of the structure of a series of rocks at any one locality by examining good vertical sections of it there, we come to trace this series in its course across a country, and study the changes which it undergoes laterally.

IX.—*Lateral Variation of Beds.*

We should in many cases find that of the beds which we had noted at one locality, many, or most, or all gradually thinned out and died away as we followed their lateral extension, and that their places were supplied by others which as gradually came in. Now, these new beds might either be of similar character to those which had died away, or altogether different.

We might, for instance, in one locality, have a series of limestones of 1000 feet in thickness, resting one upon the other, without the intervention of any other beds. As we traced this group across a country, we should perhaps find that little "partings" of shale began to make their appearance between some of the beds of limestone, and that as we proceeded these shales became thicker and more numerous, while the limestones became thinner in proportion. Some of the limestones would perhaps then altogether disappear, and the series be split up into two or more *groups* of limestone, with one or

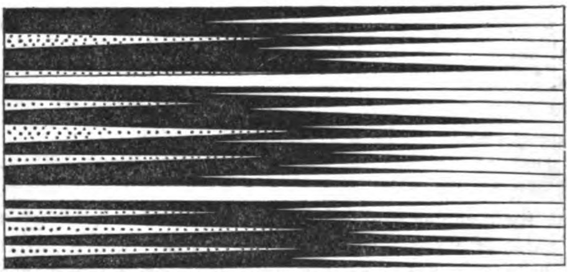

Fig. 13.

In this diagram the white bands are meant for limestones, the black for shales, and the dotted for sandstones.

two intermediate *sets* of shale-beds. Still farther on, the limestones might be more and more subdivided by beds of shale, and the shales themselves split up by beds of sandstone, until at length we should find our series consist almost entirely of sandstones and shales, with only one or two very subordinate beds of limestone, at one or two levels, to represent the purely calcareous group with which we commenced. The diagram Fig. 13, gives a rough representation of this lateral change, but requires to be drawn out to twenty or thirty times its length before it could be taken as a proximate delineation of the facts as they occur in nature.

In the same way, groups that consist principally of sandstone and conglomerate in one district may in another be composed chiefly of limestone and shale or clay, with or without any beds of sandstone.

The scale upon which these lateral changes of character are carried out is altogether indefinite. We see it sometimes take place with respect to a small group of beds within the limits of a single quarry; in other cases, a distance of a few hundred yards or a few miles is requisite before the alteration is apparent. Some groups of beds indeed preserve their mineral characters but little altered over whole countries or across whole continents. Still, judging from what we know, we must always hold ourselves prepared for change even in the rocks that seem most constant in their characters; and as a matter of fact, we know of no one group of aqueous rocks that preserves the same mineral characters in all parts of the earth.

This is what we should expect to be the case from what we know and believe to be taking place in our own oceans and seas at the present day. We know that the deposition of mechanically formed sediment must be largely occurring along the margins of coasts, or in shallow seas, and gulfs, and bays, and that the rocks thus produced must be very various in character—a patch of mud here, and a patch of sand there, with others of a wider range, but of similar character, in the more open sea, where shells and other marine animals are also causing calcareous deposits. In the great Pacific Ocean, indeed, we may very well suppose that deposits are taking place, derived from the waste of the vast number of coral reefs, having a constant character over an area quite as wide as any of the formations we are acquainted with on dry land. This great formation may not be absolutely continuous even over all that part of the ocean in which the coral reefs occur; but beds of precisely identical mineral character, and containing almost exactly the same organic remains, will be spread over large areas round several central points, where they will probably be thickest, and from which they will thin out in every direction. Some of these areas of deposition may perhaps overlap each other, while others will be separated by clear spaces of sea bottom, where probably no deposition is taking place, or by other sea bottoms, where sediment is deposited of altogether a different character from that derived from the coral reefs. All the great rivers of Eastern Asia, for instance, such as the Hoang-ho, which pours its turbid waters primarily into the Yellow Sea, and those of California and the north-west coast of America, are carrying down earthy materials into the Pacific of a totally different character from the coral-reef detritus; and some of this may be very widely spread, and form large deposits on both sides of the Pacific. If we could suppose fine sediment derived from two such different sources to overlap, now one sort thrown down, and now another, with an occasional admixture of both, we should have exactly the conditions necessary for such great formations of one kind of rock in one locality, and another kind in another district, with intermediate areas affording alternations of the two, as we find in our present formations composing our own countries.

If indeed we pass from the great Pacific into the China Sea and the northern part of the Indian Ocean, where coral islands and shoals are mingled with active volcanoes, both aerial and submarine, and are within the vicinity of the mouths of vast rivers, draining a great continent, we know of no variety of rock and no combination of mineral matter that has ever been observed upon earth that we should not feel warranted in believing to be possibly in course of formation within that area. All these different kinds of rock would be of contemporaneous formation, although of different mineral character, and they would enclose the remains of many animals and plants of the same species throughout, or of species so nearly allied as to show that their variations depended chiefly on the geographical distribution of organic beings inhabiting different parts of the globe at the same time.

Combining thus actual observation with probable speculations, we should be quite ready to understand that the same set of beds may, within the space even of the British Islands, put on very variable characters. Of this we may now advantageously examine some instances. Let us compare the two following sections :—

Near Bath, and in Gloucestershire.

			Feet.
	Oxford clay.		
5.—	Cornbrash	16	16
4.	Clay	11	91
	Calcareo-siliceous sand	10	
	Forest marble	18	
	Sand	2	
	Clay	50	
3.—	Great oolite	130	130
2.	Blue Clay	14	122
	Fuller's earth	8	
	Bastard Fuller's earth, with a band of shelly sandstone	100	
1.	Inferior oolite	30	80
	Calcareous sand	50	
	Total		469
	Lias		

Yorkshire.

		Feet.
	Oxford clay.	
5.—	Cornbrash	10
4.	Sandstone, shale, ironstone, and coal	200
3.	Impure, often oolitic limestone	30
2.	Sandstone, shale, ironstone, and coal	500
1.	Sub-calcareous, ferruginous sandstone	60
	Total	800
	Lias	

These two sections are descriptive of the beds which intervene between the two great continuous groups of argillaceous rock, called respectively the Oxford clay, and the Lias. These intervening beds are called generally the Lower or Bath oolite, because the oolitic limestones contained in them near Bath and elsewhere, are the most striking and valuable portions of them. The section near Bath is taken from Connybeare and Phillips, that for Yorkshire from Professor Phillips's Geology of Yorkshire. We see that, while in the south of England these beds are largely characterised by the presence of oolitic limestones, those in the north are almost destitute of them, but contain instead great beds of sandstone and shale, together with thin beds of coal, which are equally wanting in the south. If we examined the fossils they contained, we should find an equal change, as the beds in the north are full of carbonised plants and vegetables, which are almost altogether absent in the south, where the fossils consist of the remains of mollusca and other marine animals that are rare or wanting in the north. It seems as if in proceeding from the south to the north, we were approaching the shore of the old sea, and therefore get a greater quantity of mechanically-formed rocks, together with the products of the land, in the shape of plants that had been drifted from it, while the marine products proportionably decreased.

Had the Yorkshire rocks been those which were first examined and described, the term "oolitic" would never have been applied to them, although they may now be called "oolitic," as having been formed at the same time with the those which had previously received the name of "oolitic" rocks in Gloucestershire, and other parts of the world.

Similar results would be arrived at if we traced over a large area another group of rocks, which are called Carboniferous, from their containing in some places beds of coal. These rest upon certain beds of red sandstone, called Old Red sandstone; and if we compare them as they occur in the south of England and South Wales, in central and northern England, and in Scotland, we shall find that, while essentially made up of the same kind of materials throughout, these materials are differently arranged in different places.

We have in South Wales and the Border counties—

	Feet.
4. Coal measures, alternations of sandstones, clays, and shales, with occasional beds of coal	7000 to 12,000
3. Millstone grit, chiefly white quartzose sandstone	200 to 900
2. Limestones with thin shaly partings, called Carboniferous, or Mountain limestone	400 to 1800
1. Lower limestone shale, alternations of shales, with thin limestones . .	160 to 500
Old Red sandstone.	

(*Memoirs of Geological Survey*, vol. i.)

In Derbyshire and some adjacent counties, and in North Wales, this series becomes—

	Feet.
4. Coal measures, as before	3000 to 6000
3. Millstone grit, as before, about	800
2. Upper limestone shale, dark shale with occasional beds of limestone . . .	500
1. Carboniferous limestone, as before . .	800 to 1000
Old Red sandstone.	

The chief difference between these two sections is the occurrence of a group of beds of black shale *above* the Carboniferous limestone in the north, while there is little or none *underneath* it, the reverse being the case in the south.

In tracing these beds, however, from Derbyshire through Yorkshire and Durham to Northumberland, we find a gradual change coming in, so that while No. 4, the Coal Measures, retain their character of a multiform alternation of beds, No. 3, the Millstone grit, becomes split up by shales with beds of coal, thus blending with the Coal measures, while No. 2 acquires many beds of limestone and some of sandstone, and eventually also of coal, and even No. 1, the great limestone series itself, becomes interstratified with shales, sandstones, and coals; so that instead of the unbroken succession of beds of limestone which we have in Derbyshire, we get such sections as the following in Durham and Northumberland for the composition of No. 1 :—

	Feet.
7. Main limestone	70
6. Various alternations of shales, etc. . .	80
5. Underset limestone	24
4. Various, including one coal seam, one or more limestones, several shales, one or two principal grit rocks, flagstones, etc.	150 to 350
3. Scaur limestone	15 to 40
2. Various alternations, including a bed of coal, and one or more beds of limestone	125 to 225
1. Tyne bottom limestone	25 to 50
	489 to 839

(*Aldstone Moor, as given by Mr. Forster*).

In Scotland we have nothing above the Old Red sandstone but one great series of alternations throughout containing beds of coal from the top of the series to the bottom, so that the great carboniferous formation is no longer separable into distinct groups as in the south. All that can be said of the Scotch carboniferous series is, that it is *all* Coal measures, beds of limestone being more frequent in the lower than in the upper part of the formation, where they are commonly altogether wanting.

The great Carboniferous formation undergoes a somewhat similar alteration in its range from south to north in Ireland, where it occupies a very large portion of the surface, and is capable of being studied in great detail.

Enough, however, has perhaps been now said to give the reader an idea of the way in which the aqueous rocks, both chemical and mechanical, are interstratified with each other, the way in which they alternate when examined in vertical succession, and also how they gradually change their characters and pass into one another when their lateral extensions are followed out.

If the diagram, Fig. 13, be supposed to represent a series, not of individual beds, but a series of groups of beds (or formations as they are called), so that each of the divisions be supposed to be many hundred feet thick and many miles in extent, they will equally represent, in a rude manner, the way in which the stratified crust of the earth is made up. No single bed, no group of beds, no series of beds, no formation is of unlimited extent. They all come to an end somewhere; having at their first formation, by the very conditions of their production, gradually diminished and died away in every direction from some local centre or centres of deposition.

It may be asked here, if this be the case, How is it that geologists identify rocks by the same designation all over the globe? How is it that we speak of Devonian, or Cretaceous, or Tertiary rocks in Australia, in Africa, in Asia, and in America, as well as in Europe? The answer is, that geological terms, when applied to rocks in this sense, have a purely chronological signification; they refer to periods of time; they mean that the rocks called Devonian, for instance, in Australia were formed at the same time, or during the same great period of the world's history, as those which are called Devonian in Devonshire. How this is proved will be shown further on; but it is necessary here to warn the student of this meaning, in order that he may not form erroneous notions.

Just as we may suppose earthy depositions to be now taking place in Bass' Straits, for instance, as well as in the English Channel, so we know that mineral matter was deposited contemporaneously here and there upon the earth at all periods of its history since land and water came into existence upon it. If by any process of reasoning and investigation we can find out those rocks which were simultaneously formed, or nearly so, it is obviously advantageous to designate them by a common name, simply to point out the fact of this similarity in age, without inferring that they were ever parts of a continuous mass, or were formed of the same materials, or were produced exactly in the same way, or under precisely similar conditions.

General Conclusions.—As general conclusions from what we have hitherto said, we may state the following:—

1*st.* For the production of mechanically formed aqueous rocks the existence of *dry land* is absolutely necessary, since such rocks are the result, almost entirely, of the wear and tear of other previously existing rocks *at* or *above the level of the sea.*

2*d.* For the production of calcareous rocks animal life was necessary; for that of carbonaceous rocks vegetable life was necessary. The animal life may have been entirely aquatic, the vegetable life may have been either aquatic or terrestrial.

X.—*Joints.*

We should not long have studied the laminated and stratified structure of rocks, and paid attention to their separation into beds by planes of division which were obviously the result of distinctness and succession in the acts of deposition, without being struck by the occurrence of other planes of division, which cut the first at various angles, and assist them in dividing the rocks into regular or irregular blocks.

We should, indeed, very soon perceive that *all* rocks, stratified or unstratified, igneous, aqueous, and metamorphic, were traversed by numerous planes of division of this kind. They may be seen in any quarry, or in any natural or artificial excavation in any solid rock, traversing the rock in various directions, and separating it into blocks of correspondingly various shapes and sizes.

These divisional planes are called JOINTS.

Without natural joints the quarrying of stratified rocks would be very difficult, and that of unstratified rocks almost impossible. If beds of sandstone or limestone were undivided by natural joints, each block would have to be cut or split by artificial means on every side from the rest of the bed; but in rocks, such as granite or greenstone, which have no beds, the blocks would not only have to be cut away on each side, but *underneath* also. It would obviously be a most impracticable task to *dig out* a large block of granite from the midst of a solid mass untraversed by any natural planes of division of any kind.

For the production of natural blocks of rock there must

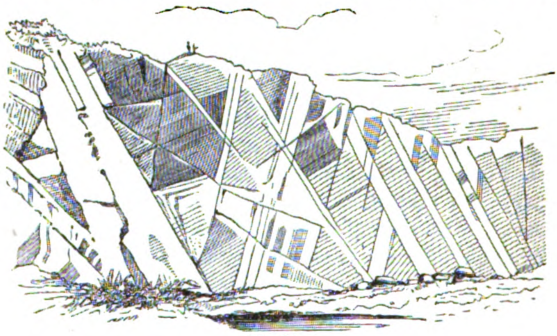

Fig. 14.

Joints in granite. Large quarries in Killiney Hill, near Dublin.—G. V. D.

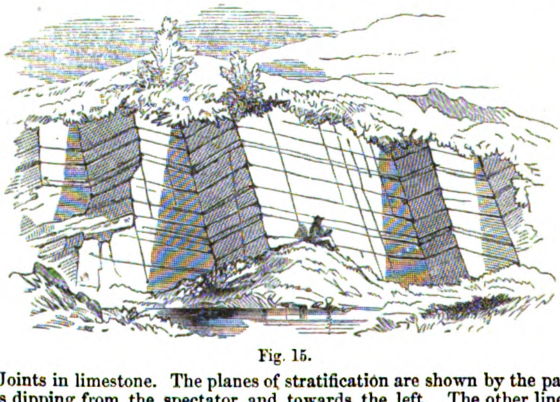

Fig. 15.

Joints in limestone. The planes of stratification are shown by the parallel lines dipping from the spectator and towards the left. The other lines are the ends of joint planes, which also form the smooth surfaces of the rock nearly at right angles to each other, as shown by the projecting corners. (Quarry near Mallow, Co. Cork.—G. V. D.)

clearly be, *at least*, two sets of joints in stratified, and three sets in unstratified rocks, each set more or less nearly at right angles to each other. (See Figs. 14 and 15).

If we compare a set of stratified rocks to a pile of slices of bread it is clear that to divide these into lumps, we must cut them in two ways, lengthwise and across. The unstratified rocks, however, would resemble the whole loaf, which we must cut at least in three directions in order to divide it into lumps, first horizontally into slices, and then lengthwise and across.

In addition to these fewest possible sets of joints in the two kinds of rock, there are in reality others in various and irregular directions.

If we pause here to inquire as to the general cause of joints, the only answer we can give, is that they are, in the first place, the natural result of the shrinkage or contraction of rocks upon consolidation.

In examining the newly formed beds of stone in the small islands upon coral reefs, they are always found to be divided by joints like other rocks. The consolidation of this stone was obviously due to the action of rain-water dissolving part of the carbonate of lime, and redepositing it as a cement, so as to bind together the previously incoherent coral sand; for the stone generally rested on and was surrounded by coral sand still incoherent. Among the coral islands on the north-east coast of Australia I often observed several beds of stone resting on each other, each more than a foot thick, inclined at an angle of 8° or 10°; that is to say, at the same angle as the slope of the beach or bank of sand on which they rested. They had to all appearance been formed, that is consolidated, in this position. The joints which traversed them, although often uneven and jagged, ran in straight parallel lines over spaces sometimes of 200 yards, or as far as they could be seen, their planes being generally at right angles to those of the beds, one set of joints running along the greatest linear extension of the mass ("strike" joints), and the other set directly across the former, and in the same direction as the inclination of the mass ("dip" joints).

The directions of these two sets of joints seemed to depend in these cases on the *directions of the principal bounding surfaces or edges of the mass.*

Professor Phillips tried many years ago, in his Geology of Yorkshire, whether the directions of the principal joints were not related in some way to the magnetic meridian, and arrived at results showing a tendency in the two principal sets of the joints of the Yorkshire rocks to arrange themselves according to certain magnetic bearings. This, however, seems to be only another way of stating that there are two principal sets of joints in the district, those of each set being parallel to each other.

Professor Sedgwick refers the directions of joints chiefly to the lines of upheaval and disturbance in rocks, calling those which run along or parallel to the "strike" of the beds, "strike joints," and those parallel to the "dip," "dip joints."* All other joints he calls "diagonal" joints.

These are useful terms, whether the two things be or be not related in the way of cause and effect.

It is certain that some joints have been produced in all rocks anteriorly to, and independently of, the action of the forces of upheaval which have elevated them; but it is very likely that the direction of the lines of upheaval may have been governed or modified by that of the principal joints, and that other joints may have been the result of the action of these disturbing forces.

In some localities, very widely extended planes of division may be seen traversing a great series of beds in perfectly parallel lines, running at wide intervals down whole mountain sides, so as to be visible at a distance of several miles, but without producing any dislocation or shifting of the beds.† Such unlimited joints were very probably produced, not from any internal shrinking on the mere consolidation of the beds, but from a simultaneous yielding of the whole mass to a great expansive or stretching force. When we come, however, to examine the joints of igneous rocks, more especially

* For the explanation of the words "strike" and "dip," see *postea*, p. 207.

† The peninsula that runs out from Glengariff to Berehaven, along the north side of Bantry Bay, is especially remarkable for these vast joints.

those of the highly crystalline kinds, such as granite, we see an amount of irregularity and want of symmetry in their arrangement which would make it difficult to attribute their origin to any widely-spread polar force or any mechanical power acting in one or two given directions.* It is true that over small areas, as, for instance, in single quarries, the regularity of the arrangement of the joints in granite is often very remarkable. One set of planes will be seen to run at such equal distances, and so strictly parallel, that if they be horizontal, or nearly so, they produce the appearance of stratification in the rock, and the workmen frequently speak of the *beds* of rock between such planes, (Fig. 14). In very large quarries, however, or in long cliffs, this appearance of regularity is found to be very inconstant and deceptive. One set of joints will most resemble stratification at one spot, and another set at another, each set being gradually obscured by the occurrence of other sets of joints cutting them irregularly and promiscuously. In one place, a multitude of many sets of joints will split up the rocks, at all sorts of angles, into numerous small angular fragments; in another, the joints will be very regular and wide apart. In the old Egyptian, as in the Indian and other quarries, where are procured those immensely long blocks of stone from which monolithic pillars and obelisks are made, there must be an absence of one or more sets of joints over unusually large spaces. It would be a very curious subject of inquiry, and one as yet untouched, to ascertain the conditions of the joints in such localities. I have observed granitic masses on the coast of Newfoundland which were apparently undivided by any joints over spaces of twenty yards in width, only one set of joints appearing at the surface, and running parallel to each other for some distance, with that interval between them. The exposure of rock, however, was not large enough to observe more than this.

The shape and the width of joints of stratified rocks vary much according to the nature of the rock. They are generally

* We are aware that some great parallel joints may in some localities be traced coursing through granite and other adjacent rocks; but we should class such joints among those subsequent ones just spoken of, and not among the original structural and congenital joints of granite and other rocks.

close, regular, and symmetrical, in proportion to the fineness of the grain and the compactness of the rock, being most irregular and uneven in coarse sandstones and conglomerates. The power of the force which produces them is, however, well shown in hard and well consolidated conglomerates, since the hardest pebbles of pure white quartz are often cut as clean through by the joints as the compacted sand in which they lie. In sandstones, joints are frequently open; in shales, they are closer, but more smooth and regular, being frequently perfect planes. In limestones, there are both close and open joints; but the open joints have frequently been widened by the action of water percolating through them, and dissolving a portion of the rock. Great fissures are sometimes formed in this way; and this has doubtless been the origin of many of the caverns which occur so abundantly in limestone rocks. In highly argillaceous limestones, the joints are often beautifully smooth, regular, and close.

In some cases, it would seem as if each bed had its system of joints formed before the other was deposited upon it, inasmuch as the joints formed in one do not penetrate the other. In other cases, a set of joints is seen to be common to a whole set of beds, and to have been produced apparently in the whole simultaneously. It is not uncommon for joints, in passing from one bed to another, to shift a little, or slightly change their angle. In such cases it may be doubtful whether a joint previously formed in the one bed may not have given rise to the formation, or at least have modified the position, of the other, in the bed above. There does not seem either to be any reason why all the joints traversing any bed or any set of beds should necessarily be of one age, but the contrary, inasmuch as we may imagine the process of solidification to take place at intervals, being at first incomplete, and afterwards becoming more perfect. Subsequent contraction would not have been so likely perhaps to widen the old joints as to produce new ones, since the shrinkage could hardly exert such a force as to overcome the effects of friction, and cause any large masses of rock to move and slide one over the other even to the most trifling extent.

Joints then may be caused, first, by the consolidation of each bed separately; secondly, by subsequent acts of consolidation, common to several beds; and thirdly, to widely spread mechanical force, affecting whole formations at once.

In the same way that the jointed structure of rocks facilitates their artificial extraction from their original site by the quarryman, it also facilitates their removal by natural causes. In examining cliffs, we may frequently be struck by the way in which a slight undermining action, if it happen to cut back to a strong vertical or highly inclined joint, has caused the ruin of vast masses of rock. Not unfrequently, too, a long strip of rock lying between two well-marked joints, closer than usual together, and running into the land at right angles to the coast, has been entirely cut out, giving access to the washing and eroding action of the breakers deep in among the rocks on each side of it.

In many cases, the erosive powers of water, especially of breakers, act not so much in proportion to the hardness or softness, or the greater or less destructibility of the material of which large masses of rock are composed, as to the number and position of the divisional planes of jointing and stratification which traverse them. A rock, even though very hard, such as quartz-rock or crystalline limestone, will be much more easily carried away by breakers or other moving water, if it be cut up by many open joints into blocks of a convenient size and shape, than much softer and more yielding rock, if it be massive, and either unjointed, or the joints be few and far between, and the sides of the blocks very close together, so as not to admit easily of the access of either air or water.

In some places, the jointed structure of rocks is sufficiently striking to attract the notice even of ungeological observers. In Van Diemen's Land, at a place called Eagle Hawk Neck, the rock, of which a large surface is exposed at low-water, is so regularly cut by joints into equal cubes, of about one foot in the side, that it has become a local celebrity, under the name of the "tesselated pavement."

In the gypsum quarries of Chaumont, near Montmartre, Paris, two thick beds of granular gypsum occur, which, instead of being divided by two principal sets of joints into quadrangular blocks, are traversed by three equally strong sets crossing each other at equal angles; and the whole mass is accordingly split into triangular and hexagonal blocks, giving the beds a columnar appearance like that so well known in basaltic rocks. (See Fig. 16).

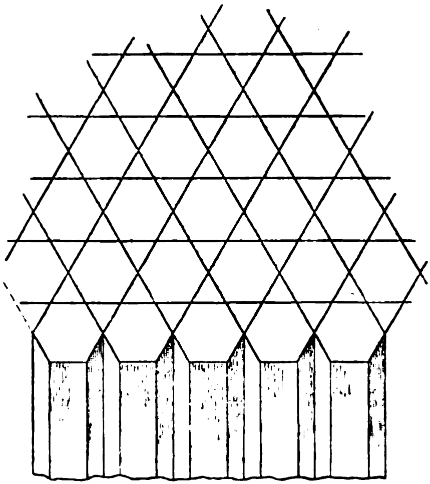

Fig. 16.
Joints in beds of granular gypsum, (Chaumont, near Paris).

The hexagons and triangles are frequently quite regular and perfect, and the result very curious, and, as far as I am aware, unique in unaltered aqueous rocks. If three sets of equi-distant planes cross each other at equal angles, the angle of intersection between any two will of course be 60°. If all three planes meet at the same points, triangular forms only would be produced; but if they be so arranged as that no more than two sets should ever intersect each other at the same point, and that each point of intersection be exactly half way between the other set of planes, as in Fig. 16, alternate triangles and hexagons of perfectly regular form will be the result.

These conditions seem to have been exactly fulfilled in the quarries near Paris, and the symmetry of arrangement has not been disturbed or obscured by additional irregular joints, which may possibly mask this, or some other symmetrical arrangement of joints in other places.

We have already said that in massive igneous rocks there must necessarily be at least three sets of planes, all more or less nearly at right angles to each other, for the mass to be separated into blocks, while in stratified rocks there must be at least two sets of joints cutting across the beds. If the planes be equi-distant and exactly at right angles, the blocks would be perfect cubes. This exact regularity, however, is not to be expected as common, nevertheless the approach to it is frequent, and it would be still more so if it were not for the occurrence of other irregularly disposed diagonal joints. We may, therefore, in practice, look upon such blocks as more or less universally cuboidal, and speak of the joints producing them as cuboidal or quadrangular joints. We have just seen that, even in aqueous rocks, other symmetrical arrangements of joints may exist, producing regular forms other than cubes; but this is more especially remarkable in those igneous rocks which occur in comparatively thin sheets, whether as beds or as "dykes," that is, as wall-like sheets traversing other rocks. In these the joints often divide the mass into long prisms.

The sides of these prisms are sometimes regular and equal, producing either hexagonal, pentagonal, or other forms. Sometimes, however, they are unequal and irregular, dividing the rock into uneven and wrinkled prisms like those exhibited by the common substance "starch."

That this prismatic arrangement is the result of contraction on consolidation is shown by the prisms usually being at right angles to the greatest extension of the mass, being vertical in a horizontal bed, horizontal in a vertical dyke, proving that the fissuring commenced at the cooling surfaces, and struck thence directly towards the centre of the mass.

Sometimes it is found that the two sets of prisms thus originating at each surface did not exactly fit when they met in the centre, as is shown in Fig. 17. At other times, however, they proceed uninterruptedly from one side to the other, the two sets either having coalesced, or one surface having cooled before the other, and given rise to divisions that were carried right across to the other.

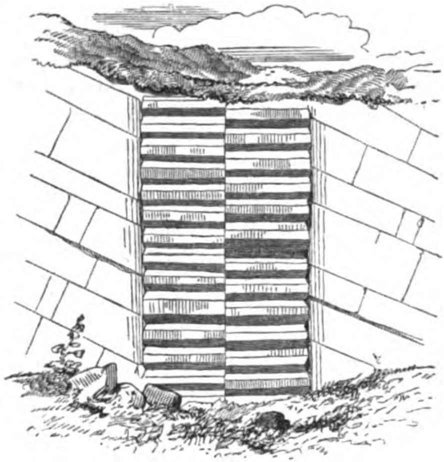

Fig. 17.

Dyke of columnar basalt, the columns not continuous across.

In addition to these prismatic joints, other irregular joints more or less nearly at right angles to the prisms also occur, and in very regularly columnar basalt and greenstone the columns are articulated, or separated at regular or irregular intervals into short blocks, by divisions, which are sometimes quite flat, sometimes curved into concave and convex surfaces, forming a kind of approach to a ball and socket joint. The origin of this structure is explained by the celebrated observations of the great Gregory Watt. If a mass of basalt be melted in a furnace, and allowed to cool again, the following results may be observed. If a small part be removed and allowed to cool quickly, a kind of slag-like glass is obtained, not differing in appearance from obsidian. If it cool in larger mass and more slowly, it returns to its original stony state. During this process small globules make their appearance, which, very small at first, increase by the successive formation of external concentric coats, like those of an onion, and the simultaneous obliteration of the previously formed internal coats, so that ultimately a number of solid balls are formed, each enveloped in several concentric coats. As these balls increase in size, their external coats at length touch, and then mutually compress each other. Now, in a layer of equal sized balls, each ball is touched by exactly six others (see Fig. 18), and if these be then squeezed together by an equal force

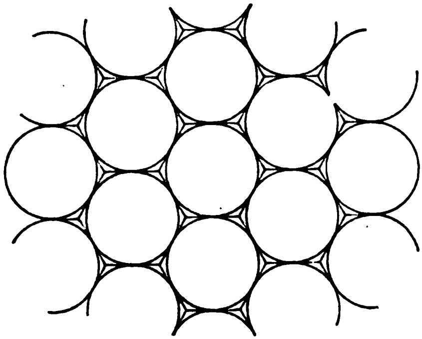

Fig. 18.

acting in every direction, every ball will be squeezed into a regular hexagon. But the same result will follow from an equal expansive force acting from the centre of each ball, or from the tendency to indefinite enlargement in their concentric coats. Each spheroidal mass, therefore, will be converted into a short hexagonal pillar. But if there are many piles of balls one above another, each ball resting directly and centrically on the one below it, we should have a long column of these hexagonal joints, and the top and bottom of each joint either flat, concave, or convex, according to variations in the amount and direction of the pressure at the ends of the columns.

There is no apparent reason why, in a cooling mass of basalt, the balls should be so arranged as that their centres should be in straight lines, and that the hexagonal vertebræ should form straight continuous pillars rather than separate discontinuous pavements. This, however, is probably the result of the simultaneous tendency in the mass to split into prisms in consequence of the joint-forming contraction on consolidation, the two tendencies acting together to produce the columns with the short ball and socket articulations.

In the case of curved columns, it is probable that the accidental arrangement of the centres of the balls overpowered the tendency to produce straight prismatic joints. Many other irregularities, resulting from the unequal action of one or the other tendency, may frequently be observed, since there are not only curved, but oblique and radiating columns; not only hexagonal, but pentagonal, triangular, and other irregular shapes, and in some instances small uncompressed or nearly uncompressed balls, may be found in the interstices between unequal and irregular columns. The pillars of basalt are usually from 6 to 18 inches in diameter, and vary in length from 5 or 6 to 100 or 150 feet. Columnar greenstone is commonly on a larger scale, the pillars being sometimes 5 or 6 or even 8 feet in diameter, and the columnar form of the rock is often only to be perceived at a distance. Almost all greenstone exhibits the tendency to decompose into rounded spheroidal blocks, on which we have just seen the columnar structure partly to depend. Felstone is sometimes also beautifully columnar, of which an admirable example may be seen in a small pass to the southward of Lough Gitane, near Killarney.—(See papers by Messrs. Dunoyer and Foot in the *Journal of the Geological Society of Dublin*, 1856). Neither is this tendency confined to basalt, greenstone, and felstone, since it is sometimes perceptible even in granite, producing in that rock the "logging stones," or "rocking stones," the "cheese wrings," the "torrs," as well as the "pots and pans," and "sacrificial basins," and other curious natural forms occurring in that rock, of which many have been attributed to ancient artificial processes.

The study of joints and the other divisional planes of rocks, and the different forms assumed by them in consequence, both when freshly exposed and when modified by "weathering," is as necessary for the landscape painter who wishes to reproduce nature, as is the study of anatomy to the figure painter. Mr. Ruskin has handled this subject in his usual masterly style.

CHAPTER VII.

FORCES OF DISTURBANCE.

I.—*Elevation of Aqueous Rocks.*

IN the preceding chapter we have been principally engaged with the facts relating to the deposition and consolidation of those rocks that have been formed under water. It will be convenient now to examine the problem of the elevation of these rocks into dry land.

It is clear that all rocks which were formed at the bottom of the sea, and which are now dry land, must have gained their present situation either by the sinking of the sea level, or by the uplifting of the sea bottom. If, however, the level of the sea be materially lowered in any one part of the globe, it must be equally lowered over its whole surface. But we find aqueous rocks on the summits of some of our highest mountains, and if these had been laid dry solely by the sinking of the sea, it is difficult to understand what can have become of a shell of water ten or twenty thousand feet deep enveloping the whole globe.

Partial floods and inundations are out of the question. Laplace determined that though the sea is often agitated by storms and earthquakes which raise it into great waves, and make it locally and temporarily overstep its limits, yet *the equilibrium of the ocean is stable, if its density is less than the mean density of the earth.* Now experiments on the attraction of the mountains of Schehallion in Scotland, and Mount Cenis in the Alps, as well as those made by Mr. Cavendish, and Reich and Baily, with balls of lead, demonstrate that the earth has a mean density at least five times that of water, and hence the stability of the sea, and the invariability of its level is beyond a doubt.*—(*Brewster's Life of Newton*, vol. i. p. 363).

We must therefore look upon the level of the sea all over the surface of the globe as absolutely invariable, unless by very great changes taking place in the form of its bed, the elevation of some parts, or the depression of others. To effect either relative or absolute change of level, then, in the surface of the sea, it is the *solid* part of the earth's crust that must first move. Even then we shall not effect absolute change of level in the upper surface of the sea, unless the elevation of its bed in one place be materially greater than its depression in another, or *vice versa.* But this we have no reason to suppose probable, and no right to assume as having taken place.

Wherever, then, we find that a change has occurred in the relative levels of land and sea in any portion of the globe, we must believe that the elevation or depression has taken place in the land, *in the solid rock*, and not in the fluid ocean. The very fluidity, indeed, of the ocean, which might at first lead us to look to its motion and change of place, as the cause of the appearance of dry land, renders any permanent *local* or *partial* change in its level impossible, while a local change in the level of solid rock is more easily possible than a general or universal one.

If, therefore, we can prove that elevation has occurred in one place, while depression happened in another, or if we can prove that any alteration of level whatever took place that was not common to the whole globe, and equal all over it, it must necessarily have been the rock that moved, and not the sea.

We may arrive at this conclusion in another way. We could not continue our observations upon stratified or aqueous rocks very long without perceiving that their beds were not invariably horizontal, but were, on the contrary, generally inclined to the horizon. Now, we have already seen that in certain cases beds of stratified rock may be formed on a con-

* More recent observations by the Astronomer Royal on the pendulum at the surface and at the bottom of deep mines, give a mean of 6.809 for the earth's specific gravity, while those made by the Ordnance Survey on the deflection of the plumb line at Edinburgh give it as 5.14.

siderable slope, or may have an original inclination due to the very circumstances of their deposition. These cases, however, are, by their very nature, limited to small areas. A steep slope cannot be of indefinite extent in every direction, and could not have strictly parallel beds deposited on it over its whole area if it were. Whenever, then, we have very widely spread beds, maintaining an equal thickness and strict or approximate parallelism over a large extent of ground, we may feel perfectly sure that those beds when first formed were horizontal. If such beds are now found in an inclined position, we may be equally certain that they have been moved since their formation, and moved more in one direction than in another. They must have been *tilted*, either by being lifted up at one end or depressed at the other. In many cases we find this motion to have been very great; the beds have been tilted and set on edge so as to rest at very great angles, and in some cases to be absolutely vertical. Beds consisting of alternations of clay and sand, with their seams of round pebbles that must clearly have been deposited horizontally, have been tilted up till they are now perpendicular (see Fig. 19). No one could look at a cliff exhibit-

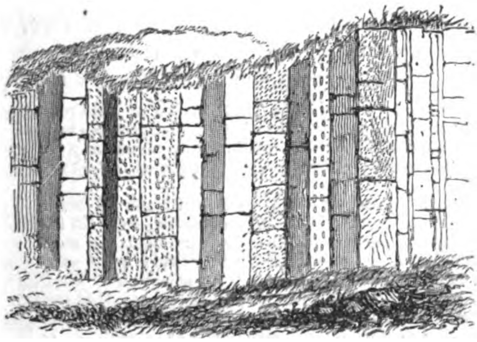

Fig. 19.

Beds containing layers of round pebbles, which must, therefore, have been deposited horizontally, now in a vertical position.

ing these facts, without feeling certain that in this case, at all events, some subterranean and internal forces had acted upon previously horizontal beds, and lifted them into their present position.

If we still hesitated to believe such motion in the solid frame-work of the earth possible, our scepticism must at length give way before the knowledge of the fact that it is still going on, even in our own day, in various parts of the earth. For a compendious account of movements of elevation and depression in the lands of the present day, either occurring within the times of history or still in progress, we must refer the reader to Sir C. Lyell's Principles of Geology, chapters xxix., xxx., and xxxi. He will there find an account of the gradual rise of Sweden and Norway, which is now going on at the rate of about three feet in a century; of the frequent elevation of land along the west coast of South America* simultaneously with the occurrence of earthquakes; of the depression of the coast of Greenland, and of both the elevation and depression of the temple of Jupiter Serapis, and its neighbourhood, in the bay of Naples, and other similar facts in other parts of the globe.†

It must suffice here to say, that these movements seem to be very slow, and to require immense periods of time before any great permanent change is effected. They may either be continuous and insensible in small periods of time, with no earthquake movement, or they may occur simultaneously with earthquakes in little shocks and starts of a few feet or a few

* Mr. Mallett, in his Report on Earthquakes in the Proceedings of the British Association, points out that these movements are not caused by the earthquake, which is a mere undulation, but accompany it; and that it would probably be more correct to say, that the earthquake was caused by the movement.

† More recent movements still were mentioned by Sir C. Lyell, in a lecture to the Royal Institution in 1856, as having occurred in New Zealand simultaneously with the earthquake of January 1855. A *step* of rock, bared of earth, nine feet high, was traceable for ninety miles at the edge of a plain along the foot of a range of hills. An elevation of five feet took place on the north side of Cook's Straits, so as almost to exclude the tide from the river Hutt, and a corresponding depression on the other side of the straits allowed the tide to flow up the river Wairua several miles higher than before.

That these permanent changes of level have not been more often observed is probably in great part owing to the want of a natural standard of level. A change of level diffused over a considerable area could only be detected on the sea coast, or by accurate measurement referring to some standard of level which had not itself been disturbed. Our only natural standard of level is that of the upper surface of the sea.

inches at a time. It is probable that no earthquake ever occurs without being accompanied by some change of level in some part of the rock shaken by it.

For the cause of these movements we must look to fluctuations of temperature in the heated interior of the earth—great accessions of heat rising nearer the surface in one part than another, causing expansion of the rocks affected by it in every direction, and thus producing an outward bulging or elevation of these rocks, accompanied by injection of molten matter among them—depression, on the other hand, being due to local refrigeration, and consequent shrinkage and contraction. As to the cause of the fluctuations of temperature, we are perhaps not in a condition to give even a guess.

To such movements as these, operating thus slowly and gradually, we must ascribe the elevation of the whole of the present lands of our globe above the waters of the sea. We say the whole of our present lands, because by far the greater portion of the dry land is covered by, or made of, rock that has been deposited on the bottom of the sea; and of the remainder, where igneous rocks now prevail at the surface, we have every reason to believe the greater part at least, if not the whole, was once covered by aqueous rock. With the exception, then, of those spots which are composed of matter actually ejected from the mouth of a recent volcano, we either know or must believe that the whole of our present lands have been once beneath the sea, and have been gradually elevated above it.

To such gradually acting forces as those we have mentioned we must ascribe not merely the elevation of all land, but all those effects of unequal elevation, of tension, of disturbance, and of great pressure resulting in fracture and contortion, which I am about to describe. If we know that such is the character of the forces now in action, and if such forces be capable of producing the effects, provided only a sufficient amount of time be allowed them, we have no right to assume that these forces have ever had a different character or a different intensity, unless good reason can be given why the amount of time could not have been large enough. If, however, it is proved from other sources that the time occupied by geological action is practically illimitable, we are not warranted in diminishing the amount of time and increasing the intensity of force simply to suit our preconceived ideas. This caution is necessary, because errors in estimating the nature of the forces in operation not only lead to false theoretical reasoning, but occasionally even to practical mistakes based upon that reasoning.

II.—*Inclination of Beds.*

The inclination of beds downwards into the earth is technically called their "dip." It is measured by the angle between the plane of the beds and the plane of the horizon. In Fig. 20, the beds dip to the south at an angle increasing from 35° to 50°. When we speak of the opposite of "dip," we use the term "rise." For instance, in Fig. 20 the beds *dip* to the south, and *rise* to the north. The place where each bed rises out to the surface of the ground is called its "outcrop" or "basset." We say that such and such beds "crop out" to the surface; and we speak of the "basset" edges of the beds. Miners use these and other terms, such as "coming out to the day," "rising up to the grass," when speaking of the "outcrop" of any bed or beds. The line at right angles to the dip, that is, the line of outcrop of a bed along a level surface, is called its "strike," a term introduced from the German by Professor Sedgwick. It is described by its line of compass bearing, either true or magnetic.* It may be called the "range" of a bed or beds across a country. Coal miners commonly speak of this as the "level bearing" of a bed, seeing that if you draw a line or drive a gallery along a bed exactly at right angles to its line of dip or inclination, it must of necessity be on a true level or have no inclination either way.

If, then, a bed "dips" due north or due south, its "strike" will be due east and west. If we know the direction of the "dip" of a bed, accordingly, we also know the exact bearing of its "strike;" but if we only know the strike, we do not necessarily learn either the direction or amount of its "dip," because it may incline to either side of

* Geologists generally use true compass bearings, a practice that ought to be adopted universally in all land operations.

the line of strike, and to any amount from the horizontal plane. In making observations, then, in field geology, it is most important to observe accurately the direction of the dip of all stratified rocks. It is also important to know its amount; but this need not be observed with such minute accuracy, since it is apt to vary continually to the amount of 3° or 4°. In Figs. 20 and 21, we have a rough map and section of a piece of country, which will explain these terms. In Fig. 21, let A A be a rocky beach, exposed at low-water; B B a line of cliff about 100 feet in height; and C C the surface of a country above the cliff, with the rock bared of grass and soil, and exposed in several places, either on the summits of eminences or the bottoms of quarries. The arrows point out the direction of the dip, the figures showing its amount. This amount increases from 35° on the north to 50° on the

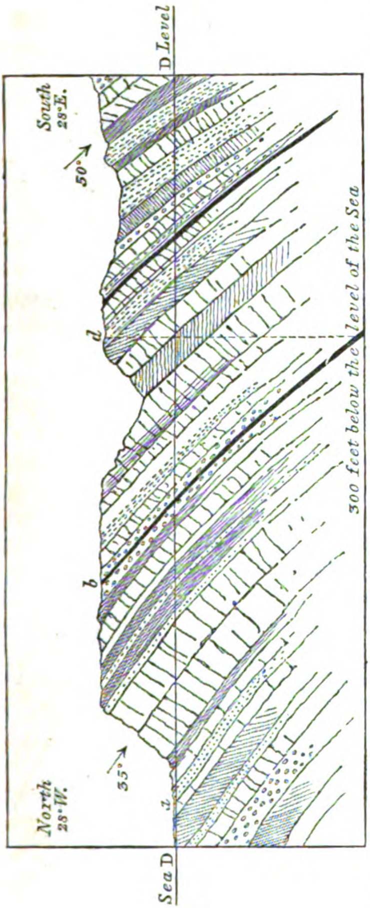

Fig. 20.

south; and we may assume this increase to be quite gradual, or that the beds are parts of curves, and not of perfectly straight planes. Then let D D be a line of section of

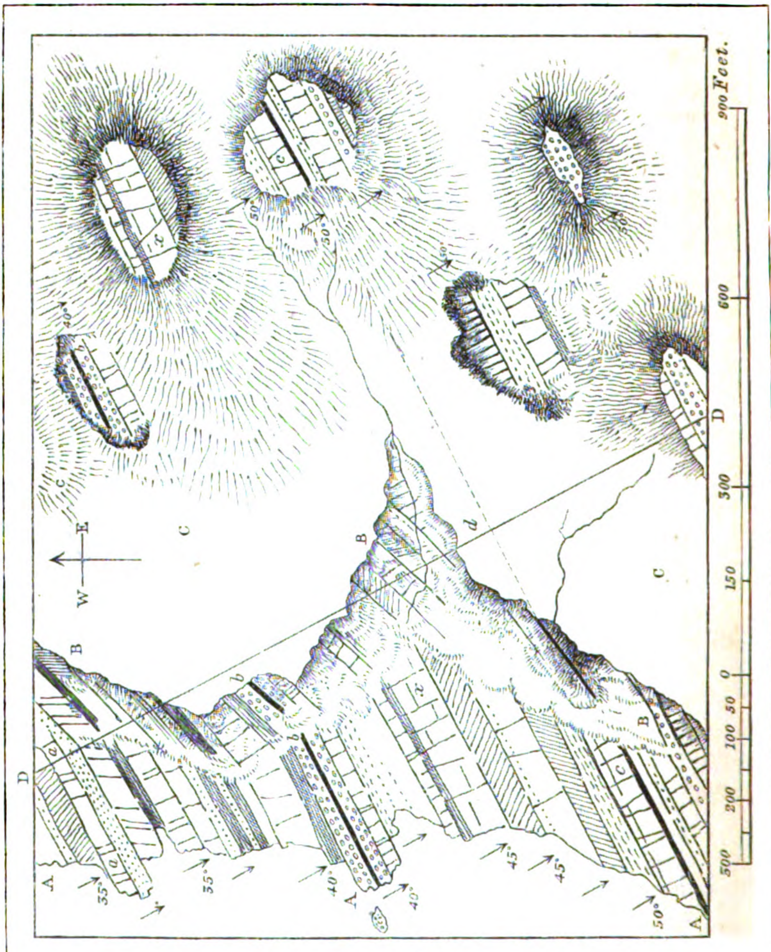

Fig. 21.

supposed cutting, at right angles to the strike of the beds; and let this section (Fig. 20) be drawn so as to give the true outline of the ground across which it passes, and representing the beds in the true position they would be seen to occupy were such a cutting or cliff really formed. Being drawn at right angles to the strike, it runs of course along the line of the direction of the dip; and its bearing, as here drawn, is about 28° west of north, and 28° east of south. The latter, then, is the *direction* of the dip. The bearing of the strike, marked by the ranges of the beds across the map, will consequently be 28° north of east if we look in one direction, 28° south of west if we look in the other. In such a locality as this, if we marked out the boundaries of the beds correctly on our map, we should feel sure of the correctness not only of the map, but of the section, and we should know the position of the beds not only above the level of the sea, but for a considerable distance below it. If, for instance, at the point *d* in the map it was of importance to sink a shaft, so as to come down upon the bed *b*, we should see at once that the depth of *b* under *d* would be, according to the scale, rather more than 425 feet. If we wished to reach the bed *a* in the same way, it would be easy, either by construction or calculation, to ascertain the depth at which it would be found in a perpendicular shaft under *d*.

It would be easy for us also to ascertain the total actual thickness of the whole set of beds shown on the map, either by actual measurement of each bed along the shore, or by constructing a section founded on the observation of their angle of dip and the width of their outcrop. The actual thickness of the beds cut by the sea level line in the section Fig. 20, for instance, would be a little over 850 feet. That is to say, those beds, if they were horizontal, would be 850 feet from top to bottom; if they were vertical, it would be 850 feet directly across them; while in their present inclined position, a straight line across their outcrop measures 1200 feet.

If we proceeded to trace those beds into the country *along their strike*, however much the direction of the strike or the *angle* of the *dip* might vary, or however they might be concealed by grass, soil, or superficial covering, we should always have to recollect that there was a thickness of 850 feet of beds to be found or allowed for somewhere; and if in the course of a few miles we came to a quarry or a cutting where the bed *x*, for instance, was shown, and we were able certainly to identify it, we should expect there to find all the other beds above and below it that we had found above and below it where they were clearly exhibited. We should feel sure we were right in this, if in the expected spots, at the requisite distance on either side of it, we found one or more of the beds *a*, *b*, or *c*, shown in other quarries, or cuttings, or cliffs in the neighbourhood.* It is in this way, by getting a knowledge of the true sections of a series or group of beds where they are well exhibited, and following them across a country, picking out one of them here, and another of them there, in ditches, brooks, river banks, cliffs or ravines, wells, mines, road or railway cuttings, and quarries, that geological maps are constructed, showing the boundaries of the several groups of rock, their range or strike across a country, and the area of surface they occupy with their outcrops or "basset edges."

II.—*Contortions.*

Where the dip and strike of the rocks are very steady, or where they run in nearly straight lines across a country, and their edges are not too much concealed by superficial covering, this is a task of no great difficulty. In many instances, however, neither the dip nor the strike of a set of beds remain constant over any considerable spaces. The beds are bent and contorted, and twisted about, so that, instead of running in straight lines, the basset edges, or outcrops of any set of beds, follow crooked and curved lines, often doubling back and running altogether out of their former course. Moreover, after dipping down in a certain direction for some distance, such beds are frequently curved up again, and rise to the surface at some other locality, forming basin or trough-shaped hollows; or again, after cropping out to the surface, the beds underneath them are bent over in a ridge-like form,

* In diagram Fig. 21, the supposed quarries or exposures of rock in the interior of the country are thickly grouped together; but if the reader will imagine them separated by much wider intervals, and scattered over a far larger space, he will have a truer notion of what usually occurs in nature.

so that the first beds come in and take the ground again, dipping in an opposite direction.

These bendings and twistings of the beds occur on every possible scale, from mere little local crumplings on the side of a bank, to curves of which the radii are miles, and the nuclei are mountain chains. When on the small scale, they are commonly called "contortions," as in Fig. 22.

Fig. 22.

There are in some instances wonderfully regular curves, visible in beds even of the hardest stone, such as beds of limestone, arches both upwards and downwards, succeeding each other with all the regularity of masonry, as in Fig. 23.

Fig. 23.
Contortions in limestone and shale (borders of Staffordshire and Derbyshire).

In other cases, especially where there are alternations of softer and more yielding beds with hard ones, the softer are seen to be puckered and crumpled, as if they had been subjected to lateral pressure and squeezed back, while the harder ones are less broken. This is shown at one part of Fig. 22.

Very curious and almost inexplicable contortions may be seen occasionally, but we must recollect, that the conditions under which they were produced, were such as it is not often possible for us to imitate, nor easy even to imagine. When the rocks were thus contorted, they were buried under vast thicknesses, often many thousands of feet, of other rock; the rocks above and below them were also of unequal densities, and offering unequal resistances to force; the forces of disturbance, therefore, even if uniform in their origin, would become complicated in direction, and unequal in intensity, by reason of these inequalities in the structure and position of the rocks, and inequalities in the pressure of the superincumbent masses. We might expect *a priori*, therefore, to meet sometimes with results not capable of any ready or simple explanation.

III.—*Anticlinal and Synclinal Curves.*

When the curves of the rocks are of greater extent, we cease to speak of them as mere "contortions." If the curvés have longly-extended axes, that is to say, if the beds are bent up into ridges, or down into troughs, which continue for considerable lengths, in proportion to their widths, we speak of them as "anticlinal" and "synclinal" curves. If, on the contrary, no diameter of the curved area be much longer than another, we call them either dome-shaped elevations, or basin-shaped depressions, as the case may be.

In Fig. 24, A is an anticlinal, and B is a synclinal curve, the beds numbered 6, 7, 8, being repeated on each side of both. At A, the lower beds, 1, 2, 3, 4, 5, are seen rising out from underneath them in the form of an arch. At B, the upper beds, 9 to 13, repose upon them in the form of a trough. It matters not whether we suppose the spaces, 1, 2, 3, etc., to represent single beds, and the hill at A a slight elevation, or whether they be taken as groups of beds, and A be supposed to be a mountain chain. The straight line which may be supposed to run directly from the eye of the spectator along the top of the ridge A, or the bottom of the trough B, is called the "axis" of the curve in each case.

This axis may be either horizontal or inclined; if horizontal, the section across it will cut the same beds wherever it be

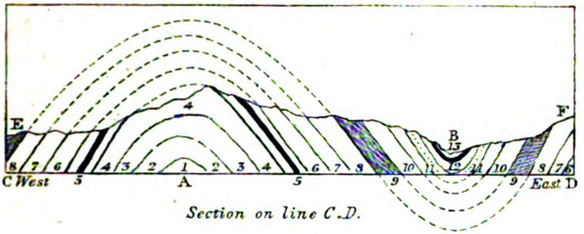

Fig. 24.

taken, the variations in its outline only resulting from those in the outline of the ground. If, however, the axis be in-

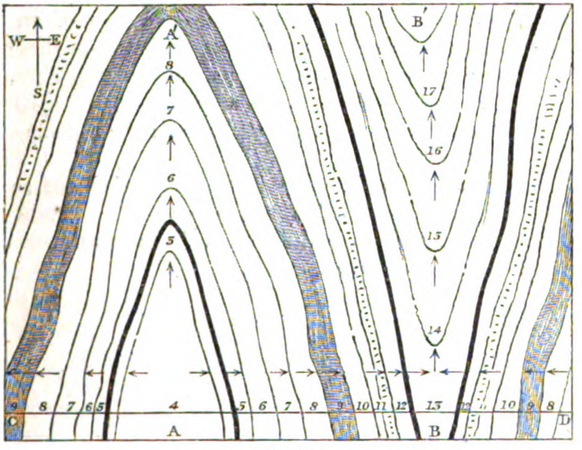

Fig. 25.

clined, different sections will cut different beds, even should the outline of the ground remain the same. This will be best shown, if we look at Fig. 24, which is a supposed plan of the ground of which Fig. 25 is a section, and suppose the axes, A A' and B B', to incline downwards to the north, or from the line of section to the other end of the map, as shown by the arrows, it is obvious that the bed 4, which forms the apex of the ridge in the section, will slope downwards along the inclined axis, and if the ridge of the hill be kept up to the same height, the beds 5, 6, 7, 8, will necessarily arch over it. In the same way, if the synclinal axis B B[1] slope in the same direction, there must either be a corresponding slope and hollow in the surface of the ground, or fresh beds, 14, 15, 16, etc., must come in, resting in the hollow of 13.

In countries traversed by many lines of disturbance, such forms as these are by no means unfrequent. They necessitate great labour in tracing them out, and making an accurate map of them, especially where the ground is itself lofty, broken, and uneven, and the complexity underneath obscured by perplexing irregularities on the surface.

Sometimes the axes of the curves slope both ways from a central point, producing long oval forms like that of an inverted boat, and there is a regular gradation from these to the circular elevations or depressions mentioned before, in which the beds are said to have a *quaquaversal dip* from or to a central point, according to whether it be a dome or a basin that is produced.

These flexures are in some instances carried out so far both on the large and small scale, as to produce actual inversion (see Fig. 26) of the beds, so that the lower surfaces appear to be the upper ones.

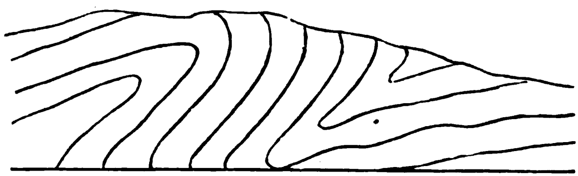

Fig. 26.

This inversion may be seen in some cases in cliffs among highly contorted beds; in other cases it requires a more widely extended observation, in order to show that the apparent order of superposition of any set of beds, in any particular locality, is the inverse of that order which is to be observed generally, and where the beds are undisturbed.

Inversion of beds is occasionally to be detected by means of the "ripple," or "current mark," or other structure produced on the surface of beds, when the peculiarities in the forms of these marks are of such a kind as that a "cast" of them shall be plainly distinguishable from the original form. In these cases the "cast" may sometimes be seen on the now upper surface of a bed, dipping under what appears to be the bottom of the superincumbent bed, but which was originally the really upper surface or "mould" on which the materials were deposited that formed the "cast" at the bottom of the succeeding bed.

The inversion of beds is likewise occasionally detected in coal mining, as in Belgium and the south-west of Ireland, where beds of coal are sometimes found with the "coal-seat" uppermost, and the "coal roof" undermost. In a disturbed part of the South Staffordshire coal-field also, the same bed of coal was passed through three times in the same vertical shaft, first in its right position, then inverted, and then again right side uppermost. It must accordingly have been bent into the shape of the letter S or Z.

We shall see presently that no mere "fault" can thus bring part of the same bed twice into a vertical shaft.

III.—*Faults, or Dislocations.*

It may easily be conceived, that the force which was sufficient to raise vast masses of solid rock, of unknown but immense thickness, from the bottom of the sea high into the air in order to form the dry land, and to bend them into the folds and contortions we have just described, was also sufficient to crack and break them through. We find, accordingly, very frequent instances of cracks and fissures running through great thicknesses of rock. Sometimes these are mere fissures; but quite as frequently there is not only a severance but a displacement of the rocks that have been severed. Beds that were once continuous are now not only broken through, but are left at very different levels on opposite sides of the fissure—many feet, or many hundreds of feet above or below the parts with which they were once continuous. When this is the case, these fractures are called "faults" or "dislocations" by geologists, for which miners in different districts use in addition the terms "slip," "slide," "heave," "dyke," "thing," "throw," "trouble," "check," and other expressions.

The amount of dislocation measured in a *vertical direction*, produced by a fault, is called its "throw," a fault being said to be an "upthrow" or a "downthrow," or an "upcast" or "downcast," according to the side from which we view it. Its amount is stated in fathoms, yards, or feet, measured perpendicularly from the surface, provided the surface be horizontal, from a given horizontal plane if it be not. If, for instance, a bed of coal, where it is cut by a fault, as at A, Fig. 27, be

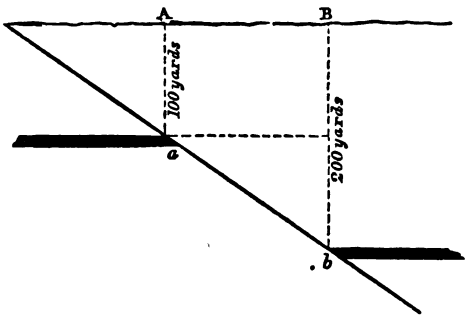

Fig. 27.

100 yards from the surface, and the other part of the bed immediately on the other side of the fault, as at B, be 200 yards from the surface, or from the assumed horizontal datum, the throw of the fault is said to be 100 yards, without regard to the distance measured laterally from A to B along the surface,* or from *a* to *b* along the fault.

Faults vary in character and in effect,

1st. According to the nature of the rocks which they

* In taking accounts from miners as to the characters of faults, it is necessary to be on one's guard, and be quite sure that the sense in which they use these terms is properly understood. In some districts they would speak of the distance A B, measured along the surface of the ground, or the horizontal distance between the ends of the beds, as the "width" of the fault, looking only to the extent of "barren ground" as to that particular bed, and paying no attention to the real width of the actual fissure itself, which might be not more than a few inches, or perhaps even not more than one.

traverse, whether they be hard or soft, or an alternation of both.

2dly. According to the position of the beds which they traverse, whether these be horizontal, inclined, or contorted.

3dly. According to the number of lines of fracture, their direction, inclination, and combination.

1. When faults traverse a mass of rather soft and yielding beds of rock, such as shales and thin sandstones, the fissures themselves are often mere planes of division, just as if the rock had been cut through with a knife. Very frequently, in this case, the two contiguous surfaces of the fault are found to be quite smooth and polished by the enormous friction that has taken place, producing the appearance well known to geologists under the name of "slickenside." In some cases, although the fracture seems quite clean and sharp, yet the beds on each side are found to be traversed by a great number of small, irregular, and discontinuous "slickenside" surfaces, as if a jarring and tremulous grinding motion had been produced in the mass of the beds. Sometimes the beds end abruptly without any distortion, Fig. 28; but sometimes they seem to have been bent and pulled down along the plane of the fault to a certain extent, as in Fig. 29.

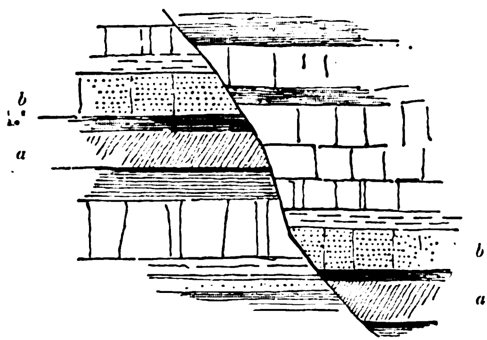

Fig. 28.

In Fig. 29, the beds would be said to "rise towards the upthrow," and "dip towards the downthrow;" and this is naturally the most usual occurrence, though we believe not invariable, as there are said to be instances where the very opposite of this takes place, and the beds seem to "rise" to a downthrow fault.

When faults traverse very hard and unyielding rocks, such as thick hard gritstones, hard limestones, or hard siliceous

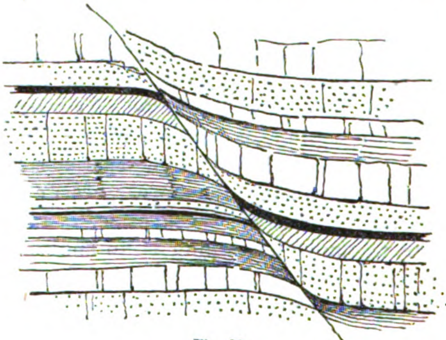

Fig. 29.

slates, and still more, if they penetrate igneous rocks such as granites and felstones, the fissures are apt to be much wider, and often very irregular. If the original fracture shall have

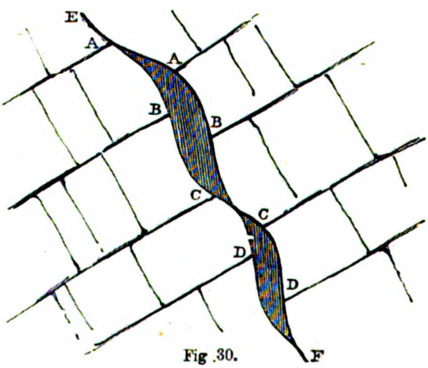

Fig .30.

taken place not in one plane, but so as to produce two jagged, and broken, or uneven and irregular surfaces, with cavities and protuberances as in Fig. 30, and these two surfaces slide one over the other, it is very unlikely that they would ever, unless restored to their original position, be made *to fit exactly* so as to close again upon each other throughout their extent. Protuberance might rest against protuberance, or come against a hollow not large enough, or not of the requisite form, to receive it, and thus the two walls of the fissure would be kept partially and irregularly apart, the fissure being closed in some places and open in others. In Fig. 30, an uneven fracture having traversed the hard beds A, B, C, D, and dislocation taken place, the result would be the irregular fissure E F.

It is true that the grinding process, as the surfaces moved upon each, would often greatly diminish this irregularity, and in soft rocks probably obliterate it; but in hard rocks it is much more usual to find the irregular openings above described still remaining.

Where alternations of hard and soft beds occur, there may be a combination of the two effects, the fissure being quite closed where soft beds are brought together, or even where soft beds are brought against hard, but more or less open where two hard beds come in contact.

When we speak of open fissures, however, we by no means intend to assert the frequency of fissures now open and empty. They are almost invariably filled with materials either derived from the ruins of the adjacent rocks at the time of the fracture occurring, or accumulated there afterwards.

Some fissures, even in the most soft and yielding rocks, have similarly been kept open, or rather the sides of the fault kept apart by fragments and debris that were dragged into them at the time of their occurrence. Such fragments, often of large size, are found along the lines of faults both vertically and laterally, for it is not unfrequent, in tracing the line of a fault along the surface of the ground, to find lumps and patches, some yards in diameter, of the broken beds caught and resting in the gaps of the fracture.

2d. As it is comparatively rare to find beds in a strictly horizontal position over any considerable area, it is necessary to study the effect of faults on inclined beds, and on beds with an inclination varying either in angle, in direction, or in both. If any bed or set of beds "striking" in a given direction, and "dipping" at a given angle, be broken through by a fault, the effect of the vertical "throw" is to produce at the surface the appearance of a lateral "shift."

Let us suppose Fig. 31 to be a horizontal plan of the outcrop of a set of beds, of which we may suppose *a a* to be a

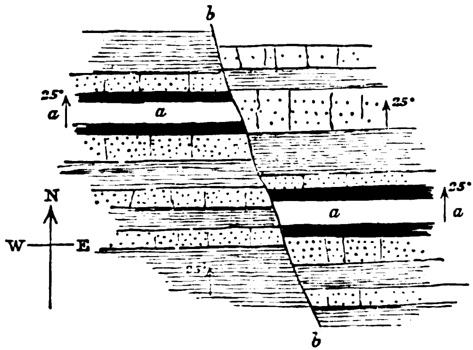

Fig. 31.

Fault traversing inclined beds, and producing apparent lateral shift. Plan.

limestone interstratified with sandstones and shales, and that they all dip steadily to the north at an angle of 25°, and that these beds are traversed by the fault *b b*, causing a "downthrow" to the east, or an "upthrow" to the west, which is the same thing. It is evident, then, that the outcrop of the beds will be farther south on the east side of the fault than they are on the west.

To render this more evident, let Fig. 32 be a diagrammatic section along the direction of the line of fault, showing the beds on both sides of it, and let us look only at the limestone *a a*, disregarding the other beds. If we suppose the part (*b*) dropped vertically down to (*c*), and the part (*d*) in the former continuation of the bed down to (*e*), it is clear that a vertical throw of the bed *a a* on one side of the fault will place it in the position *á á* on the other side of the fault, the respective outcrops of the two pieces of the same bed being at the present surface of the ground at the points *b e*. In other words, the apparently lateral shift of the outcrop of *a a* in the plan, Fig. 31, has been produced by the vertical throw of the inclined beds on opposite sides of the fault. It follows, also, that the higher the angle at which the beds dip, the less will be the apparent shift at the surface produced by the same

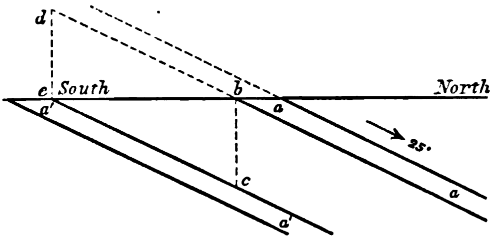

Fig. 32.
Diagrammatic section of Fig. 31.

amount of throw. In Fig. 33, the angle of inclination is increased to 60°, the vertical throw, or the distance between *b* and *c*, remains the same as in Fig. 32; but it is obvious

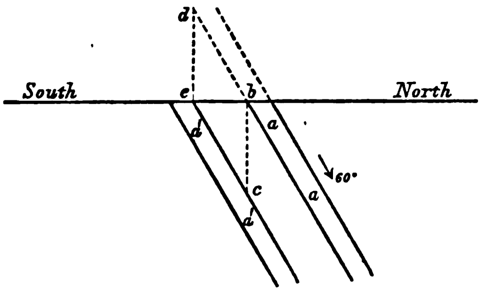

Fig. 33.

that the apparent lateral shift or distance between *b* and *e* is greatly diminished. This diminution would continue with the increase of the angle of inclination, until the beds were actually vertical, when it is plain that no amount of vertical throw could produce any apparent lateral shifting, for the ends of the beds in the opposite sides of the fault would merely slide up or down along each other. In a set of vertical beds, then, it would be almost impossible to detect a fault, however great may have been the real fissure and dislocation. On the contrary, when the beds lie at a very low angle, a very small dislocation shifts the outcrop of the beds in a very remarkable manner.

It is obvious, from an inspection of Figs. 32 and 33 that if we know the inclination of the beds, and the amount of the vertical "throw" of the fault, we may easily calculate what will be the apparent shift of their outcrop at the surface; and if, therefore, we find the outcrop of one, it will be easy to discover the outcrop of the other.

On the other hand, if we know the distance between the outcrop of the beds on opposite sides of the fault and their angle of inclination, it will be easy to calculate the amount of the vertical "throw," or to discover the depth (or distance, *b c*) at which the one part of the bed will be found lower than the corresponding point on the other side of the fault.

In practice, allowances have to be made for irregularity in the surface of the ground, and for variations in the angle of inclination of the beds, and also for changes in the amount of "throw" in the fault, but in the above consideration of the

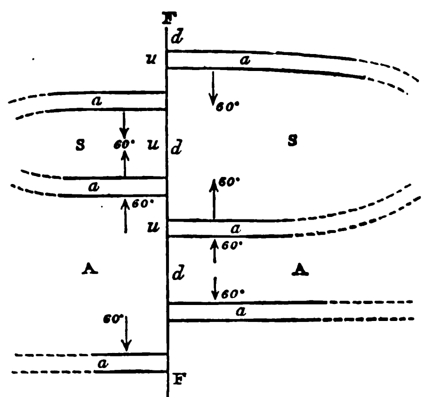

Fig. 34.
Fault across synclinal and anticlinal curves. Plan.

simplest case lie the elements of much practical utility in mining and other operations.

That this apparent lateral shift at the surface is really due to vertical elevation or depression, may be shown further by examining its effect on beds thrown into anticlinal and synclinal curves.

Let Fig. 34 be a plan in which *a a a* is a bed having a synclinal or basin-shaped depression at S S, and an anticlinal form at A A, dipping, as shown by the arrows, at an angle of 60° in each direction, and let it be traversed by the fault F F. It is clear that no lateral shifting will account for the places of the broken ends of *a a* on opposite sides of the fault, since they are shifted in opposite directions; while their present positions are easily and obviously accounted for on the supposition of a vertical elevation on the side of the fault marked *u u*, or depression on that marked *d d*, and a subse-

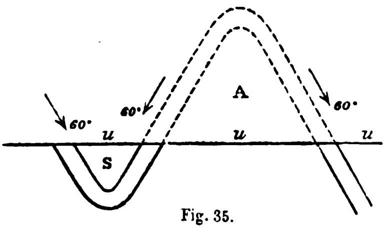

Fig. 35.

quent planing down of the whole to one level surface. If we draw two sections parallel to the fault, and on opposite sides of it, one, as in Fig. 35, along *u u*, the upcast side, and the

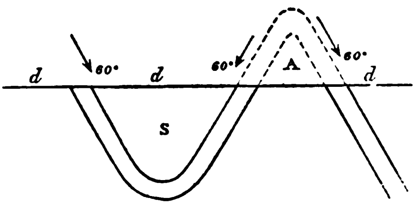

Fig. 36.

other, as in Fig. 36, along *d d*, the downcast side, putting in the beds with a dip of 60°, as directed by the arrows in the plan, we should at once see that, in Fig. 35, on the upcast side of the fault, the beds will meet below S, at a point much nearer the surface than they do in Fig. 36 on the downcast side; in other words, that the bottom of the synclinal is at a higher level in the first than the last case. In the same way the point A, where the anticlinal lines would meet if produced, is higher above the surface in Fig. 35 than in Fig. 36, or the whole of the bed *a a* is more nearly out of the ground in Fig. 35 than in Fig. 36. It is plain that these appearances are the result of the vertical elevation of the beds on one side of the fault F F in Fig. 34, or their vertical depression on the other side of it. The greater the throw on the downcast side the more widely will the outcrops of a synclinal curved bed be separated, and the more nearly will the outcrops of an anticlinal curved bed be brought together, while on the upcast side of the fault the reverse is the case, the outcrops of a synclinal curve will be brought together, and those of an anticlinal will be separated. When either the angle of the dip or direction of the strike of the beds vary along the course of a fault, its effect upon the position and form of their outcrop becomes equally various. This effect may be still farther complicated by a change in the amount of the "throw" of a fault in different parts of its course.

3d. We have hitherto supposed the fault to run directly across the beds, or nearly so, but some faults may either, in whole or in part of their course, run obliquely to the strike of the beds, instead of directly across it, and instances may

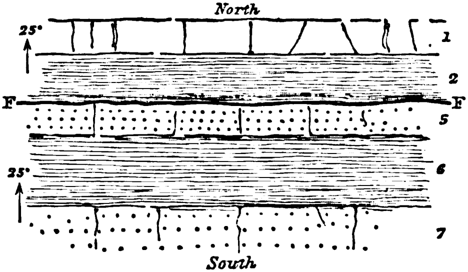

Fig. 37.
Fault along strike. Plan.

occur of dislocations even running along the strike, so as to entirely conceal some of the beds, as in Fig. 37, which is a plan, where the fault F F, running directly along the strike of the beds, conceals part of No. 2, the whole of 3 and 4, and part of No. 5, as may be seen by the section, Fig. 38.

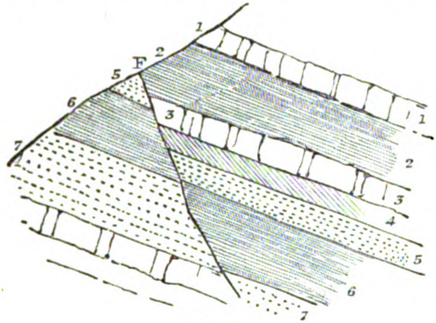

Fig. 38.
Section of Fig. 37.

If the magnitude or throw of the fault diminishes in one direction, we should have some of these beds coming out in that direction, as in Fig. 39, producing a slight variation in the strike of the beds.

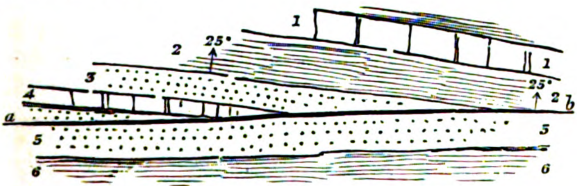

Fig. 39.
Fault along strike, with variation in throw. Plan.

Many other modifications may arise according to the variations in the direction of the faults, with respect to the strike of the beds, or in the amount of their "throw."

3. The number and association of faults also requires consideration in order to properly understand their effects.

If we suppose a single line of fault only to exist, it involves the assumption that the beds have been bent or bulged either upwards or downwards on one side of the fault, or upwards on one side and downwards on the other.

If in Fig. 40 we suppose the line *a b* to be a crack or fissure traversing a set of beds, or if we suppose it to be a crack in a plank of wood, or any other flexible substance, ending each way without meeting with any other crack or fissure,

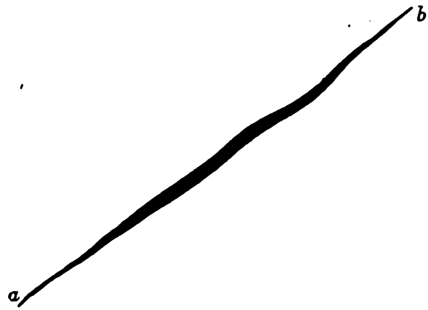

Fig. 40.

it is obvious that although the parts will be *severed* along it, they will not be shifted vertically unless some force be applied to push or bend upwards or downwards, as in Fig. 41, the part on one side of the fissure, while the other part is held fast, or pushed in the opposite direction.

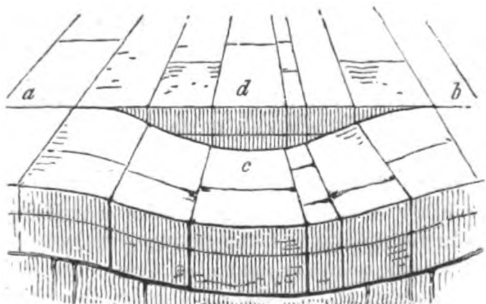

Fig. 41.

Single line fault, produced by bending of beds on one side of fissure.

In Fig. 41 some beds are supposed to be cracked by the fissure *a b* and the part *c* to have been bent down, but we might just as easily have supposed the part *d* bent up, or both operations to have taken place simultaneously. Without some such *bending*, no dislocation could have occurred.

Such "single line faults" have been produced, as is proved in coal-mining. They generally have one, but sometimes more points of maximum "throw" near the centre, and gradually diminishing each way till they die out. Not unfrequently they split towards one or both extremities, as is shown in the plan, Fig. 42, in which the main fault *a b* is

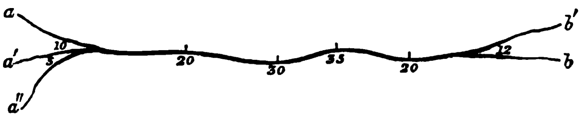

Fig. 42.
Plan of fault splitting at the ends.

seen to be split into three at one end and two at the other. The figures represent the amount of the downthrow at each point in feet, yards, or fathoms, as the case may be.

It is possible that this bending of the beds along the line of fault may occur more than once, so that they may be thrown into undulations, and thus more than one maximum throw may be produced. This undulation, too, may also become so great that the downthrow may change sides, as is

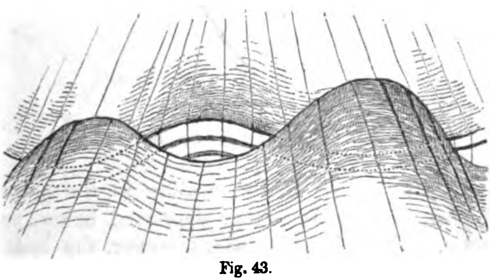

Fig. 43.
Single lined fault, with alterations of throw produced by undulations of beds along it.

attempted to be shown in Fig. 43. This actually occurs in nature sometimes, the fault appearing to die away when the beds come together, and then to set on again with a dislocation in the opposite direction. The Fig. 43, however, is to be taken as a mere diagram to help the explanation, and not as an actual representation of nature, where the undulations are rarely if ever so rapid. Single lines of fracture are probably in general much more extensive than the actual dislocated spaces, since such bendings and bulgings as are here shown to be necessary to cause dislocation, would be more likely to occur near the central portions of a fracture than near its extremities.

When there is more than one line of fracture, the fact of dislocation becomes more easy to understand, since there is no difficulty in conceiving that the angle, or corner of ground included between the intersection of two faults, has been dropped down below, or squeezed up above the corresponding beds on the outside of them. In the plan Fig. 44,

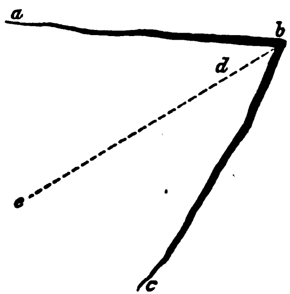

Fig. 44.

Dislocation by two fissures.

let *a b* and *c b* be two faults meeting in the point *b*, the included part, *d*, may be either depressed below, or raised above *a b c*. Even in this case, however, the beds on one side or other of the faults must be bent up or down in the direction of *e d*, because, as the two faults end or die out at *a* and *c*, the whole of the beds must be on the same level there, and one part or other must change that level in proceeding in the direction *e d*.

There is a modification of this case shown in Fig. 45, where we have one long continuous fault A B, with one or more lateral branches, *c d*, *e f*, *i k*, etc. proceeding out of it, or leading into it, as we may choose to consider them, and

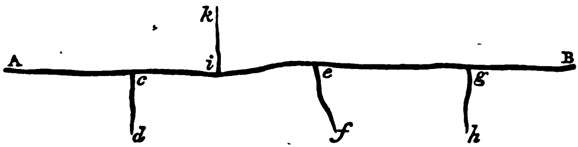

Fig. 45.
Great fault with lateral branches. Plan.

either on one or both sides of it. In this case, while the whole mass of ground is thrown down on one side of A B, with respect to the other, the particular portions between *c d*, *e f*, or the corners between any one of them and the main fault may have additional minor dislocations of their own.

A long powerful fault is often composed in the whole, or part of its course, of a number of parallel fissures very close together, along a narrow band of country, breaking the rocks into a corresponding number of steps, as in Fig. 46, which either "throw" all in the same direction, or having some

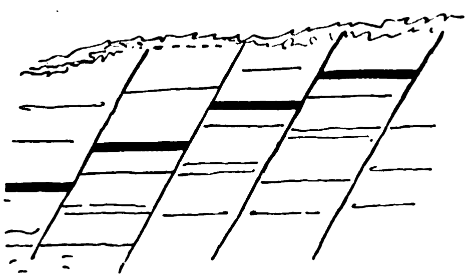

Fig. 46.
Step faults.

steps in opposite directions, produce a balance of "throw" in one direction, so that it is treated as one wide fault.

In order to have any mass of beds entirely cut off on all sides from those that surround them, and wholly depressed below, or raised above them on every side, it is obviously necessary that we should have at least three straight faults, or one or two curvilinear faults surrounding the fractured piece of ground. Such dice-like masses of ground let in bodily among a strange set of beds do occur in nature, though they are very rarely met with.*

Faults and fissures are sometimes vertical, as at A, Fig. 47, but more commonly inclined at various angles, even so low in some instances as 20°, as at B, Fig. 47.

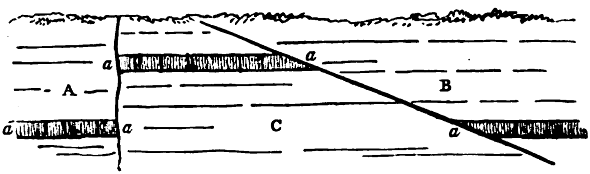

Fig. 47.

Varied inclination of faults.

In speaking of the inclination of a fault, it is better not to use the term "dip," as if it were a bed, but to adopt that of "hade" or "underlie." In inclined faults, and it almost always happens that faults are inclined, there is one nearly invariable rule, which is, *that the fault "hades" or "underlies" in the direction of the downthrow.*

As a corollary of this rule also, another equally important one may be stated, namely, that however inclined may be the fault, *no part of any bed will ever be brought vertically under another part of it*, and therefore superior beds can never be brought *by any* fault under those originally below them.

Small exceptions to these rules may sometimes occur in rare instances; when they do, the fault that produces them is called a *reversed fault.*

In Fig. 47, for instance, the fault between B and C hades under the downcast piece of the bed (*a a*); and it is obviously impossible for a vertical fault, or one inclining in the proper direction, to bring any part of the bed *a a* vertically

* In the neighbourhood of Bunmahon, in county Waterford, detached masses of Old Red sandstones are let in among the Silurian rocks, so as to be entirely included by them on every side.

beneath another part, and consequently no part of the beds above *a a* can ever be brought underneath it.

I have never myself met with any exception to this rule, except on a very small scale, and where it might easily happen that the exception was more apparent than real, the apparent inclination of the fault being merely a local bend or indentation in a vertical or nearly vertical fault.

The reason of this rule is sufficiently easy to understand when we come to look at faults on the large scale. Suppose that in diagram, Fig. 48, we have a portion of the earth's

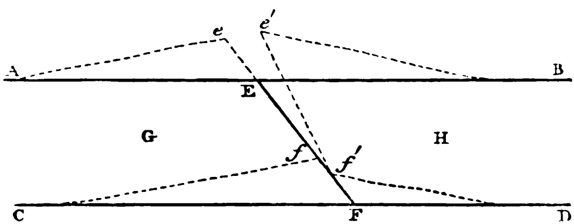

Fig. 48.

crust, of which A B is the surface, and C D a plane acted on by some wide-spread force of expansion tending to bulge upwards the part A B C D. If, then, a fracture take place along the line E F, it is obvious that the expanding force will on the side of A C have the widest base, C F, to act upon, while it will have a proportionately less mass to move in the part A E C F which grows gradually smaller towards the surface, than on the other side of the fault, where with the smaller base F D, the mass F D B E continually grows larger towards the surface. The mass G will consequently be much more easily raised into the position A *e* C *f*, than the mass H into the position D *f'* B *é*, the elevation of which could hardly take place without leaving a great open gap along the line of fault between F E and *f' é*, and, moreover, without leaving the projecting piece *é* overhanging without any support.

This is yet more clearly perceptible if we suppose two such fissures, as in Fig. 49, inclining towards each other, since if we suppose the included piece I to be elevated into the position indicated by the dotted lines, it becomes utterly unsupported unless we suppose huge dykes or ejections of igneous rock to issue out along each fault. But this would remove the case from the class of fractures we are at present considering.

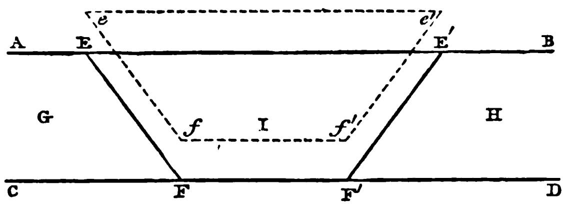

Fig. 49.

In another case which we might imagine, that of two parallel faults inclining in the same direction, as in Fig. 50; the included piece I might be elevated without leaving an open fissure, but still the part *I* would overhang in an unsupported condition, and the enormous friction along two sides of the piece I would have to be overcome. I am not aware indeed of any case similar to this having been even supposed by any one.

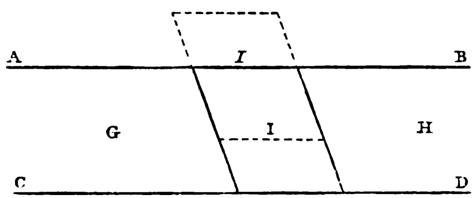

Fig. 50.

Professor H. D. Rogers, in his paper on the "Laws of Structure of the more disturbed Zones of the Earth's Crust" (*Trans. Royal Soc., Edin.*, vol. xxi. p. 3), in describing faults along the axes of anticlinal curves, where inversion has taken place on one side of the anticlinal, speaks of the uninverted part of the anticlinal having been thrust up the inclined plane of the fault, over some of the inverted beds, as in Fig. 51.

Professor Rogers does not allude to the fact of this form producing a *reversed* fault, nor is it quite clear in his paper whether the structure thus described has been absolutely observed in sections, or is merely introduced hypothetically as an explanation of certain puzzling phenomena. If actually observed, a detailed description of the locality would be very interesting, neither am I prepared to combat the hypothesis, if it be one, since it is just in such greatly disturbed districts that "reversed" faults are likely to occur.

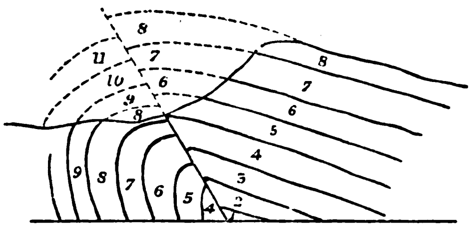

Fig. 51.

Inversion, with reversed fault.

Another published example of a reversed fault on a large scale is given in the Rev. Professor Haughton's paper on the "Mining District of Kenmare."—(*Journal Geological Society, Dublin*, vol. vi. p. 2.) In this case also, no notice is taken of the fault, as drawn, being a "reversed" one; and though it is in a highly disturbed district, and running parallel to the axis of a synclinal curve, yet as its plane does not coincide with that axis, but cuts across it obliquely, and buries some of the upper rock under the lower in a very peculiar manner, it appears to me a far less probable form of fault than that described by Professor Rogers.

Faults ordinarily extend indefinitely downwards. We cannot comprehend the possibility of fracture and displacement having taken place in any uncontorted set of beds without all those below having been equally disturbed, unless we come to a part where another fracture occurs, producing an equal amount of displacement in an opposite direction. This junction between two opposite faults produces what is often called a "trough," the faults being called a "pair of trough faults." The opposite faults of a trough may be either unequal in "throw," as *a c* and *b c*, in the trough A, or equal, as *d e*, *f e*, in trough B. In the former case, the displacement affects the whole mass of the surrounding rock, as may be seen by tracing the bed X through the dislocations; in the latter case, it only affects the mass B, which is in-

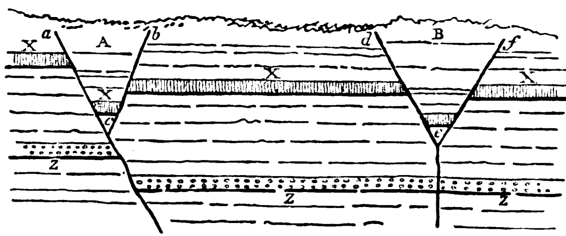

Fig. 52.

Trough faults.

cluded between the faults. In the latter case, we may see that the bed X on the outside of the trough B is on the same level on both sides.

The mode of explanation of these trough faults that seems to me the most probable, if not the only one, is the following:

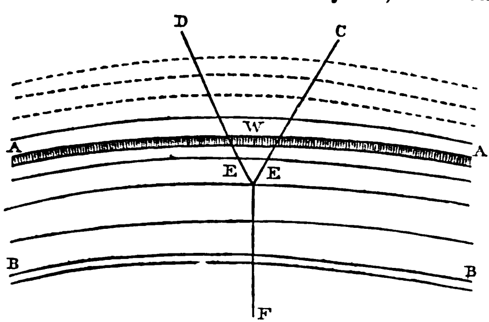

Fig. 53.

Suppose the beds A A, B B, etc., to have been formerly in a state of tension, arising from the bulging tendency of an internal force, and one fissure, F E, to have been formed below, which on its course to the surface splits into two, E D and E C, as in Fig. 53. If the elevatory force were then continued, the wedge-like piece of rock W, between these two fissures, being unsupported, as the rocks on each side separated, would settle down into the gap, as in Fig. 54. If the elevatory action were greater near the fissure than farther from it, the single fissure below would have a tendency to gape upwards, and swallow down the wedge, so that eventually this might settle down, and become fixed at a point much below its previous relative position. Considerable friction and destruction of the rocks, so as to cut off the corner *g h* (Fig. 54) on either side, would probably take place along the sides of the fissures, and thus widen the gap, and allow the wedge-shaped piece W to settle down still farther.

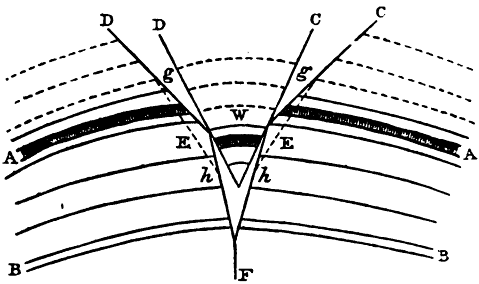

Fig. 54.

When the forces of elevation were withdrawn, the rocks would doubtless have a tendency to settle down again, but these newly included wedge-shaped, and other masses, would no longer fit into the old spaces, so that great compression and great *lateral* pressure might then take place.

The reader must recollect that the Figs. 53 and 54 are mere diagrams to assist his comprehension, and not actual representations, in which there would necessarily be introduced a much greater amount of irregularity and complexity. This may be seen by an inspection of Fig. 55, at the end of the volume, which represents the commencement of a trough fault, on the small scale, in the middle of the thick coal of South Staffordshire. This was carefully drawn to scale by a competent observer, Mr. Johnson of Dudley, and will show that fractures similar to those just spoken of actually occur in nature, and what are the circumstances attending them.—(*See Records of the Geological Survey*, vol. i. part 2, p. 313). In this Fig. the coal, C C, has apparently once been more completely arched, and on the cessation of the elevatory action, has tended to settle down again. The insertion of the wedge-shaped piece of the upper beds A has prevented its gaining the original horizontal position; but the pressure of the superincumbent mass has caused it to crack in various places, and the part of the coal next the wedge B B was completely crushed, and its grain or lamination and internal structure destroyed by the compression under which it suffered, being reduced to a state as if made of "a paste of coal-dust and very small coal."

The late Sir H. De la Beche once mentioned to me a modification of a trough fault among the dislocated rocks of Cornwall and Devon, in which the line of junction of the faults, or bottom of the trough, instead of being horizontal, was inclined, and the wedge-shaped piece had probably slided laterally down the trough. Such a case might doubtless occur among hard rocks, in which the fissures were smooth and straight, and great dislocation took place on the side of the lower end of the trough, to allow of room for the motion of the included wedge-shaped piece.

Examples of "trough faults" are by no means uncommon in disturbed coal-measure districts, and are doubtless equally common elsewhere, where they cannot be detected. Their study is instructive, as giving us often more accurate ideas than we should otherwise possess as to the nature of faults.

We have already seen, in tracing faults superficially along what may be called their lateral extension, that it is impossible to conceive displacement to occur except in consequence of a second fault meeting the first, or in consequence of a bulging of the beds along a part of the line of the fault.

Similar reasoning will apply to the vertical extension of a fault.

Mr. W. Hopkins has shown us that fractures in the crust of the globe have taken place in obedience to certain mechanical or physical laws. If a tract of country of indefinite length and breadth, composed of a set of nearly homogeneous beds, supposed to be originally horizontal, and nearly equally tenacious all over, be acted on by an expansive force from below, such as an elastic gas or a molten fluid would exert, those beds will be strained so as to tend towards bulging upwards, until a number of parallel fissures are formed, commencing at points below the surface, and running up to it. They may be crossed either then or subsequently by another set of parallel fissures at right angles to the first set. These are the normal results which may, in actual fact, be complicated by many irregularities arising from conditions different from those which were assumed.

It seems to follow from these results, that for displacement to have taken place among the fractured masses, two or more faults should meet below, so as entirely to sever the masses from each other, and allow of unequal motions being communicated to them, or that faults should gradually end downwards on the surfaces of highly curved, undulated, and contorted beds.

The intrusion of igneous rock will in some instances increase the dislocations; but the student must be on his guard against attributing to local intrusion of igneous rock, effects of elevation, or contortion, or fracture, which are due probably to very widely extended accessions of heat expanding large masses of rock of all kinds simultaneously over great countries, and the subsequent contractions when that heat is diminished or taken away. Small local intrusions of igneous rock act principally as stays and wedges to prevent the dislocated beds settling back into their former places, but can rarely be looked on as the actual causes of disturbance. When we come, indeed, to consider large intrusions of great granitic masses into the rocks above them, we see a fertile source of dislocation, first, by the expansion of the superior rocks from the mere protrusion of the bulk of the molten mass, and afterwards from contraction in consequence of the cooling of that mass, which contraction, as we have already seen, p. 84, might amount to even one-fourth of its bulk.

Where any large mass of matter, too, has been ejected over the surface of the ground, the withdrawal of its bulk will have tended to leave a void space in the interior, which, if it were not filled up with other igneous matter, would be followed by subsequent sinkings and dislocations of the rocks over it.

IV.—*Mineral Veins, the result of Cavities formed by Dislocations.*

In studying faults, our object was principally to describe their effect in dislocating the beds which they traverse; the form, the width, and the extent of the fissures themselves was only noted as affecting the beds; and the contents of the fissures, when any spaces or cavities existed between their walls, was scarcely spoken of at all.

It was shown, however, that when faults traversed hard rock, they must necessarily, unless the fissure be a perfect plane, be more or less open in places, some portions of their walls being kept apart by the protuberances of other parts. It was said also, that fragments of the fractured rocks were often found in the fissures, and these fragments must necessarily contribute to keep the sides of the dislocated portions apart from each other.

Now, in some districts, these more or less open faults and fissures have become the repositories of minerals that have been subsequently introduced into them.

These minerals are usually in a crystalline form, and consist commonly of quartz, calc, heavy, fluor, and other *spars*, together with the *ores* of one or more metals, such as lead, copper, tin, iron, zinc, antimony, mercury, silver, gold, and platina.

Fissures containing minerals in this form are called "mineral veins," or "lodes."

Spars and ores, however, are not confined to fissures such as we have been describing. They are found occasionally in all kinds of cracks and cavities, whatever may have been the cause of the hollows, and even in little nests, lining detached holes, often no larger than the fist, and entirely surrounded by solid rock. They are found also in long pipe-like hollows in limestone, which are due apparently to the eroding action of acidulous waters; in the interstices between beds and joints similarly or otherwise enlarged, as well as in cracks, resulting from desiccation in the middle of nodules. Those in pipe-like and irregular cavities are called "pipe veins," as distinguished from "lodes," which are also called "rake veins." Wherever, indeed, permanent hollows and interstices of any kind, size, shape, or origin, exist in hard rocks, and where they are kept open for great periods of time, there appears to be a possibility, and, in particular districts, a probability, of crystallized minerals, spars, and ores, being formed in them.

That they occur most frequently and in most abundance in such fissures as we have described under the head of faults and dislocations, is due probably to the great range and extent of those fissures, and to the fact of their necessarily having many hollows and cavities throughout that extent wherever they traverse hard and solid rocks.

There is also another reason why the quantities of crystallized minerals should be greater in such fissures than elsewhere, and that is, that any subsequent disturbances in the mass of the rocks will tend to produce subsequent motions along the lines of the old fissures, and thus form additional cavities, which may be filled up by fresh accessions of spars and ores.—(See *Geological Report on Cornwall, etc.* by Sir H. T. De la Beche, p. 344, etc.)

I have already said that faults, and therefore mineral veins, are sometimes perpendicular, but more often inclined. This inclination, however, is generally a high one—more often above than below an angle of 45°. Now, any subsequent fractures and dislocations which may traverse the original faults or veins, will shift or displace their course at the surface of the ground, just as if they were similarly inclined beds. What has been said, therefore, at p. 221 as to the apparent lateral shifting of inclined beds being due to vertical elevation or depression, will also be true with regard to the intersection and shifting of veins. If, in Figs. 31, 32, and 33, *a a* be a vein instead of a bed, the explanation of the positions at the surface of the various parts of it will equally hold good.

In studying the intersection of fissures or veins, however, it may happen that the apparent shifting at the surface may not be due to any dislocation of one vein by the other at all. They may both have been produced simultaneously, one or the other not having been continued exactly in the same straight line. It may happen, too, that, instead of *b b'* having cut through and shifted *a á* (Fig. 56), *b b'* may have been the first formed, and that when *a á* was subsequently produced, it ran along *b b'* for a certain space before it was continued into the "country" on the other side of it.

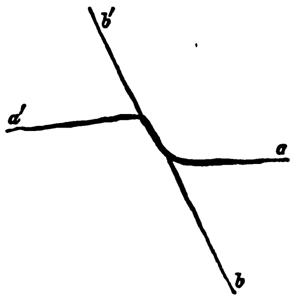

Fig. 56.

Great care, therefore, is necessary in examining the intersections of mineral veins, before deciding on the relative age or on the exact nature of the dislocations that have caused or affected them. Having said so much here as to the connection of mineral veins with faults and dislocations, we shall defer their further consideration to a future place.

V.—*Cleavage. Another result of the physical forces brought to bear on rocks subsequent to their consolidation.*

We have now described three kinds of divisional planes traversing rock—those, namely, which we might call *congenital*, or planes of lamination and stratification; those which are necessarily *resultant* on consolidation or joint planes; and those which we may term *accidental*, such as fissures, faults, and veins. There is yet another kind to be described, which we may call *superinduced* planes of division; and these are planes of "cleavage" and "foliation."

By "cleavage," or "transverse" or "slaty cleavage," as it is sometimes called, we understand a tendency in rocks to split into very thin plates, having a certain given direction over wide areas independently of any original lamination or stratification of the rocks. It is a structure which is most especially remarkable in clay slate, but is sometimes apparent in sandstones and limestones. Where it exists it is always most perfect in the finest grained rocks, splitting them into

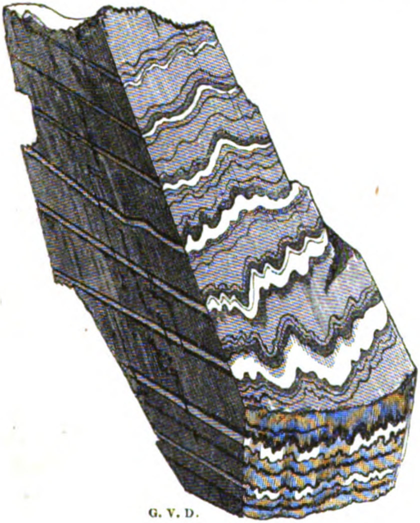

Fig. 57.

Portrait of a block of variegated slate from Devil's Glen, county Wicklow. The crumpled horizontal bands are the beds, the fine perpendicular striæ in front, are the cleavage planes, the fine lines on the darkened side merely represent *shadow*, and must not be taken for planes of division in the rock like those in the front which do not pass through the white bands.

an indefinite number of thin leaves or plates, perfectly smooth and parallel to each other. The coarser the rock, the fainter, the wider apart, and the more rough and irregular do the cleavage planes become.

This cleavage may either coincide with the original lamination of the rock, or cut across it at any angle. When it cuts across the bedding of the rock, the original lamination, or tendency to split along the planes of deposition, is generally obliterated, the laminæ being sealed up, or, as it were, welded together. This cementation of the original plates of lamination is not quite invariably the case. I have met with at least one instance where the rock, an indurated shale, split as readily along the original lamination as along the cleavage planes, and was thus minced into long, needle-shaped spiculæ of slate.—(*Report of Geological Survey of Newfoundland*, p. 75.)

Transverse cleavage in sandstone usually divides the rock into coarse slabs only, the upper and under surfaces of the sandstone often breaking into dog-toothed indentations. In traversing conglomerates, the cleavage planes leave the pebbles standing out in relief, and do not cut through them as joint planes do.—(*Professor Sedgwick.*)

Cleaved limestone generally has the original bedding greatly obliterated and obscured; the slabs are thick and uneven, and their surfaces often coated by argillaceous films, sometimes giving to the cleavage the exact appearance of bedding. Among trap rocks, some very fine-grained felstones are occasionally affected by cleavage, and fine-grained feldspathic and hornblendic ashes are often so affected.

The direction of cleavage planes is generally constant over considerable areas, retaining the same compass-bearing through whole mountain chains, or across large countries, without paying any regard to the contortions and convolutions of the rocks. One of the best examples of this steady direction in the strike of the cleavage planes is the south of Ireland, over the whole of which, from Dublin to the Mizen Head and the Dingle Promontory, the direction of the cleavage never varies 10° from east 25° north, whatever rocks it traverses, and however different these rocks may be in lithological character and geological age.

This steady direction generally coincides with that of the main lines or axes of elevation and disturbance which traverse the district, and consequently with the "strike" of the beds.

The inclination of the cleavage planes varies from perpendicularity to within a few degrees of horizontality, but has no apparent reference to the dip or inclination of the beds.

In passing through beds of different texture, the cleavage planes often vary their angle a little, having a tendency to strike more perpendicularly across the coarser than the finer grained beds. When the inclination of the cleavage planes and that of the original planes of lamination become nearly coincident in any locality, they sometimes appear to coincide entirely, as if the cleavage went a little out of its way, as it were, to coincide with the bedding.

The finest and largest roofing slates seem to be those of a bluish grey or pale green colour. Where they become either very red or quite black, they are more brittle, and more readily decompose, owing probably to the presence of peroxide of iron in the one, and carbonaceous matter in the other. Bands of colour, such as faint red, green, white, or grey, may sometimes be observed on the sides of slates, often coinciding with slight changes of grain or texture. These, which are called the "stripe" of the slate by Professor Sedgwick, mark its original stratification. The bands in the block, about 18 inches in height, which is figured in Fig. 57, shows this stripe very well. The white bands are pale greenish, or greyish fine-grained grit—the intermediate parts being purple slate of various tints and degrees of colour. They are the original laminæ of deposition of the rock. Irregular blotches, however, of different colours, occasionally occur; and sometimes even pretty regular broad bands of colour are to be seen, which do not coincide with the bedding, but go sometimes directly across it, as proved by beds of sandstone interstratified with the slate. Care must be taken, therefore, in field observations, not to rely too implicitly on mere bands of colour in slate rocks.

Professor Sedgwick was the first to systematically observe and describe the phenomena of slaty cleavage. His observations will be found in the *Transactions of the Geological Society*, vol. iii., on *The Structure of large Mineral Masses*, and also in his *Introduction to a Synopsis of the British*

Palæozoic Rocks, 3d Fasciculus, p. 33. In the latter, he gives the following as the results at which he had arrived :—

"1st, That the strike of the cleavage planes, when they were well developed, and passed through well-defined mountain ridges, was nearly coincident with the strike of the beds.

"2d, That the dip of these planes (whether in quantity or direction) was not regulated by the dip of the beds, inasmuch as the cleavage planes would often remain unchanged, while they passed through beds that changed their prevailing dip or were contorted.

"3d, That where the features of the country or the strike of the beds were ill defined, the state of the cleavage became also ill defined, so as sometimes to be inclined to the strike of the beds at a considerable angle.

"4th, Lastly, that in all cases where the cleavage planes were well developed among the finer slate rocks, they had produced a new arrangement of the minutest particles of the beds through which they pass."

One of the most striking effects of cleavage is the distortion it produces on fossils or other small bodies embedded in the rocks, lengthening and pulling them, as it were, in the direction of the cleavage, and contracting them in the opposite direction. Relying on these facts, which were first distinctly noticed by Professor John Phillips, Mr. Sharpe attributed the production of cleavage to the action of great forces of compression squeezing the particles of rock in one direction, and lengthening them in the opposite.—(*Quarterly Journal Geological Society*, vol. iii. p. 87.) Mr. Darwin also, from his observations in South America, formed similar ideas as to the origin of cleavage, and speaks of cleavage planes as being probably parts of great curves, of such large radius as that any portions of them that can be seen at one view appear to be straight. More recently, Mr. Sorby, resting on the fact of beds of sandstone which occur in slate being contorted, and their dimensions being contracted at the sides and expanded at the tops and bottoms of the curves, the axes of which curves coincide in direction with the cleavage planes, while the beds of slate above the sandstone are little or at all bent, shows that the particles of the slates must have been compressed at right angles to the cleavage planes, and lengthened along them, so as to allow of their being squeezed into the same contracted space as the sandstones, without much bending of the surfaces of the beds.—(See *New Philosophical Journal*, 1853, vol. lv. p. 137; or *Lyell's Manual*, 5th edition, p. 611.)

By microscopical examination, Mr. Sorby found that the minute particles of clay-slate were either lengthened in the direction of the cleavage planes, or that those minute particles, which were of unequal dimensions, were so re-arranged as that their longer dimensions coincided with the planes of the cleavage.

Professor Sedgwick at one time thought that he could perceive a tendency to a symmetrical arrangement of the inclination of the planes of cleavage with respect to the axes of lines of elevation, the dip of the cleavage being inwards on each side of the mountain ranges. He afterwards, however, saw reason to abandon this conclusion. Mr. Darwin speaks of the fan-like arrangements of the cleavage planes which have been described by Von Buch, Studer, and others; and Mr. Sharpe says that this apparent fan-like arrangement is due to parts of two contiguous curves meeting where their adjacent sides become perpendicular. But we must refer the reader to his papers on this subject, in the third and fifth volumes of the Journal of the Geological Society before quoted, and in the Philosophical Transactions for 1852. A second cleavage plane cutting across the first at right angles, and also across the bedding, is described by Mr. Sharpe in his second paper on cleavage in the Geological Journal, vol. v. p. 3, and was also long before observed and mentioned by Professors Sedgwick, Phillips, and others. Mr. Sharpe attributes this likewise to compression.

The subject has recently been investigated by Professor Tyndal, who, in a paper in the Philosophical Magazine, vol. xii., distinctly refers the origin of cleavage to the same force of compression, acting at right angles to the cleavage planes, that Mr. Sorby and Mr. Sharpe had referred it. Professor Haughton, in a paper in the same volume, has deduced mathematically a value for the compression of the rocks, from examining the amount of distortion suffered by fossils in some particular instances in consequence of this compression.

There seems indeed now little doubt that mechanical compression is the true cause of cleavage; but the whole subject requires still more accurate and detailed observations than have yet been made on it. I have seen reason to suspect—in some districts of North Wales, for instance—that subsequent movements and dislocations have affected large cleaved districts in such a way as may have altered both the dip and strike of the cleavage from their original position. Direct observation then, now, will only lead us astray, unless it be corrected by a more accurate knowledge than we yet possess of the amount and direction of these dislocations, and of their relative age compared with that of the cleavage. The dip of the cleavage especially is very easily mistaken, unless it be observed in very clear and deep excavations. Superficial causes have frequently affected and sometimes completely reversed it to very considerable depths, as may be seen in Fig. 58.

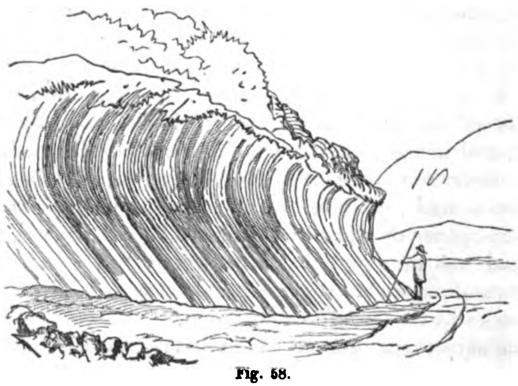

Fig. 58.
Surface bending of cleavage planes.

When these superficial bendings of slate occur on steeply inclined ground, they may perhaps be referred to the action of gravitation on substances loosened by weathering, or the "weight of the hill," as it has been called. In other cases their origin is more obscure, and I have seen one instance in

North Wales, where, on the horizontal surface of an isolated boss of rock, the slates were so sharply and abruptly bent back and laid nearly flat, and partly consolidated in that position, as to give the idea of its being due to some sudden and great force, such as the grounding of an iceberg.*

Thoroughly to work out the subject of the "cleavage" of any district would require months of continuous and laborious observation in a country, the geological structure of which had in other respects been thoroughly and accurately surveyed; and, with the exception, perhaps, of North Wales, no country has yet been surveyed with anything like an approach to such accuracy.

It must be recollected that it is one thing to arrive at a conclusion as to the cause of cleavage, and the laws of its production, and another to ascertain those laws or general rules of occurrence of cleavage planes in nature. The first may be done in the closet, or the museum, as has been done by Sorby, Tyndal, and Haughton, but the latter can only be done by the field surveyor, and that *after* and not contemporaneously with the general survey of the country.

VI.—*Foliation.*

The *foliation* of the *schists* appears to be equally a superinduced structure with the *cleavage* of *slates*. It is, however, quite clear that even if the cleavage of slates have a mechanical origin, the foliation of schist cannot be due to such a cause alone. Mechanical pressure may be readily supposed to communicate a certain mechanical texture, but cannot by itself cause a difference in chemical composition. Now, foliation is defined by Mr. Darwin, to whom we owe the recent technical use of the term, first introduced by Professor Sedgwick, to mean "a separation into layers of different chemical composition," while cleavage means only a "tendency to split," in a mass of the same composition.

Nevertheless, the folia of schist are in some districts

* Without intending to impeach the accuracy of any recorded observations, I yet cannot feel sure that many even of my own registered observations on cleavage in different localities may not be affected by errors of the kinds alluded to above.

arranged in certain given directions by compass over very wide areas. Mr. Darwin says that the gneiss and mica schist of South America, for instance, have their layers or folia always arranged in a certain given direction, even for hundreds of miles. For three hundred at least in the Chonos and Chiloe islands, it does not vary a point of the compass from N. 19° W. and S. 19° E. Over the eastern parts of Banda Oriental the foliation strikes N.N.E. and S.S.W., and over the western parts W. by N. and E. by S. In Venezuela, according to Humboldt, it is uniformly N.E. and S.W.—(Darwin, *Volcanic Islands*, p. 163.)

According to Mr. Sharpe (*Transactions Geological Society*), the foliation of the gneiss and mica schist strikes across Scotland in directions varying from N. 50° E. in the south of the Highlands to N. 25° E. in the north. The dip of the folia of schist resembles that of the dip of cleavage planes, in being much more uncertain in direction and quantity than that of the strike.

Some geologists have held that gneiss, mica schist, etc., were originally formed nearly as they are now, being the direct result of the erosion of granitic rocks, of which the quartz, feldspar, and mica were arranged in regular layers as we now find them, the only change having been a mere consolidation or induration. The perfect parallelism of these layers, however, over such wide areas as those before mentioned, would of itself be against this supposition, and in favour of the rearrangement of the particles of the rocks, in obedience to some wide and general force.

As to the nature of this force, Mr. Darwin and Mr. Sharpe, as well as Professor Sedgwick, agree in looking on foliation as the extreme term of cleavage, "that foliation and cleavage are parts of the same process; in cleavage, there being only an incipient separation of the constituent minerals; in foliation, a much more complete separation and crystallization." If, however, this be true, I do not see how this process can be the merely mechanical one to which we have just seen reason to assign the production of cleavage.

Mr. Darwin even appears to look upon many of the great divisions in foliated rocks, which are ordinarily termed beds or strata, as merely farther results of the process, different mineral substances having been segregated from each other on the large scale.

In large greatly altered districts, however, the very amount of the alteration has so completely changed the character and texture of the rocks, that it is more difficult to detect that it is a change, than in other districts, where the alteration having taken place on a smaller scale, and to a less extent, its nature may be more readily grasped.

In the south-east of Ireland, one great mass of granite has been erupted through the clay slates of the district, forming a continuous range of granite hills from Dublin Bay to the neighbourhood of New Ross, a distance of 70 miles. Between this range and the coast, other smaller intrusive bosses of granite make their appearance at the surface through the clay slate rocks. The clay slates are dark-grey, blue, or black, but sometimes pale-green, or greenish-grey, with occasionally red or purple bands. They are generally of a dull earthy texture, and without lustre. Small bands of grey siliceous grit frequently occur in them.

Wherever the granite comes to the surface, a belt of slates surrounding it is converted into mica schist, with, in some few places, beds of perfect gneiss. Crystals of garnet, schorl, andalusite, staurotide, etc., make their appearance in these altered slates in greater and greater abundance as they approach the granite. The width of the metamorphosed belt is generally proportioned to the size of the granite mass which it surrounds. Round the smaller granite bosses it is sometimes not more than 50 yards wide; round the main granite mass it sometimes reaches to two miles. It matters not through what part of the slate rocks the granite rises, or which beds strike towards the granite; they are all found to be affected in the same way as they approach it.

In going towards the main granite ridge, it is found sometimes at a distance of two miles from the outcrop of the granite (which is, however, much nearer, probably in a vertical direction), that the slates have acquired a "glaze," as it were, or micaceous lustre, with a soapy feel. This lustre is apparent throughout the mass when the slates are broken, and even when they are ground down into sand or powder. This micaceous resemblance increases as we approach the granite, till at last distinct plates and folia of mica are to be seen,, and the whole assumes the ordinary character of mica schist, occasionally passing into a kind of gneiss.

Together with the micaceous lustre on the surface of the slates, the rocks often assume the puckered and corrugated structure of mica schist. I at one time thought that this corrugated structure might be a metamorphic one, like the foliation; but on examining localities where the small bands of siliceous grit were interstratified with the slates, I fonnd these grit bands to be equally corrugated and puckered. The structure, then, must be ascribed simply to a mechanical force compressing the rock laterally.

In the majority of instances, too, the folia of the mica schist, whether straight or puckered, were parallel to the grit bands, and therefore to the original lamination and stratification of the rock. In these instances, the micaceous folia were largest and best developed. In other cases, the foliation ran across the bedding, coinciding apparently with the cleavage, as remarked by Professor Ramsay in a similar case in North Wales. In these instances I generally found the micaceous folia short and discontinuous, being apparently interrupted by the changes of texture or composition in the original lamination of the rock. I could, however, easily conceive that where the rock was quite homogeneous, the folia of mica schist might be almost as extensive as the planes of clay slate.

Some of the beds of gneiss in this district are obviously beds of sandstoné, originally interstratified with the shales, the rocks having all the appearance of interstratified beds of shale and sandstone at a distance, and until they are broken open and found to be perfect mica schist and gneiss. Other gneiss beds are massive and thick-bedded, and containing large crystals of feldspar (apparently orthoclase) becoming quite porphyritib and completely mineralized, but still having a foliation parallel to what is apparently the original stratification of the mass, which in one conspicuous instance (near Graiguenamanagh) is nearly horizontal.

I do not think that the person most sceptical as to the fact of the metamorphic origin of mica schist and gneiss, could examine the rocks bordering the southern end of the granite range in Carlow, Kilkenny, and Wexford, without becoming a complete convert to the theory. For myself, I can no longer feel the slightest hesitation in accepting the metamorphic origin of all those which have been described under that head in Lithology, page 147, *et seq.*

VII.—*Denudation. A consequence of the Elevation of Rock.*

We have, in a previous section (see *ante*, p. 86), spoken of the erosive action of moving water upon aqueous rocks while in course of formation, and in treating of the formation of mechanically formed aqueous rocks, we have tacitly assumed the fact of great disintegration and erosion of previously existing rock, in order to afford the materials of which these mechanically formed rocks were composed. We have now also considered the general effects of disturbing forces in elevating aqueous rocks from the bottom of the sea into dry land, so far as regards the new positions into which these rocks have been thrown, and the divisional planes and dislocations which have been produced in them. We have, however, yet to study some other of the less immediate results of these elevating forces.

We have already alluded to the erosive action of the sea breakers, tides, and currents, along the margin of the land, and that of the atmospheric agencies over its whole surface. It is impossible for rock to pass from beneath the sea through the destructive plane of the sea level, without suffering loss in the process, that loss being greater in proportion to the slowness of the movement, or the length of time every successive horizontal margin of ground is kept within the influence of the waves. It is equally impossible for rock to exist as dry land without suffering loss from the action of the atmospheric agencies, that loss also being proportionate to the length of time it remains above the sea exposed to their influence. We are naturally apt to underrate the amount of these erosive agencies, because we see them to be small in any periods of time during which we can observe them, or have them recorded in history. We are naturally apt, on the other hand, when we look at the magnitude of their results, to suppose much more destructive agencies to have been formerly in existence than those we now see around us. When, however, we come to reason on the matter, we find it very difficult for any one to imagine what these agencies could have been if they are altogether different from "existing causes;" and equally difficult for any one to suppose existing agencies to have ever acted with much greater intensity than at present, unless we assume the general physical laws of the world (not to say of the universe) to have been altogether different from what they are now. It would seem to be necessary, for instance, to suppose the law of the attraction of gravitation, and the attraction of cohesion, in the erosive powers of running water, and the expansive force of heat, to have been different from what they now are. Because such is the balance between all the physical laws and forces that now act upon the globe, that it seems scarcely possible to imagine any change in one without a corresponding change in all the rest. But a change in these laws would also involve a corresponding alteration in the form and structure of organic existences. If, therefore, the forces of denudation had ever been materially different from what they are now, the size of fragments, the modes of accumulation, and the size and molecular structure of fossil animals and plants, would all have shown traces of that difference. Now, no such general adaptation to altered circumstances is apparent in rocks or fossils, either of old or of new periods; and there appears, moreover, to be far more extravagance in assuming such great and sweeping changes to have passed over the world, without leaving unmistakeable signs of their occurrence, than in merely allowing the time during which existing causes have acted to be indefinitely extended.

We shall therefore take it for granted, in accordance with the tenets of the Lyellian philosophy, that all geological effects are due to causes such as are now acting in some portion of the globe or other, or to some modification and combination of those causes, such as we may reasonably assume to take place now and again in the course of the earth's history.

To estimate aright the lapse of geological time, the observer, when he looks, for instance, into the bed of the mountain torrent, and sees it encumbered with blocks and boulders, against which the stream is continually fretting, must look forward to the period when this friction of the waters shall have worn down the rocks into fine sand or mud, and carried them onward to the ocean; and recollect that such a period is but one second of geological time, one beat of the geological clock, and the result of such an action but one stroke of the geological hammer, under whose repeated blows the very mountains themselves shall ultimately be removed and cast into the sea. He must be prepared to attribute to such seemingly insignificant and slowly acting causes, whether of the river or the breakers of the sea, all the precipitous valleys and ravines of mountain chains; all the erosion of rock which gives to elevated land its cliffs and precipices, its hollowed and indented surface; and yet greater effects even than these. For the amount of such denudation is to be exactly measured by the quantity of the mechanically formed aqueous rocks, and as our present lands show us vast sheets of sandstones and clays, hundreds and thousands of feet in thickness, hundreds and thousands of square miles in superficial extent; and every particle of these enormous masses of rock is the result of the erosion of previously existing rock, it follows that the amount of denudation which has affected the lower or older rocks, is something inconceivably great. Just as when we see a noble pile of building, we know that a hole or quarry must have been made somewhere in the earth equal, at least, to the cubical contents of the solid parts of that building; so, when we see a vast mass of mechanically formed aqueous rock, we must feel assured that a gap was made somewhere in the surface of the earth equal to the solid contents of those rocks.

The truth of these observations cannot be gainsaid; and we may therefore feel prepared for the belief in the occurrence of any amount of denudation, and of its having been entirely caused by such slowly-acting agents as we are now familiar with.

In examining the outcrop of a set of beds along the surface of the ground, either in "the field" or by aid of geological maps and sections, we must be often struck with the fact that the present terminations of the beds are not their former or original terminations. Beds rise successively to the surface, and end there abruptly, that were once obviously continued beyond or above the present surface of the ground. In Fig. 20, p. 210, the beds on the beach and those in the cliff are the same. It is clear that they have been cut down on the beach to their present level, and that before they were so cut down they rose upwards to the same height as those in the cliff. In the same way, those in the cliff itself, and which stretch from it into the land, formerly extended upwards to a greater height than they now do. Now in many instances we can tell how far they formerly extended upwards. In Figs. 24 and 25, the anticlinal and synclinal curves into which the beds are thrown enable us to estimate the amount of this cutting down or denudation for the beds there drawn. In Fig. 24, p. 215, we see that beds 2, 3, 4, bend continuously over No. 1; and we should naturally conclude that beds 5, 6, 7, 8, etc., once equally extended continuously over the anticlinal, A. If we doubted the fact, we should be convinced of it when we traced them in the map (Fig. 25), and found them gradually meeting and continuous over the anticlinal farther towards the north.

Similarly in the synclinal curve B, though we might suppose by the section that No. 13 was the highest bed, we should find that towards the north it was overlaid by beds 14, 15, etc.; and we should be compelled to conclude that the latter had once been continuous over the whole. The dotted lines in Fig. 24 would, if completely carried out, and bed 13 were represented as arching continuously over A, give us the measure of the amount of solid rock removed by denudation from above the present surface of the ground E F, so far as the beds there drawn are concerned.

It makes no material difference in this reasoning whether we suppose the spaces 1, 2, 3, etc., to represent single small beds of a foot or two in thickness, or groups of such beds, and suppose the whole series, 1 to 15, to represent a vertical thickness of many hundred or many thousands of feet.

Neither would it make any difference in our reasoning, so far as the amount of denudation is concerned, if we were to modify our conclusions by supposing, in all those cases in which great thicknesses are concerned, that the whole mass of beds were never continuous over the anticlinal curves *after* the total amount of elevation had been reached. We may suppose that soon after the elevation commenced, and simultaneously with the first arching of the beds, the denuding forces began to act, that they took advantage of the very first cracks that were formed to commence the erosive process, and that long before the bed No. 1 attained its present position on the axis of the curve, more or less of the higher beds 7, 8, or 12, 13, etc., had been removed, and a surface given to the rocks more or less approximating to the surface they at present possess.

Another very clear case in which we can estimate the amount of denudation is that of an "outlier," as it is called. It often happens that a number of beds, rising at a slight angle from beneath the surface, end in a steep slope or "escarpment," as at A in Fig. 59. In front of this escarp-

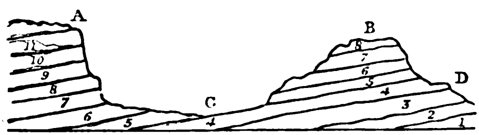

Fig. 59.

Escarpment and outlying hill.

ment there often rises an isolated hill as B. In descending the escarpment, we pass over the edges of the beds 11, 10, 9, 8, etc., in regular succession, and find 4 coming out from beneath them, and stretching continuously across the intermediate flat or valley, and forming the base of the hill B; and on ascending the side of B, we find the very same beds 5, 6, 7, 8, resting on each other in the same order as we saw them in the escarpment A, and at the same angle of inclination, so that the conclusion becomes irresistible that they were once continuous across the intervening space C. This space then is due to the erosive action which has removed the upper beds, and denuded or laid bare the lower bed No. 4, across the valley C, and for an indefinite distance on the other side of the hill B. We should feel quite certain that not only the beds 1, 2, 3, 4, but also 5, 6, 7, etc., had stretched across this space formerly, and had also extended beyond the hill B for some indefinite distance in the direction of D. This latter conclusion we should in many cases find confirmed by the occurrence, at a distance perhaps of many miles beyond B, in the direction D, of a locality where the beds dipping in an opposite direction from that in Fig. 59, these very same beds (1 to 8 of Fig. 59) are brought in again in the very same order and with exactly the same character as before. (See Fig. 60.) In some cases, such a little isolated basin forms the only remaining patch of the beds left in this new district,

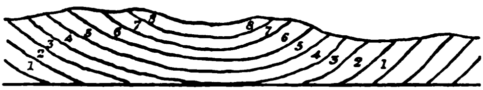

Fig. 60.
Outlying basin.

by having been dipped down below the level of the surface formed by the denuding agent, and remaining as a monument of their former extension over the wide intervening space between this new locality and that of the escarpment and outlier before mentioned.*

Geological maps of large countries often enable us to prove by such reasoning as this the former extension of a great mass of beds over very wide areas, and consequently the very large amount of denudation that has taken place. In many instances we can show the geological date of this denudation, that is, we can prove it to have taken place before the time when such and such beds were deposited, the age of which is known, and which we find lying across the edges of the denuded beds. This leads us to the next sub-

* For some striking details on the subject of denudation, see Professor Ramsay's paper on the Denudation of South Wales, etc., in Memoirs of the Geological Survey of Great Britain, vol. i.

ject of Unconformability. We must, however, always guard ourselves against attributing to the last period of denudation that occurred, with respect to any set of beds, effects, a large part of which perhaps took place at previous periods. Almost all lands have risen from the bed of the sea, not once only, but many times, having passed through many periods of alternate elevation and depression, suffering denudation at each passage through the upper surface of the sea, and during each period of existence as dry land. It appears probable, from the observations of Mr. Darwin and others, as also from the very nature of the case, that a period of slow and gradual elevation is the one most favourable to the action of the destruction of pre-existing rock, or to denudation, while a period of depression is that most favourable to the deposition and formation of new rocks on the surface of the old. Many districts, however, might be depressed without being covered by the deposition of new rock, or by so thin a skirt of it, that it might be easily stripped off during a subsequent elevation; and in every new period of elevation the erosive forces would most probably act again upon their old lines, deepening former hollows, and thus intensifying the previous features of the old lands on their re-emergence from the sea.

VIII.—*Unconformability. The result usually of elevation, denudation, and subsequent depression.*

When one set of beds have been elevated and denuded, and another set of beds are deposited on this denuded surface,

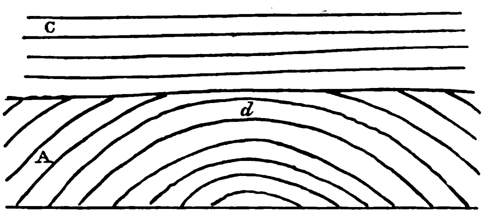

Fig. 61.
Unconformable beds.

the two sets are said to be *unconformable* to each other. In Fig. 61 the arched and denuded set of beds A are covered by the unconformable set of beds C. Whenever two sets of beds lie at different angles of inclination, they are *apparently, or obviously unconformable.* In Fig. 61 this discordance of inclination is seen strikingly at either end of the figure, but if we confined our attention to the central part *d*, we should not perceive any unconformability.

Beds, then, may repose apparently at the same angles over considerable spaces, and yet be unconformable in reality. In Fig. 62, again, two sets of beds, A and C, are shown, which

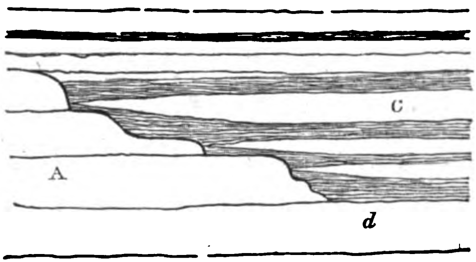

Fig. 62.

Unconformability in horizontal beds, in consequence of denudation of lower group.

are both horizontal, A ending in a broken cliff, with C abutting directly against it in that part, although it rests in apparent conformity on A at the point *d*.

The essential point in unconformability is that the upper group of beds shall rest upon different parts of the lower group at different places, and this could not happen without previous elevation and consequent denudation having affected the lower group. It proves, then, the lapse of a considerable interval between the deposition of the two sets of beds.

Now, although this interval may have been occupied by the process of destruction going on in one locality, there is no reason why production may not have been taking place at the same time in another locality. Whenever, then, we find two sets of beds unconformable to each other, we must suppose that there is a set of beds wanting there which may elsewhere be found, and that where they are found there will be probably no unconformability. If Fig. 63 represent the state of things at one locality, where the three sets of beds ABC were deposited in regular continuous succession, Figs. 62 or 61 may represent the other localities, where the inter-

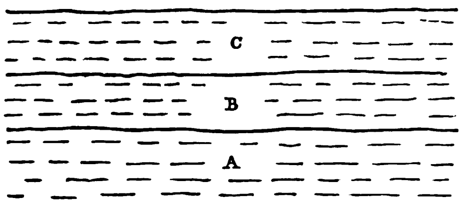

Fig. 63.
Three conformable sets of beds, A, B, C.

val here occupied by the deposition of B was there employed by the forces of elevation and denudation in the destruction of a previously existing part of A. It is even quite possible that the materials which were used in the locality represented in Fig. 63 in the composition of B, were partly derived from this destruction and breaking up of a portion of A in one of the other localities, and that we may accordingly find in B pebbles or angular fragments of A.

At the meeting of the British Association at Cheltenham, Professor H. D. Rogers proposed a set of terms which would have a good deal of convenience. If we call a set of regularly formed consecutive beds resting on each other a geological "sequence," we might then speak of

1. A conformable sequence.
2. A conformable nonsequence.
3. An unconformable sequence.
4. An unconformable nonsequence.

I should, however, be strongly inclined to deny the possibility of case 3, since the interval required for such an amount of slow elevation and denudation as would produce unconformity in any place, would necessarily be fatal to the production of a geological sequence, since it would be sufficient for the production of other beds elsewhere that would here be absent, and consequently the sequence here must be broken.

IX.—*Overlap. The result of depression, with or without previous denudation.*

There is a minor degree of unconformability to which the term overlap is applied. This consists in a greater extension of the superior set of beds than that possessed by those on which they rest, so that they overlap and conceal their edges. In Fig. 64 the beds 1, 2, 3, are successively overlapped by

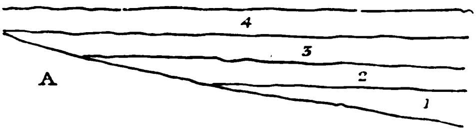

Fig. 64.
Overlap.

those above them. This may in some instances have been the result of a more partial deposition in the lower beds, from the defect of material or other cause, but in other cases it has been the result of the gradual depression of the old land, and the consequent extension of the area of water in which alone deposition can take place.

While unconformability, therefore, proves an elevation and denudation, and an absence of continuous deposition, overlap may take place in a perfectly continuous series, merely proving the fact of a depression of the area contemporaneously with that deposition.

CHAPTER VIII.

PETROLOGY OF THE IGNEOUS ROCKS.

WE will now consider the general forms and modes of occurrence of the principal kinds of igneous rock, and their relations to the aqueous rocks. I have previously spoken, under the head of Lithology, of the different kinds of igneous rock, and shown that these differences partly depended on the difference of their chemical composition, and partly on the texture resulting from the physical circumstances—as pressure and rate of cooling—under which their consolidation took place. The granitic rocks, or those which are most completely crystalline and most thoroughly saturated, as it were, with silica, cooled slowly and under great pressure, that is to say, at some considerable depth in the interior of the crust of the globe.

The volcanic rocks, on the other hand, were consolidated at the surface, while the intermediate and variable class which we have called trappean, may have been solidified under various and intermediate conditions.

I.—*Fundamental Granite.*

As a matter of fact, it has been found that in all parts of the globe, wherever the base of the aqueous rocks has been brought up to the surface and exposed to view, that base rests upon granitic rocks. By the "base of the aqueous rocks" is meant the lowest aqueous or sedimentary rocks known in the particular locality, *whatever may be their age*, whether they be some of the oldest known rocks, or whether they be of a much later date than those, and whether they retain their original characters unaltered, or have been metamorphosed into mica-schist, gneiss, or any similar rock.

It is by no means intended to assert that the converse of this is true, and that wherever granite is found at the surface, there the lowest of all known rocks, or even the lowest rocks of that particular locality, will be found reposing on it. On the contrary, we shall show presently that granite frequently comes *through* great masses of rock, without bringing them up along with it. But at every place where any rock does make its appearance at the surface *from underneath the lowest* of the *stratified* rocks known in that locality, that rock is a granitic one, and wherever any large mass of granite comes to the surface, we have no reason to believe that any other rock but granite would be found underneath it. I do not here speak of any veins, or intrusive dykes or sheets of granite, but of large, widely extended masses. In short, we have every reason to believe that if we pierced vertically downwards into the earth at any part of its surface whatever, we should eventually come either to granite or to yet molten and unconsolidated rock, which on cooling would form granite. Again, in many parts of the world granite is found occupying large areas of the surface; and we have no reason to suppose that any other rock but granite would be found under those surfaces, although, if we sank deep enough, we might perhaps come eventually to red-hot granite, and ultimately to yet molten granite. These facts and these opinions have naturally led many early geologists to the conclusion that the earth was a once molten globe of fiery matter, and that on cooling there was formed about it a primæval crust of granite; and they hence inferred that much of the granite now to be found at or near the surface was actually part of this primæval crust. At one time, indeed, it was held that all granite had this primæval character; but this notion has long been exploded, since *intrusive*, and therefore subsequently consolidated masses of granite, have been found penetrating rocks of almost all ages in different parts of the earth.

Now the hypothesis of the earth having once been a molten globe of fiery matter is one for which more or less good argument may perhaps be brought forward; but it is one with which the geologist has properly little or nothing to do. The geologist who wishes to reason safely may grant the probability or possibility of this molten globe having existed, of its having cooled down till a granitic * crust was formed about it, of the temperature having been gradually lowered till the existence of water and air become possible upon it, and yet maintain that no part of this primæval crust is now in existence, and that none of the rocks now open to our observation can date back their formation to this quasi-fabulous and mythical age of the earth, this pre-historic or pre-geological period of its duration.

Whatever may have been the nature of the primæval crust of the globe, that crust had been more or less completely destroyed and remodelled by the erosive action of water, and the remelting action of heat, before the commencement of even the earliest of our geological periods. The very lowest of the unaltered stratified rocks of which the age is known, namely, the Cambrian of North Wales and Ireland, are made up of indurated clays, sands, and gravels, which were derived from the waste of previously existing stratified rocks, exactly like themselves.—(*Professor Ramsay*). The crust of the earth then was, before that earliest of our periods, made up of stratified and unstratified aqueous and igneous rocks, as it is now made up of them. Just so much of these earlier rocks are preserved to us as have not been since destroyed by the action either of fire or of water. Over very large areas, very early rocks, having been attacked from above, have been eroded and destroyed by the action of water; and the old base on which they rested has been denuded, and is either now exposed at the surface, or has been re-covered by other rocks subsequently deposited upon it. Over very large areas, very early rocks,

* If we were inclined to speculate on such a state of things as the first cooling of the crust of a molten globe, in which the expansive power of heat must have been acting intensely even at the surface, we might perhaps reasonably doubt the possibility of so dense a rock as granite being formed upon that surface. Porous trachyte, pumice, and obsidian, would occur to me as more probable productions than granite.

having been attacked from below, have been so baked, so altered and metamorphosed by the action of heat, and by the many physical and chemical forces which heat has set in motion, as to have been altogether transformed from their original state, and many of both aqueous and igneous origin actually remelted down perhaps, and reabsorbed into the molten masses of the interior, in which they either still remain as molten rock, or from which they may have been subsequently reconsolidated as newer igneous rock. Some ancient rocks have been in other areas spared by both these processes; but as these processes are continually going on, and continually shifting their areas of action, it is clear that, in proportion to their antiquity, all rocks must have been more or less affected by them, and that we can reason back to a period in the earth's history, the coæval rocks of which have only one or two undestroyed or unaltered areas still left upon the globe; and going one or two steps still farther back, we arrive at a period of which *none* of the coæval rocks can remain in their original recognisable state.

Dismissing, then, all speculations as to the primæval crust of the globe, and the primitive character of granite, let us come to what we know to be true.

II.—*Internal Heat of Globe.*

That the earth has a great internal heat, is rendered almost certain by the following facts:—

1. The specific gravity of the globe is, according to the old observations, about 5.0, or, according to the recent experiments of the Astronomer-Royal, Mr. Airey, about 6.7. Now, the specific gravity of granite varies from 2.6 to 2.9; that of basalt is about 3.0; that of rock in general is from 2.5 to 3.0. The earth, therefore, is more than twice as heavy as it would be if made of any known rock, such as that rock appears at the surface. The pressure of gravity, however, would render any such rock, as granite for instance, much more than twice as dense as it is at the surface, long before it reached the centre.* We should expect then that the globe

* According to Leslie, water would be as heavy as mercury at a depth of 362 miles, air as heavy as water at 34 miles. At the centre of the globe,

would have a much greater specific gravity than 5 or 6, if it were not for some expansive force in its interior counteracting the pressure resulting from gravitation. We know of no such force except that of heat.

2. As a matter of direct observation, it is found that in all deep mines the temperature of the rock increases as we descend at the rate of 1° of Fahrenheit for every 50 or 60 feet of descent after the first hundred. This is the case in every part of the globe, and in all kinds of rock.

Deep springs also, and wells, such as the deep Artesian well of Grenelle, at Paris, are always found to have a high temperature. At Grenelle, the water brought from a depth of 1798 feet has a constant temperature of 81°.7 of Fahrenheit, while the mean temperature of the air in the cellar of the Paris Observatory is only 53°. Very accurate and careful observations have lately been made by M. Walferdin on the temperature of two borings at Creuzot, within a mile of each other, commencing at a height of 1030 feet above the sea, and going down to a depth, the one of 2678 feet, the other about 1900 feet. The results, after every possible precaution had been taken to ensure correctness, gave a rise of 1° Fahrenheit for every 55 feet, down to a depth of 1800 feet, beyond which the rise of temperature was more rapid, being 1° Fahrenheit for every 44 feet of descent.—(*Cosmos, May* 15, 1857).

Hot springs are usually found to proceed from great faults or fissures which penetrate deeply into the crust of the globe.

3. As another result of direct observation, we may state that all igneous rocks proceed from below upwards, coming out of the interior of the earth; and that, as just observed, whenever we are able to see the actual base of the aqueous rocks in any district, we find them reposing upon cooled igneous rocks, generally granite, and that, *cæteris paribus*, the lower the rocks, or the deeper they have formerly been buried, the more marks do they bear of having been subjected to a great heat.

steel would be compressed into one-fourth of the dimensions it has at the surface, and most stone into one-eighth, if the law of compression be supposed to be uniform from the surface to the centre.

We may look, then, upon the great internal heat of the globe generally as a fact pretty well established; and it appears that if the increase of heat towards the centre goes on at the same rate that it does near the surface, all water would be boiling at a depth of 9000 feet under the British Islands, and that at the comparatively small depth of 20 or 30 miles, the heat would be sufficient to fuse any of the substances we know at the surface.

There are said to be, however, certain general astronomical and physical considerations which make against the supposition of the earth's being a molten fluid mass, with only a slight external crust, and render it probable, that, however intense the temperature, the mass is still solid, either entirely or in part, to a very great depth into the interior.*

In this case, it appears that the molten masses which have formed, on cooling, the igneous rocks we are acquainted with, either proceed from detached lakes of fiery liquid, or were rendered fluid by some special and locally acting circumstances.

Speculations, however, on the general state of the interior mass of the globe, although interesting, have, like those on its primæval condition, little theoretical and no practical importance; and as we shall be for ever probably condemned to remain in ignorance concerning it beyond a few general facts such as those before mentioned, they need not occupy more of our attention.

III.—*Position and Form of Granite.*

Granite generally makes its appearance at the surface in large masses, occupying considerable areas, and extending for a great but unknown depth into the interior. Veins of granite, often branching and crossing each other, sometimes proceed from these masses, penetrating the adjoining rocks, and

* Mr. W. Hopkins gives 800 miles as the minimum thickness of the solid external crust of the globe. Professors Henessy and Haughton, however, and also, I believe, Professor Jellett, dissent from a part of the reasoning on which that conclusion is based, and think that no certain conclusion can as yet be arrived at respecting the thickness of the solid crust of the globe. (See *Papers in Phil. Trans., and in Trans. of R. I. Academy*).

dykes, or wall-like sheets, of granite rock are frequently found in their neighbourhood, running sometimes for several miles in straight lines through other rocks.

Smaller bosses of granite are likewise not unfrequent in such districts, apparently the tops and eminences of larger masses that are still concealed below.

Granite generally forms high mountainous ground, and hills composed of it have commonly a heavy rounded outline and sombre aspect. Sometimes, however, granite is found as the surface rock over considerable spaces of low gently undulating ground, in which case the plain is commonly diversified by small rounded knobs and bosses of rock.

Granite is also found not unfrequently as the rock forming the axis of mountain chains, or the nucleus of mountain masses.

When it forms the true axis of a mountain mass, the rocks which rest upon it dip from it in every direction, and the lowest of the stratified rocks are found nearest to the granite, as in Fig. 65, where G is a mass of granite forming the axis

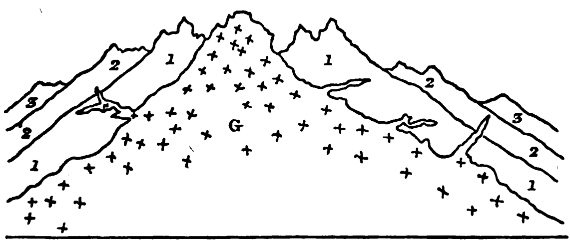

Fig. 65.

Supposed position of granite.

of a range, and 1, 2, 3 are the stratified rocks dipping from it in each direction, the lowest or oldest, No. 1, being next to the granite, and the highest or newest, No. 3, the furthest from it. This central and fundamental position is the one usually assigned to granite where it appears in a mountain chain. Without attempting to deny that it frequently does hold this position, I am yet rather inclined to doubt whether it has not in many cases been assigned to it as a matter of course, without adequate investigation. I am disposed to suspect that the rocks nearest the granite having been most altered, and the most altered rocks having been assumed to be the oldest or lowest, this position may often have been taken for granted instead of proved. We know, at all events, that in many cases granite, where it occurs as the constituent of a mountain range, and as the geographical axis of such a range is not the true geological axis, inasmuch as it does not bring up with it the lowest rocks of the country, and has not the central and fundamental position, nor has it exercised the elevatory action assigned to it in Fig. 65.

The granitic district in the south-east of Ireland, extending from Dublin Bay to near New Ross in county Wexford, is one of the largest and most persistent of the British Islands, being 70 miles long, and from 7 to 17 miles wide. There were in this district at least two great geological formations, each consisting of slates or shales and sandstones, and each several thousand feet thick, at the time of the outburst of this granite. These two formations are known as the Cambrian, which is the lowest or oldest, and the Lower Silurian, which rests unconformably upon the Cambrian. Now in no instance is any part of the lower or Cambrian formation found reposing on or coming against the granite at the surface, though it does come to the surface in some places within two or three miles of the granite, as shown in Fig. 66. The Silurian rocks, however,

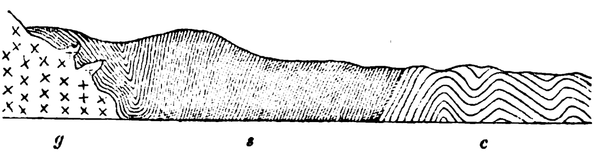

Fig. 66.

Section near Douce Mountain, county Wicklow.
g, Granite.
c, Cambrian.
s, Silurian.

have been broken into, and lifted and altered by the granite, which has sent veins into them, as in Fig. 67; and we are compelled to suppose, therefore, that the granite must have *come through* the Cambrian rock below, before it can have penetrated into the Silurian rocks which now rest upon it. Neither, although the main direction of the granite is parallel to the general strike of the rocks and principal lines of disturbance in the district, does the eruption of the granite seem to have had much effect on the general elevation of the country, but simply to have partaken of it, along with the other rocks, and to have had its direction governed by the direction of the forces of disturbance that were acting at the time of its intrusion. The Silurian slates, which are frequently vertical and greatly contorted over all the district, often appear to dip at or towards the granite, at a distance of about two or three miles from its present surface boundary, and to have been only so far affected by the proper elevatory action of the granite as to be crumpled up or dog-eared against it for a short distance close upon its flanks (see Fig. 66).

If we passed from Ireland into Cornwall and Devon, similar conclusions could be drawn from the relations of the granitic masses there with rocks of a still newer date, namely, with those called Carboniferous and Devonian. The granite penetrates and alters rocks of both those periods, and is therefore newer than both. It has not, however, by its irruption brought up the lowest rock, namely, the Devonian, everywhere on its flanks. On the contrary, where it cuts into and alters the Carboniferous rocks, we are compelled to suppose that it has passed through and left behind the Devonian. Neither does the granite of Cornwall and Devon appear to have acted in any sense as a geological axis or centre of elevation, but simply to have partaken with the rocks of the district of whatever disturbances occurred during or since its intrusion; and the granitic veins appear to have been shot into the cracks and crevices of the rocks, which were opened for them by those disturbances, and not to have made any of those cracks and fissures for themselves.

In other parts of the world, as has been said before, granite is found in the same way bursting through, sending veins into, and altering rocks of still newer date, rocks of what are called the Secondary periods, and rocks of what are called the Tertiary periods; and granite must be forming now wherever molten rock of the proper chemical composition is cooling under the requisite physical conditions, that is, deeply seated under the pressure of great masses of other rock.

It is doubtless true that granite is found more frequently associated with the older rocks than with the newer; in other words, with the lower rather than the higher rocks. The reason of this, however, is clear from the very source of granite being in the interior of the earth. Granite, in order to reach the higher, must pass through whatever lower rocks there may be in the way. Many eruptions of granite may have proceeded a certain distance from the interior, penetrating only the lower rocks; but none can have reached the upper without penetrating the lower. That granite should be most frequently associated with the lowest rocks follows, too, from the very nature of granite. Molten rock that reached or came near to the surface would not, on consolidating, form granite, but some other kind of igneous rock—a felstone trap or a trachytic lava, as the case might be. There is also still another reason why granite is found principally in connection with low rocks that have formerly been deep-seated, and that is, that all granite now found at the surface must be there in consequence of vast denudation having taken place, by which great masses of other rocks have been removed, together perhaps with much of the granite that once existed above the present surface. This denudation of course exposes the lower rock to view, while the parts of the higher rocks that were perhaps equally penetrated by the granite have been swept off and removed

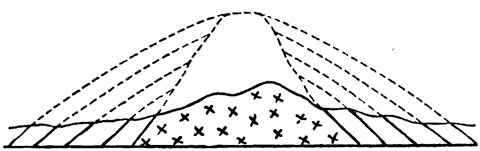

Fig. 67.

The dotted lines represent the former extension of stratified rocks, equally penetrated by *g*, the granite, but the penetrated parts removed by denudation.

(see Fig. 67); the other parts which remain being now at a distance from the granite, and showing no signs of such penetration.

It is therefore where the lowest or oldest rocks come up to the surface that we should expect most frequently to meet with surface granite, as we find to be the case.

IV.—*Age of consolidation of Granites, and of production of Surfaces of Land.*

There is a remarkable class of results which follow from this deep-seated origin of granite, and from the necessity of great denudation having taken place before it can appear at the surface.

In the first place, it proves the fact of this denudation having occurred. Wherever we find granite forming the surface of the ground, however lofty may be the summits of the granite mountains, or however widely spread the extent of the granite plains, we may feel sure that at the time of its consolidation it was covered with a thickness of at least several thousand feet of other rock, and that this thickness has been removed by the gradual action of erosion by moving water.

2dly, We may in many cases ascertain the date of this denudation, namely, that it took place and was completed before such and such a geological period; and thus we get a geological date for the production of the present outline of the surface of the ground.

3dly, We get a date for the formation or consolidation of the granite itself, since we know that this must have occurred previously to the denudation.

In the case, for instance, of the granites of the west of England and the south-east of Ireland, mentioned before, we are able to prove that the granite of Wicklow, etc., is older than the granite of Cornwall. We saw, indeed, that the Wicklow granite penetrated older rocks than did that of Cornwall; but, so far, there was nothing to tell us when the Wicklow granite penetrated those rocks. It might have been that the granites were produced at the same time, that of Wicklow only reaching so far as the Silurian rocks, while that of Cornwall burst through into the rock above, namely, the Devonian and Carboniferous.

If, however, we follow the Wicklow granite into the adjacent counties of Carlow and Kilkenny, we should find that rocks of nearly the same age as those of Devon and Cornwall, namely, those called Old Red sandstone and Carboniferous limestone, reposed directly upon the granite in such a way as to show that not only had the granite been cooled and consolidated, but that it had been denuded and brought to the surface in that locality before the Old Red sandstone had commenced to be deposited.

For a space of about twenty-five miles, the Old Red sandstone first, and then the Carboniferous limestone, overlap the Silurian, and come across it on to the granite. They are quite unaltered by the granite. The granite sends no veins into them, and moreover the lower rock, namely, the Old Red sandstone, is more or less made up of sand derived from the materials of the granite, as in Fig. 68, where the sandstone

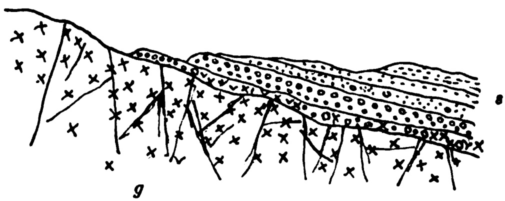

Fig. 68.

Sandstone *s* resting upon granite *g*, and made out of the sand derived from it.

s is partly, or entirely made up of the debris of the granite *g*. It is clear, then, that the *bare* granite formed the bottom of the sea in which those rocks were deposited; in other words, that all the vast mass of Silurian rock which had covered the granite at the time of its consolidation had been removed by denudation before the period in which the lowest of those newer rocks came into existence.

But the granite of Cornwall and Devon penetrates rocks which were deposited at the same time, or nearly so, with the Old Red sandstone and Carboniferous limestone of Carlow and Kilkenny, and is therefore newer than those rocks, and consequently much newer than the Wicklow granite. But we may draw this yet further conclusion. The surface upon which the Old Red sandstone of Kilkenny reposes is of course older than that rock; but that surface is continuous, with only slight modifications, over all the adjacent granitic and Silurian district of Wexford and Wicklow. The conditions as to denudation and form, etc., of the surface covered by the Old Red sandstone and Carboniferous rocks, are obviously, by inspection of the map, nearly the very same conditions as those of the adjoining surface, which is uncovered by those rocks. Moreover, there is reason to believe that those rocks did once extend over much more of that surface than they do now, because detached patches of them are found here and there resting upon it. Therefore it follows that the main outlines, and all the principal features of the surface of the ground which now forms the counties of Wexford and Wicklow, and parts of the adjacent counties, are older than the period of the Old Red sandstone. The principal part of the denudation by which that surface was formed took place before the period of the Old Red sandstone, and any subsequent action, either atmospheric, when it was dry land, or marine, when it may have been passing through the surface of the sea, has been principally efficacious in removing rocks subsequently deposited upon it, or in modifying features, the outlines of which were graven at that ancient date.*

These views on the nature and origin of granite are not exactly those which the student will find expressed in most geological works, though they are implied in the recent writings of many geologists. They are based upon what may now fairly be called the Lyellian philosophy of geology, a philosophy daily becoming more prevalent as its truth becomes more apparent and its applications more extended. The student, however, must expect still to meet with difficulties arising from the use of the old nomenclature, which is apt to still adhere to our tongues after the corresponding ideas have passed away from our thoughts.

* This conclusion is one admitting of a much wider application than has yet been given to it. The present surface of the ground in most of the areas which are occupied by old rocks are surfaces of very ancient date, recent denudation having had but comparatively slight effect upon them.

V.—*Granite Veins.*

Granite veins often differ sensibly in lithological character from the parent mass which they proceed from; and sometimes the external margin of the granite differs also from its deeper and more central portions. Veins very frequently become more fine-grained, and they lose commonly the mica and sometimes more or less of the quartz which the mass contains, becoming less crystalline and more earthy. Some-

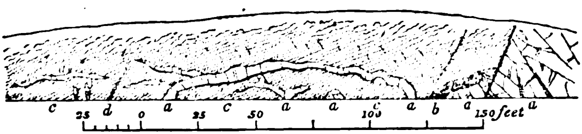

Fig. 69.

Railway cutting at Killiney (Dublin), showing junction of granite and slate, with granite veins.

a, Granite.
b, Black slate unaltered.
c, Gray slate converted into mica schist.

times they take up into their constitution additional materials, derived from the rock which they penetrate and traverse. A striking instance of this latter occurrence is described by Professor Haughton in his paper in the Journal of the Geological Society, London, vol. xii. p. 3, where he describes the granite of Carlingford mountain as sending veins into, and cutting through some beds of the carboniferous limestone, and having its feldspar changed from an orthoclase, which was the feldspar of the granitic mass, into anorthite, in consequence of the addition of the lime which it had taken up from the limestone. Anorthite is said by the Continental geologists never to occur except in recent volcanic rocks, and they appear to look upon its production as a mark of age, and suppose it therefore to be an impossible constituent of granite. This case, however, proves that it is a mark not of age, but of place, and of peculiarity of condition, and that a molten mass proceeding from actual granite may, in different parts of its course, contain different minerals, and become changed into different rocks according to the circumstances in which it is placed.

Other veins are to be found in granite itself, different in character from the surrounding rock, such as veins of eurite (see *ante*, p. 79) traversing coarsely crystalline and highly micaceous granite. Such veins may sometimes be due to subsequent intrusion of molten matter into the cracks of the granite; and when they do not consist of granitic rock, but of traps, such as greenstone and basalt, they undoubtedly are so due. In many instances, however, I believe them to be contemporaneous veins—either segregated from the mass while it was quite fluid, or—perhaps more frequently—on the first commencement of consolidation, portions of the still molten mass below were injected into the cracks and fissures formed on the first attempt at consolidation of its upper portion. This I believe to be the generally true explanation of veins of eurite or other granitic matter differing from the mass of the granite. Such veins are commonly found to be confined entirely to the granite, and not to penetrate into the surrounding rocks, even when the granite itself does send off many veins into those rocks. In other cases, however, veins of "eurite," or of granite differing in texture from the surrounding granite, are seen to pass from the granite into the adjacent slates. These are of course formed subsequently to the consolidation of the granite which they traverse, but still they may in many instances be not long subsequent to that consolidation, and their consolidation may have been contemporaneous with that of lower portions of the granite.

The elvans or veins of quartziferous porphyry, that is, a granular crystalline mixture of feldspar and quartz, which are common both in Cornwall and Devon, and near the granite of the south-east of Ireland, are probably in reality granite veins, or veins proceeding from a granitic mass. Large masses of similar rock, however, occur in Wicklow and Wexford, forming mountainous hills with all the character of granite hills, except that the rock differs somewhat in texture from granite and contains no mica.* These rocks, for which I have suggested the name of elvanite, but which Continen-

* Recent explorations in company with Professor Haughton, induce me to believe that this elvanlike rock is only the external skin, as it were, of true granite below.

tal geologists might possibly call pegmatite, are probably one of the intermediate varieties between true granite and a purely feldspathic or feldspatho-siliceous trap (felstone). They should, however, still be retained among the granitic rocks. The other granitic rocks described in part i. p. 70, resemble granite in their mode of occurrence, being generally massive and underlying. Pegmatite, protogine, and syenite are indeed commonly mere local varieties of granite. Large masses of greenstone-porphyry, or felstone-porphyry, or quartziferous-porphyry (elvanite), also occur in some districts as massive, deep-seated, underlying rocks, with all the petrological character of granite. These rocks, however, are by no means universally found as underlying rocks, since all kinds of porphyry often occur in bed-like masses, either as great intrusive veins or dykes, more or less nearly horizontal, or as contemporaneous traps.

VI.—*Form and Position of Trap Rocks.*

The trappean rocks may be especially characterised as being intrusive and overlying rocks when compared with the

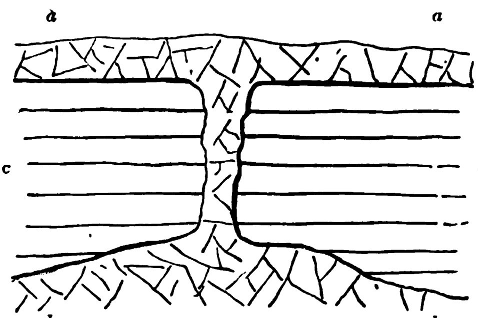

Fig. 70.

Overlying trap proceeding from underlying mass.
a, The overlying igneous rock.
b, The underlying igneous rock.
c, The previously existing rock, whether igneous or aqueous.

granitic class; but, inasmuch as they always proceed from below, it is obvious that every "overlying" mass of igneous rock must have a connection with some underlying mass by means of an intrusive pipe, dyke, or vein (see Fig. 70). The terms "pipe" and "vein" sufficiently explain themselves. "Dyke" is a North British term for a "wall;" it is sometimes by miners applied to a mere fault or fissure, but by geologists is always understood to mean a wall-like mass of igneous rock filling up a fissure in other rocks. A dyke may come up through any kind of previously existing rock, whether igneous or aqueous, trap dykes sometimes traversing granite, and overlying masses of trap resting on that or any other kind of rock whatever.

They may also reach and flow along all kinds of places—the surface of the dry land, when they become volcanic rocks, and would be called lava; the bottom of the sea, when they would probably be called lava or trap, according to its depth and the circumstances of time and pressure under which they cooled; and in between the beds of aqueous rocks at different depths, or perhaps between the horizontal or other joints of previously cooled igneous rocks, whether granitic or trappean.

Those portions of trap rocks which have spread out upon the bottom of the sea, and have thus become buried between two consecutive deposits of aqueous matter, are called "contemporaneous traps."

In the old Silurian districts of the British Islands great sheets of *felstone* and of *feldspathic ash* are thus interstratified with the aqueous rocks, and have since suffered with them all the accidents of flexure, contortion, and fracture that subsequent disturbing forces have brought upon those districts. Some fine-grained traps and ashes have undoubtedly been even affected by slaty cleavage and made into trappean slate, though, as some of them, like the clinkstones of Mont Dor and Velay, may assume a finely laminated or slaty structure on cooling, this character requires to be very carefully observed before it is attributed to the same cause that cleaved the aqueous rocks.

Felstones, both contemporaneous and intrusive, occur also in great variety and in important masses in the Devonian and Carboniferous rocks of the south-west of Ireland, near Killarney and near Berehaven.

Greenstones occur likewise in contemporaneous beds interstratified with both "ash" and aqueous rocks. The beds of "toadstone"* in the limestone of Derbyshire form one instance of this, and other instances occur abundantly in Ireland and other parts of the British Islands.

In other cases both felstones and greenstones have been injected as great sheets, or as dykes, or as veins, into the previously existing rocks.

In the case of intrusive sheets of trap running in between beds of other rock, we may suppose that having been forced up through previously formed fissures to a certain height, the molten rock then met with such an opposition above that it was as easy for the expansive force which was impelling it to lift the beds above as to break through them. The planes of stratification then became those of least resistance; some horizontal cavities or some marked division between the beds was perhaps taken advantage of, and the molten stream, beginning to flow in, was injected with sufficient force to float the mass above upon its surface.

Sheets of greenstone thus injected have been traced by the Government surveyors sometimes for miles among the Silurian rocks of North Wales. They have been found also by mining in the South Staffordshire coal-field over an area of above twenty square miles with a thickness varying from fifteen to sixty feet.—(*Records of School of Mines*, vol. i. part ii. p. 244).

VII.—*Distinction between Intrusive and Contemporaneous Trap.*

It is sometimes not very easy to distinguish between such injected sheets and beds of contemporaneous trap.

If a sheet of trap rock (whether felstone or greenstone), after running for some distance between two certain beds, cut up or down and proceed between other beds, as in Fig. 71, it is obviously intrusive and not contemporaneous.

* Toadstone is a local name, either given because the rock often resembles a toad in colour, or more probably derived from the German word "todstein" or "dead stone," because the lead veins "die out" on approaching the toadstone, and were supposed not to reappear beneath it.

If the beds above a sheet of trap be as much altered or "baked" by the igneous rock as those below, or if it send any veins up into the beds above it, it is equally plain that it must be an intrusive sheet.

If however, the bed below the trap be altered, while that above it, composed of equally alterable materials, is quite unaffected, we may conclude that the trap was poured out and flowed over the surface of the lower bed, and that the upper bed was subsequently deposited upon it; in other words, that the trap is contemporaneous and not intrusive as regards the beds in that place.

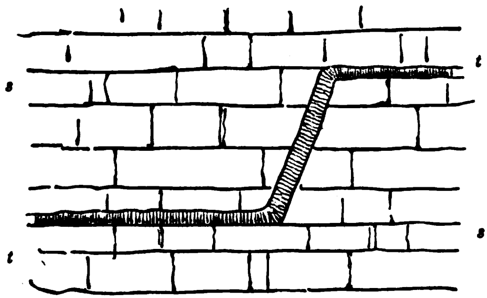

Fig. 71.

s, Stratified rock.
t, Trap running partly between, partly across the beds.

This conclusion would be confirmed if the upper surface of the trap be rugged and uneven, and if the stratification and

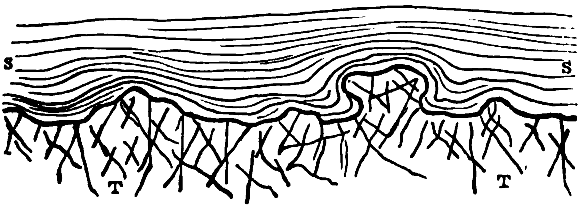

Fig. 72.

s, Stratified rock, the lamination of which conforms to the rugged surface of *t*, a trap, in such a way as to show that it was deposited upon it.

lamination of the bed above conformed to these rugosities, as suggested in Fig. 72.

In the "toadstone" of Derbyshire globular masses of the upper surface are often almost completely included in the superincumbent limestone, clearly showing that the limestone was deposited at the bottom of the sea on the uneven surface of the cooled trap.

If, again, the bed above the trap contained any fragments clearly derived from the erosion of the trap, it would prove the trap to be a contemporaneous one. At Carrig-o-gunnel, near Limerick, a great mass of greenstone, sometime amygdaloidal, is overlaid by a still larger mass of brecciated "ash" consisting of fragments of trap and fragments of limestone, and the beds of limestone immediately above this contain rounded pebbles and small flakes of the trap, demonstrating that it was formed by an outburst in the bed of the sea in which the adjacent limestone was being deposited.

When beds of trap (whether purely feldspathic or feldspatho-hornblendic) are clearly interstratified with beds of "ash" or "tufa" of the same character, whether that ash were subaerial or submarine ash,* it becomes almost certain that the trap is contemporaneous; for that ash is clearly derived from some contemporaneous trap somewhere, and the chances would be greatly against a sheet of similar trap being subsequently injected into those ashes, without producing in them great and obvious alteration, or cutting them with dykes and veins so as to clearly show its intrusive character.

Even should the ash show a considerable amount of alteration from its original state as a mechanical deposit, such, for instance, as the production of crystals of feldspar, it would not be conclusive evidence against its being an "ash," or against the contemporaneous age of the trap beds associated with it, since such alteration might be the result of a subsequent general action, which had taken place with regard to the whole mass of the rocks, but had produced a greater effect on the "ash" than on the other rocks, because its nature made it more easily impressable, and more open

* The student must regard the term "ash," introduced by Sir H. De la Beche as merely an English synonym of the Italian word "tuff," or "tufa," when the latter is applied to igneous materials. The advantage of using the term "ash" is the avoidance of the ambiguity arising from "tufa" being sometimes applied to calcareous or other depositions of a soft friable character.

and liable to change than the solid igneous or the simple and more homogeneous aqueous rocks.

It is partly, perhaps, for this reason, as well as on account of the original alternation and partial blending * of the results of aqueous deposition and igneous outflows and dejections, that in some highly and generally altered districts such as North Wales and the lake district in England, the south-east of Ireland, and the border highlands of Scotland, it is often difficult to determine the difference between actual trap and "ash," or between ash and other mechanically-formed rocks, such as some varieties of sandstone or slate. In such districts we get great irregular bosses and mountainous masses of trap of various kinds, apparently the centres or foci of eruption; we get huge continuous sheets of felstone and other kinds of trap spreading over great areas interstratified with "ash," sandstone, and slate; we get still more widely-spread sheets of "ash," sometimes hardly distinguishable from trap when near the igneous foci, but becoming thinner and more obviously mechanical, more completely conglomeritic or brecciated, or more calcareous and more regularly bedded as we proceed from these foci, and we get the whole of these rocks cut through and penetrated in different places by subsequently-formed dykes, veins, and intrusive sheets of other traps (greenstones, felstones, syenites, elvanites, etc.), altering the rocks more or less entirely according either to their chemical composition or to the mass of the intrusive trap, and thus completing the complexity and confusion which the geologist has to unravel.

When such a district has been greatly upheaved and disturbed, thrown into many and complicated folds, and broken by many faults running in various directions, heaving and dislocating the rocks now one way, and now another, and with ever varying amounts, sometimes throwing them as much as three or four thousand feet from the level of the corresponding beds on the other side of the fault; when, in

* See the "Memoirs" of Professor Sedgwick in Proceedings of Geological Society; also his "Letters to Wordsworth" in the Guide to the Lakes, and "Introduction to Palæozoic Rocks," 3d Fasciculus; also Murchison's "Silurian System," and the maps and sections of North Wales and south-east of Ireland, published by the Geological Survey.

addition to this, such a district has been worn and eroded into all kinds of hollows, valleys, and glens, with precipitous cliffs and crags, separated by more or less inaccessible ravines; and when, yet more, the rocks are frequently disguised by partial decomposition, and concealed over wide intervening spaces by soil, by vegetation, or by superficial accumulations of gravel, clay, and sand, it will be readily understood that it is no easy or unlaborious task, though often a healthy and delightful one, to trace out all this complexity, to restore order to all this confusion, to delineate the outlines and positions of the rocks as they now are, and to reason back to their original state, and to the causes which produced them.*

VIII.—*Relations between Felstone and Greenstone.*

I have occasionally been struck in some of the districts just alluded to, with the association of felstone and greenstone, it being rare to find any considerable mountain mass of felstone without irregular patches of crystalline greenstone disseminated about it. The irregular outline of these greenstone patches gave them the appearance of being subsequently intrusive into the felstone, but the frequent association of the two has sometimes led me to speculate on the possibility of the two rocks having been part of the same molten mass, and having settled or segrégated apart from each other on the cooling of the whole. There seems no very cogent reason why we should necessarily suppose the whole molten mass to have been completely homogeneous; but granting that it was so, is it not possible that, when a deep-seated mass of trap commences to cool, a separation may take place, and one more fusible portion of it may be segregated from the rest, and thus one or more local centres might be established, into which the greater portion of the more fusible bases

* I believe I am correct in saying, that some districts of North Wales have been visited and revisited not less than ten times, during the progress of the Geological Survey, by *the same observer*, before their structure was rightly comprehended. This was more especially the case in some of the wilder districts, which required some hours' walking "over moor and mountain" before they could be reached.

(silicates of lime and iron) should be concentrated? These local patches, which, on the ultimate complete refrigeration of the whole, would form greenstone, while the rest of the mass was felstone, or elvanite (quartziferous porphyry), as the case may be, *might* retain their fluidity for a time, till, on the consolidation and consequent contraction of the other mass, they were squeezed in various directions into the cracks and fissures that would then be caused, and then cool rapidly in consequence of their greater extent of surface.

IX.—*Trap Dykes and Veins.*

There do occur, however, quite a sufficient number of independent intrusive masses of greenstone, enclosed entirely in slate or other rock, to render these speculations unnecessary in many instances.

As a good instance of an intrusive vein of igneous rock, we give the following (Fig. 73), taken from Rec. Sch. Mines, vol. i. part 2, p. 242, as having been drawn carefully to scale.

Fig. 73.

a, "White rock" trap.
b, Altered coal.
c, Sandstone.

The igneous rock here is a white trap springing out of the greenstone ("green rock") of the neighbourhood. Its chemical composition, as determined by my friend Mr. Henry, is—

Silica	38.830
Alumina	13.250
Lime	3.925
Magnesia	4.180
Soda	0.971
Potash	0.422
Protoxide of iron	13.830
Peroxide of iron	4.335
Carbonic acid	9.320
Water	11.010
	100.073

showing a great amount of variation from any ordinary greenstone, in the presence of so large a quantity of carbonic acid. This alteration is probably the result of its having come in contact with a coal, and having been consequently affected by the subsequent percolation of carbonic acid, which has converted the silicates of lime and iron into carbonates. The alteration of the coal, in consequence of the heat of the trap, is equally great, as it has in many places lost its bright lustre, and its regular "face" has parted with much of its bituminous or inflammable character, and more nearly resembles anthracite than bituminous coal, though different from both, being often full of concretions of iron pyrites, or of carbonate of lime, or other minerals. In the language of the colliers, the coal is said to be "blacked," and to be now "brazil," or "brassil," and consequently not worth the trouble of "getting."

A wonderful example of a trap dyke is the one so well known in the north of England as the Cockfield Fell dyke, a nearly vertical wall of trap, 18 or 20 yards thick, which runs in a nearly straight line from north-west to south-east, for a distance of about 70 miles, cutting through all the rocks from the coal measures into the lower oolites, and baking the lias and every other rock it meets with for a distance of some yards from its sides. Its effect on one of the coal beds under Cockfield Fell, is well described by Mr. Witham in the *Transactions of the Natural History Society of Newcastle*, vol. ii. p. 343. The coal, I believe, is originally about 6 or 8 feet thick, one of the principal bituminous coals of the district. In approaching the dyke, it begins to be affected at a distance of 50 yards from it; it first loses the calcareous spar which lines the joints and faces of the coal, and begins to look dull, grows tender and short, and also loses its quality for burning. As it comes nearer it assumes the appearance of half-burnt cinder, and approaching still nearer the dyke, it grows less and less in thickness, becoming a pretty hard cinder only 2 feet 6 inches in thickness. Eight yards further it is converted into real cinder, and more immediately in contact with the dyke, it becomes by degrees a black substance, called by the miners "dawk," or "swad," resembling soot caked together, the seam being reduced to 9 inches in thickness. There is also a large portion of pyrites lodged in the roof of that part of the seam which has been reduced to cinder.

X.—*Form of Basalt.*

Basalt is rarely, if ever found as an underlying rock, and not often as an intrusive sheet. It occurs commonly either as a dyke, or as an overlying mass. One of the most celebrated plateaux of basalt is that in the north-east of Ireland, covering almost the whole county of Antrim with a mass 300 or 400 feet in thickness, and 50 miles long by 30 wide, or about 1200 square miles in area. The basalt occurs in three or four sheets, in many places beautifully columnar and interstratified with beds of ash or "ochre," as it is called, associated with beds of lignite; one of the columnar beds dipping gradually into the sea on the north coast is known as the Giant's Causeway. Many dykes are perceivable in the district, cutting through different kinds of rock, altering the Lias shales into a Lydian stone, and the Chalk into a crystalline marble. The basalt of the west of Scotland is likewise beautifully columnar, as at Fingall's Cave and other places, while that of Arthur's Seat is massive, and often crystalline, showing distinct crystals of olivine, and being highly magnetic from the abundance of magnetic oxide of iron.

The ash associated with the basalt of the Calton Hill is very admirably exhibited on all sides of it.

The greenstone of Salisbury Crags has greatly altered and indurated the gritstone below it (one of the carboniferous sandstones) which is converted into a kind of quartz rock.*

It is probable that all these basalts and greenstones were of submarine formation, but the lower part of many lava streams proceeding from subaerial volcanoes, or at all events

* Professor Ramsay informs me that Professor Edward Forbes had conceived the idea, which has lately been completely confirmed by the Geological Survey, that the igneous rocks around Edinburgh belonged to two very different periods, the one part probably carboniferous, and the other much more recent, probably Tertiary, perhaps contemporaneous with the Miocene (?) basalts of the north of Ireland and the west of Scotland.

from volcanoes which are now subaerial, are as regularly columnar basalt as the Giant's Causeway itself.

XI.—*Forms and Positions of Volcanic Rocks.*

Lavas differ from traps partly in mineral character, such as the occurrence of augite instead of hornblende, and of labradorite or anorthite instead of orthoclase, etc., but principally in the texture and form of the rocks, rather than their composition.

True lavas have always been poured out either on the dry land or in shallow water, forming regular flows or "coulées" of molten rock. Cooled under these circumstances, the upper surface of a lava stream is generally quite porous and vesicular from the escape of the gases pent up within. The upper portion of such a bed consists of loose blocks of cinders of all sizes, from rough masses of two or three feet in diameter, to those of as many inches. It might be likened to a mass of clinkers, slags, and cinders, from a huge foundry. The far end of a lava stream has been described as a slowly-moving mass of loose porous blocks, gradually rolling and tumbling over each other with a loud rattling noise, giving evidence of the pressure of a viscid mass of cooling lava within. The upper end of a lava stream, where it issues perfectly fluid from the intense heat of the volcanic orifice, moves much more rapidly.

All rock is a bad conductor of heat, so that, when once a lava stream acquires a cooled crust, the mass within may remain glowing hot for a considerable period of time. We are told of persons walking about on the cooled surface of a lava stream while able to roast eggs or light cigars in the cracks and crevices of the crust. Caverns are sometimes formed in lava streams by the sudden escape of the molten mass below, leaving the cooled crust standing like the roof of a tunnel.

In such a mass, it is obvious that, while the upper surface was light, porous, and cindery, the lower portion, cooling much more slowly, and under pressure, might be solid, compact, or crystalline. As a matter of fact, wherever old lava streams have been cut into, either naturally or artificially, and their lower portions laid open to our inspection, we find the vesicular character of the upper surface gradually disappearing below, and the rock passing quickly into a hard, compact stone, often columnar, and frequently quite crystalline.

The hornblendic or augitic lavas more readily assume the columnar form than the feldspathie lavas or trachytes, which, however, on the other hand, are often much more highly crystalline than the augitic dolerites or basalts.

The lower parts of many lava streams are not to be distinguished by any internal characters (and probably not by any differences in chemical composition) from columnar basalt.

Many old basalts, indeed, which are ordinarily considered as trappean rocks, may have had a porous cindery upper surface at the time of their formation, that surface having been subsequently washed away by denudation.

Almost all true lavas are embedded in, and surrounded by vast piles of ashes, dust, and fragments, ejected from the volcanic orifice from which they themselves proceed, or from some neighbouring orifice. They commonly issue from a cup-like hole, or crater, either on the summit or on the flanks of a great conical pile of such loose ejectamenta.

XII.—*Elevation Theory of Craters.*

Von Buch and other geologists formerly took it for granted that lava would not solidify into thick masses of compact or crystalline stone, if it had been poured out down a slope having an inclination of more than 3° or 4° to the horizon. It has been shown, however, by Sir C. Lyell and others, that this assumption was a gratuitous one.

Upon it was based the "elevation theory" of cones and craters, which supposed it necessary that all lava streams, and the associated beds of ashes, etc., should have been once nearly horizontal, and subsequently elevated into their present inclined position and qua-qua-versal dip, by an upheaving force acting on a central point. This theory is here mentioned chiefly that the student may know what the elevation-crater theory was.

It is not intended to deny the possibility of such an elevation, since a dome-shaped elevation and qua-qua-versal dip is a common occurrence among stratified rocks, and may have been given equally to igneous rocks, as in the case of Mount Jorullo, stated by Humboldt to have swollen up like a bladder to a height of 1600 feet above the surrounding ground. But we wish to guard the student against supposing it the necessary mode of formation of all volcanic cones and all crateriform hollows from which beds of lava incline downwards in all directions. Almost all volcanic cones have been formed by the frequent ejection into the air of cinders, blocks, and ashes, from one central orifice, round which they have fallen nearly equally in all directions, (except perhaps that from which the wind was blowing at the time,) together with the occasional outflow of a molten lava stream, which has either broken down one side of the lip of the crater, or has broken through at some lower and weaker point in the flanks of the cone.

On the flanks of a great volcanic mountain minor lateral cones and craters are frequent at the surface, and are probably much more numerous within; many former excrescences having been buried and concealed by subsequent accumulations (whether of lava streams or ashes) ejected from the central region.

XIII.—*Cone within Crater.*

In great volcanic mountains it is not unfrequent to find the ruins of a former grand central cone, from the interior of which a new central cone is commencing to grow. This is the case in the Peak of Teneriffe, where the present cone rises from a corner of the space now called the Pumice Plains, that was once the interior of a much grander cone, the ruined walls of which may still be traced in a line of crags surrounding the Plains.

In the volcanic mountain of the Bromo in Java,* which lies in the centre of a great volcanic range, from one end of

* See Voyage of H. M. S. Fly, vol. ii. p. 68.

which Mount Semiru rises to a height of 12,000 feet, and from the other Mount Arjuno to 11,000 feet, there is an excellent example of a similar structure. The Bromo is a flat-topped mountain, about 8000 feet high, formed by a narrow circular ridge sloping steeply down on the outside, and having a perpendicular precipice within, only broken and accessible at one or two points, and being generally a thousand feet in height. The circular space within this great wall is four or five miles in diameter, and a large part of it is a flat expanse of fine sand, called the Laut Pasir, or Sandy Sea. From near the centre of this rises a rough conical mound, 600 or 800 feet high, deeply furrowed on all sides, and having on one side a number of subordinate cones and craters, partly growing out of it, as it were. One of these had been frequently active in 1845, when I visited it, and was then belching out much smoke and steam, with a great rumbling noise proceeding from the depths of the funnel-like crater.

For further details of volcanic mountains, and an account of their distribution, we must refer the reader to Lyell's "Principles of Geology," Daubeny on Volcanoes, Wilkes's Voyage, Scrope's "Central France," Johnstone's Physical Atlas, Walterhausen's Ætna, etc. See also a very interesting paper by Mr. Scrope in the Geological Journal, vol. xii. p. 4.

XIV.—*Dykes and Veins of Lava.*

Just as among the trap rocks we found dykes and veins frequent, seeming sometimes to be the mere extensions of the mass below into the cracks and crevices of the rocks above or around it, sometimes apparently the feeders of overlying masses, so we should find volcanic cones and the surrounding districts penetrated in every direction by dykes and veins of compact lava, serving often to bind together or to support the otherwise rather incoherent materials; and we should know, although we could not see it, that every lava stream had its central pipe or feeder in the interior of the mass from which it had proceeded. It is probable that, both in the case of traps and lavas, the size of the dykes or feeders often bears but a small proportion to the mass of the overlying rocks that proceeded from them.

It is not absolutely necessary, in the case of a volcanic cone, that the flow of lava and the central pipe or feeder should remain in connection, and cool and consolidate together; for when the lava ceased to be impelled so as to flow over the crater, the portion left in the funnel might sink down and perhaps ultimately cool and consolidate at a considerable distance below, and might possibly make even a different kind of rock from the ejected mass.

This may sometimes occur also among trap rocks, since it is quite easy to conceive that an overlying mass or an injected bed might be deserted by its feeder on the internal impelling power being withdrawn, and the orifice by which it rose might be closed, so that two kinds of rock may be formed at different places, and possibly of rather different character, though once perhaps actually forming part of the same molten mass.

XV.—*Association of Trachytes and Dolerites.*

In many volcanic regions there appears to be an alternation, or to have been a succession, in the different products; the lavas being at one time trachyte, and at another dolerite. It was formerly supposed that the trachyte was always the lower or the older of the two, and that flows of trachyte were never found above flows of basalt or dolerite. I am not prepared to say how far this relation of position has been borne out or not by recent researches.

Bunsen, however, in a paper formerly cited (Sc. Memoirs), in speaking of the trachytic and augitic lavas of Iceland, refers their origin to two separate volcanic foci, and even speaks of a third separate volcanic focus for the intermediate lavas, though he also speaks favourably in another place of all the volcanic rocks arising from one mass.

The identity or very great similarity of the various volcanic products in all parts of the world, seems to point to a common origin for them. The frequent association in all parts of the earth of the two great classes of these products, the trachytic or purely feldspathic (or highly siliceous, with little alkali, lime, or iron), and those in which the feldspathic minerals are largely mingled with hornblendic or augitic (containing much alkali, lime, and iron), seems to show that their separation is not so much due to diversity of origin, as to some cause tending to segregate the one from the other, out of a generally diffused mass, in which the constituents of both may be equally mingled.

The association previously mentioned of felstone and greenstone among the traps seems to be reproduced in that of trachyte and dolerite among the lavas. In both instances the occurrence of pure or unmixed feldspathic rocks is less frequent and less universal than that of those in which the feldspar is mingled with the more basic minerals. Trachytes and felstones seem both to be confined to certain localities, in which, however, they are very abundant, sometimes alone, and sometimes largely mingled with dolerites, basalts, or greenstones. These latter rocks, on the contrary, are not only found in association with the former, almost wherever these igneous rocks appear, but also in many other districts, in large or small quantities, unaccompanied by any other igneous rocks.

If we assume all igneous rocks to proceed either from one central molten mass of equable constitution throughout, or from separately fused portions of perfectly similar constitution, might we not suppose that the difference in the constitution of the various products which we find at the surface depended on the circumstances and conditions in which they had been placed? The portions now open to our examination had probably to pass through different thicknesses and different kinds of other rocks; they would be placed then under different conditions of temperature and pressure, which might perhaps alone cause a separation to take place in their different ingredients; they might also take up in their passage other ingredients of different character from those which they originally possessed, or larger proportions of one or other of their original ingredients. In those places or at those times when violent accessions of heat approached most nearly to the surface, trachytes and felstones might be poured out, while at other periods of less intensity no molten rock could reach the surface unless it were composed of more easily fusible minerals. These more readily fusible substances might be conceived either to have separated in liquid strings and veins from the consolidating rocks below, or to have been acquired by the upper portion of the mass from the rocks it met with in its passage towards the surface, the substances thus added having acted as an additional flux to matter which would otherwise have solidified before it could have been poured out.

Some such hypothesis as this seems to me less forced than one which obliges us to suppose separate deep-seated foci or reservoirs for every variety of igneous rock, those varieties frequently occurring in the same district, and alternating one with the other over the same space of ground.

If it be well founded, it will enable us to account for the gradual changes in one connected igneous mass, as also for the veins and patches of different character sometimes to be found occurring very abruptly in such masses, independently of the supposition of a subsequent intrusion of one igneous rock through the body of another. This would often relieve us of a difficulty where the veins are confined to the igneous rock and do not penetrate the adjacent aqueous rocks. We might then look upon such veins as veins of segregation, occurring probably at the time of the contraction consequent upon the mass of the rock passing from a molten to a solid state, or from a pasty to a crystalline state (see *ante*, p. 84), while yet some parts of it remained fluid.

XVI.—*Origin of Volcanic Action.*

It still remains an undecided question whether the heat by which rocks are molten in the interior of the earth be due to an original central heat or to mere local causes. Dr. Daubeny maintains Davy's hypothesis of the probability of volcanoes arising from the heat generated by the oxidation of large masses of the metallic bases of the earths and alkalies, independently of any central heat. We have, however, already seen that there is a high degree of probability for the existence of a great internal temperature.

Professor Phillips has remarked that the fact of internal heat by no means excludes the hypothesis of the local intensity of volcanic action near the surface being due to the local chemical causes to which Dr. Daubeny ascribes them. The linear arrangement, however, of the great volcanic bands of the earth's surface suggests, as Humboldt says, the idea of their being arranged over great cracks in the crust of it, by which the molten matter of the interior escapes to the surface. The existence of these cracks, on the other hand, may be equally efficient, as allowing the access of water to the elementary or simple substances of the interior, and their consequent oxidisation and combustion.

Even granting the central heat and fluidity of the earth to be a fact, there still seems to be a difficulty in supposing our lava streams to have any direct connection with this central fluid portion. If they had, they would apparently be kept constantly molten, and constantly at the same height in all volcanoes, unless, indeed, we suppose the attraction of gravitation not to be universally perpendicular to the earth's mean surface.

XVII.—*The Contents of Mineral Veins.*

Having described the veins of igneous rock, and the cracks, fissures, and faults which affect all rocks in different places, we are now in a position to re-examine the subject of mineral veins, with a view especially to their contents.

In veins or dykes of igneous rock, we have seen that they are either *veins of segregation* with or without fissures, or *veins of injection*, liquid matter having been forced into fissures, either previously existing or formed at the time of injection. There is commonly in such veins no farther dislocation of the adjacent rocks than will allow of the intrusion of the igneous matter.

We have also seen that in "faults" the fissure will probably be closed in soft and easily compressible rocks, while in hard ones it will often stand open either wholly or in part, the walls or sides of the fissure being kept asunder by the knobs and protuberances which result from the irregularities of its form.

It is of course quite possible that molten matter may gain access to such a fissure, and fill it up with a dyke or vein of igneous rock. If, however, it be not so filled up, it will be ultimately more or less completely filled with other kinds of mineral matter, and in a different way.

Blocks and fragments of the adjacent rocks may fall into such a fissure, and such blocks are often found in mineral veins. If it have anywhere any open communication with the surface, different matters may be swept into it by floods or springs. Branches of trees, gravel, sand, and clay, and other surface matters, have accordingly been found in mineral veins.

Besides these matters, however, thus introduced by mechanical causes, many minerals have been chemically deposited in fissures, and it is to these chemically deposited substances that we look as the true contents of a *mineral vein.*

The number of minerals found in such veins is far greater than that of the minerals forming the principal constituents of rocks. Silica or quartz, however, among the earthy minerals, maintains an equally abundant presence in veins as in rocks. In addition to the earthy minerals, however, such as quartz, fluor spar, baryta, calcite, strontia, etc., mineral veins are the principal repositories of the metallic minerals, the ores of copper, lead, tin, zinc, mercury, antimony, silver, gold, platina, etc. etc.

It is to these metallic minerals that the miner of course chiefly looks, and he generally speaks of the earthy minerals as the gangue, matrix, or vein stuff of the "vein" or "lode."

The mineral contents of a vein is sometimes confusedly dispersed through it, the "vein stuff" being either crystalline or amorphous, and the ore occurring either as disseminated crystals or nests, or as "strings" or "ribs." Sometimes there appears a regular arrangement of the various substances, the "cheeks" or "walls" of the "lode" being lined with a layer of crystals of one kind of substance, with their points or apices directed inwards, each of these layers being covered by a crystalline layer of another substance impressed by the crystals of the first, and therefore evidently deposited upon it, and after two or three such alternations a rib of ore is found in the centre.

In other instances the vein will be filled with only one kind of substance, sometimes the "vein stuff," sometimes the ore.

Such structures as that in Fig. 74 seem necessarily to involve the idea of successive depositions of the different coatings or linings of the vein, the central rib of ore being the last or newest.

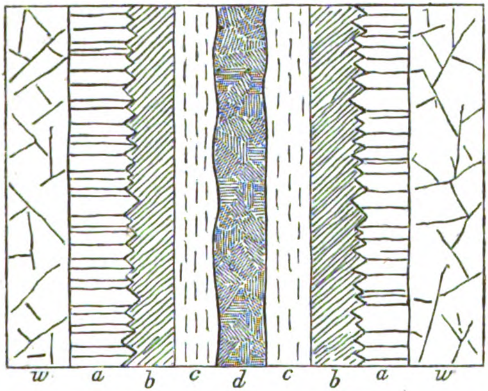

Fig. 74.

a. Coating of one mineral, say quartz.
b. Coating of a second mineral, say fluor spar.
c. Coating of first mineral, or of a third, say sulphate of baryta.
d. Rib of ore, as copper or lead.
w w. Walls of the lode.

Assuming, however, the vein to have been filled with an aqueous solution of these minerals, it is not absolutely necessary to suppose them to have been successively introduced, since all the substances may have been in solution together, and circumstances having been favourable at one time to the deposition of one substance and to that of another at another time.

In some veins it appears that after being filled up, subsequent movements have taken place, causing fresh openings, and new deposits of crystals formed in these openings. These subsequent movements have often produced shining striated surfaces, the effect of enormous friction, which are known as "slickensides;" but these are not confined to veins, since they are found in "faults," and in broken or contorted and fractured rocks of all kinds, where a grinding motion has been communicated to different parts of the rock.

Where "lodes" and "cross courses" occur together in a district, their contents are often different, one kind of minerals being found in one and another in the other. Where the date of the "cross course" is newer than that of the "lode," which is often the case, it is easy to understand the difference in their contents. When, however, the two veins are contemporaneous, as sometimes happens, it is not so easy.

Sometimes the cross courses contain no ores themselves, but the parts of the right lodes near the cross courses are found to be more than usually rich. By "right lodes" are meant those mineral veins which run parallel to each other with a certain magnetic bearing over a given district of country, and by "cross courses" those which cross these more or less nearly at right angles. Both in the north and west of England the "right lodes" run nearly east and west, the "cross courses" nearly north and south.

Of the various hypotheses proposed to account for the origin of the contents of mineral veins, none perhaps are altogether satisfactory. Mr. Were Fox called attention to the fact of currents of electricity traversing veins, and there appears no difficulty in supposing that if veins are filled with water more or less acidulated and impregnated with mineral solutions, a great natural "electro-plating" process may be set up, by which different minerals may be deposited at different times or in different parts of the walls of the lodes. Where the minerals, however, and especially the metallic ores, are derived from, is another question, whether directly from original repositories below, or indirectly by segregation in minute particles from the adjacent rocks. That the fissure should remain open for a great and indefinite period of time, and that its sides should be hard rock, seem the two essential conditions, though perhaps the latter may only be necessary to ensure the former.

The mineral contents of veins seem to be by no means permanent, even when complete, since crystals of minerals are often found that have not their true form, but the form of some other mineral; the originally deposited crystal having decomposed and been removed, and the newer one deposited in its place. Vast periods of time must have elapsed for such processes to have taken place.

If the mineral contents of veins have not been deposited from aqueous solutions either filling the veins or trickling down their sides, the only other alternative appears to be to suppose them the result of sublimation. This supposition seems to have lately lost the favour with which it was once received, it having been objected to it, that the temperature of the walls of the vein must necessarily be too low for sublimation to take place, or for minerals to continue in a state of vapour in any but the lower and more deeply-seated parts of veins. To this objection, however, it might be replied that the mineral veins, now near the surface, were probably deep-seated, and covered with vast thicknesses of other rock, at the time the minerals were formed in them, and therefore their walls may have had then a very high temperature. Moreover, it may be doubted how far it is impossible for minerals to be brought into them in a state of vapour even now. With respect to lead, at all events, I recollect to have been shown a chimney a mile long, built along the side of a hill, proceeding from some lead works in the county of Northumberland, with chambers in it at intervals, and to have been told that its expense was repaid in a few years by the quantity of lead deposited in these chambers, which would otherwise have been dissipated in the state of vapour into the atmosphere. It was the noxious action of these mineral vapours on the surrounding crops which first necessitated the erection of the chimney.*

* As this was a recollection of twenty years ago, I wrote to Mr. Sopwith, the eminent manager of Mr. Beaumont's mines, respecting it, and in answer I was informed by him that formerly "large quantities of lead were carried off in the state of vapour and deposited on the surrounding land, where vegetation was destroyed, and the health of both men and animals seriously affected. This led to various extensions of the horizontal or slightly inclined galleries in use at Mr. Beaumont's mines, and the quantity of lead extracted rapidly repaid the cost of construction. The latest addition of this kind was made at Allen Mill, and it completed a length of 8789 yards (nearly five miles) of stone gallery (or chimney) from that mill alone. This gallery is eight feet high and six feet wide, and is in two divisions widely separated; one being in use during such times as the *fume* or deposit (a black oxide of lead) is taken out of the other. There are also upwards of four miles of gallery for the same purpose connected with other mills belonging to Mr.

It appears then, that, provided it be possible for mineral vapours to be generated and gain access to fissures in rocks, it is not impossible for some of them at least to be condensed and deposited on the sides of lodes in the way in which we now find them, even close to the present surface.

This method of formation, however, would not account for the strings of ore that are often found leading from lodes into the minute cracks of the walls, frequently horizontal, and often more or less completely blending with the rock itself; nor would it account for the detached nests and concretionary lumps of ore frequently found, entirely enclosed in rock, both in the neighbourhood of mineral veins and elsewhere.

In the rounded concretionary blocks of ironstone, for instance, found in the clays of the coal measures, crystals of galena and of blende are often found together with those of iron pyrites, carbonate of lime, and others. In the mountain limestone and Old Red sandstone rocks of the south of Ireland and elsewhere, small cavities are found, not so large as the fist, filled up with crystalline concretions of galena and of specular iron ore.

Any explanation of the formation of the contents of mineral veins must include that also of the deposit of these detached and isolated nests of minerals, as well as the formation of quartz veins in general, and all other veins, and strings, and nests, and cavities that have been more or less completely filled by any crystallized mineral substances of whatever kind.

If we take the crystalline stalactites and stalagmites forming in caverns as the basis of our reasoning on this subject, and suppose all other cavities to have been either filled or to be in process of filling by crystalline minerals in a similar way, we shall probably not be far from the truth.

We may not be so well acquainted with the exact nature

Beaumont in the same district and in Durham, and further extensions are contemplated. The value of the lead thus saved from being totally dissipated and dispersed, and obtained from what might be called *chimney scrapings*, considerably exceeds ten thousand pounds sterling annually. It should be observed, however, that the mines of which these chimneys or flues are an appendage, are the largest lead mines in the world, and that the royalties or freehold rights of mining belonging to Mr. Beaumont, in the county of Northumberland alone, extend over more than a hundred square miles, in addition to extensive leasehold mines in the county of Durham."

of the process by which other minerals are dissolved in one place and re-deposited in another, as we are in the case of carbonate of lime, but we may feel pretty well assured that water is the principal medium through which other agents act in the one case as carbonic acid does in the other.

The association of different minerals in different veins, may possibly some day throw some light on the nature of these processes. Werner, for instance, says that galena or lead glance, copper pyrites, blende, and calamine frequently occur together; as also cobalt, copper, nickel, and native bismuth; tin, wolfram, tungsten, molybdena, and arsenical pyrites, etc. It appears that magnetic iron (the emery of the gold diggers) generally occurs with gold. Silver also is commonly found in lead ore. Recent experiments of Dr. Percy show us that minute quantities of gold occur in almost all lead ores, as well as in all copper and iron pyrites.

The relation between the contents of mineral veins and the nature of the rock which they traverse is also important. The lead veins of the north of England traverse limestones, sandstones, and shales, and their contents vary according to the nature of the substances which form the walls of different parts of the "lodes." It is even said that the "lodes" vary in contents in different beds of limestone, but it does not appear that the richness of a lode is constant for any beds of limestone. When one or both walls consist of shale, the lode is always poorest, but this may be the result simply of the greater contraction of the fissure and unstable condition of its walls when soft than when they are hard.

The supposed relation between mineral veins and the age of the rocks they traverse is probably an accidental one only. Mineral veins may be expected in all highly-indurated and greatly fractured rocks, whatever may be their geological date. Neither does the connection between mineral veins and the occurrence of igneous rocks appear to be better founded, than on the probability that igneous rocks will be most likely to be found in the same indurated and fractured districts which we have seen to be essential for the production of mineral veins.

PART II.

PALÆONTOLOGY.

ZOOLOGY AND BOTANY.

CHAPTER IX.

DEFINITION.

PALÆONTOLOGY is the study of "fossils." The old geologists used to include minerals or any other distinct bodies that were found in rocks under the term of fossils. By "a fossil," however, is now meant the body, or any portion of the body, of an animal or plant buried in the earth by natural causes, or any recognisable impression or trace of such a body or part of a body. "Fossils," then, are "organic remains," including under the word remains even footprints or other such transient impressions. MM. D'Orbigny and Pictet introduce into their definitions of the word "fossil," the time when and the circumstances under which this burial took place. It appears to me that this is not necessary. Nobody would say that shells lately thrown up on the beach, and covered with sand, were *buried in the earth*, while every accumulation of shells, or bones, or plants which could be said to be *buried in the earth* by any other than human agency, even if that burial took place last year, would be well worthy of the attention of the Palæontologist, and might be, without impropriety, spoken of as *fossil*. Here, as elsewhere, no hard line can be drawn between the present and the past. All such terms, then, as *sub-fossil* which we sometimes meet with, are inconvenient and unnecessary.

Neither can we include in a definition of a "fossil" any reference to its present state. Some fossil shells found in comparatively old rocks, such as the soft compact clays of the oolitic series, are in fact less altered from their living state than many shells included in recent coral reefs. Wood again may be found in such rocks still soft and but little altered, while in much more recent formations it is entirely mineralised and converted either into flint or into coal.

Petrifaction.—Any substances firmly buried in pure clay, not impregnated by any active mineralising agent, and kept from the presence of air or water, may be retained unaltered for an almost indefinite period.

On the other hand, it has necessarily happened that in the majority of instances the enclosing rock has either itself contained some active substance, or has given passage to percolating fluids that have effected changes; or again, the substances contained in the enclosed body itself have acted on each other, or on the surrounding rock, and thus the fossil has become more or less mineralised or *petrified*, as it is called. We have seen previously (p. 140, *et seq.*) that rocks themselves undergo great alteration in their internal structure in the course of time, and that minerals are changed or metamorphosed *in situ* from one into another by the gradual action of chemical laws. Fragments of animals and plants, dead, and therefore subject to the inorganic and not to the organic laws of existence, to the *mineral* laws, as they might be called, and not to the laws of life, must of course be subject to the same actions as the mineral constituents of rocks.

The hard parts of animals, especially such as bones, shells, and corals, are composed principally of those mineral substances (salts of lime, etc.) which are most easily acted on by the most frequently occurring chemical processes. In breaking open fragments of coral lying on a coral reef, the internal parts are very frequently found to be filled with a mass of crystalline carbonate of lime, obliterating or obscuring the organic structure. When shells or corals are embedded in rock percolated by water, it is almost impossible for them to escape that partial re-arrangement of their particles which shall give them an internal crystalline structure.

If the water contain any mineral substance, such as silica, sulphuret of iron, etc., and the rock be such as to allow of the original carbonate of lime being removed, nothing is more likely than that, particle by particle, the one mineral should be substituted for the other, and the lime-shell, etc., be converted into a flint or iron pyrites one. It depends altogether on the surrounding circumstances, and the nature of the processes set up, whether buried wood be converted into coal or into flint or opal.

Still, as this conversion is a molecular one, taking place only in the ultimate particles of these substances, which are of inconceivable minuteness, the organic structure is often perfectly preserved, the little internal pores or cells retaining their form so completely as to be recognised by the microscope even in the minutest fragment of the fossil. It is as if a house were gradually rebuilt, brick by brick or stone by stone, a brick or a stone of a different kind having been substituted for each of the former ones, without either the shape or size of the house, or the form or arrangement of one of its rooms, passages, or closets, or even the number and shape of the bricks and stones, having been altered. All the hollow spaces are, however, generally filled up either by the earthy matters in which the fossil is enclosed, or by mineral substances which have percolated through their walls.

It sometimes also happens that the substance of the fossil has been altogether removed, and merely its "mould" or impression left in the rock that enclosed it. This mould or external cast, in some instances, also encloses an internal cast consisting of the matter which gained access to the interior of the fossil. Sometimes the fossil is very distinct, and can be completely detached from the matrix or rock in which it is enclosed. Sometimes, on the other hand, it is so intimately united with the matrix, and so blended with the substance of the rock, that we can only observe a section of it when the rock is broken open. Sometimes the fractured surface of the rock must be polished before we can distinguish the structure or even the outline of the fossil.

Classification of the Animal and Vegetable Kingdoms.

It is obvious that in order rightly to understand the facts of palæontology we must have some knowledge of existing animals and plants. Fossil animals and plants are either of the same species as those now living or of different species. in order to ascertain which of these is true, we must necessarily know the living species when we see them. Whether the species of fossils be living or extinct, in order to draw any conclusions respecting them, as to the place where they lived, for instance, and the circumstances under which they were buried, we ought to know the habits of the living species with which they are identical, or to which they are most nearly allied.

No man can become a palæontologist who is not also a naturalist, (botanist and zoologist); and no man can become a thorough zoologist who has not had that early training in anatomy which falls to the lot of the medical student only. To become a thorough palæontologist, then, a man must have what is called a medical education. Many men, however, even without this make themselves masters of a particular branch of the subject, but always with difficulty and always with a certain deficiency of authority. Good palæontologists are rarer even than good chemists and mineralogists. Still a certain amount of palæontological knowledge is more absolutely necessary to the geologist than even the merest smattering of mineralogy, and more useful to him than the most profound acquaintance with that science. But in order to acquire even a smattering of palæontology we must be at least acquainted with the general outlines of botany and zoology. I am accordingly induced to insert here, for the convenience of the student, such an abstract of the classification of the animal and vegetable kingdoms as shall serve to give him an idea of the totality of the organic kingdom, both living and fossil, and afterwards to lay before him an abstract of those animals and plants which are found in a fossil state.

The animal kingdom was divided by Cuvier into four sub-kingdoms: Vertebrata, Mollusca, Articulata, Radiata. Recent authorities have, however, seen necessary to divide it into five, splitting the Radiata into two, and re-arranging some of its constituents.

The following classification is one supplied to me by my friend and colleague Professor Huxley, with the exception of that of the Mammalia, which is the recent classification of Professor Owen. In perusing it the student must be guarded against taking its arrangement as strictly a linear one. The highest animals are doubtless placed first and the lowest last, and this idea of subordination runs throughout; but it is impossible to carry it out accurately in detail, since many of the orders should be arranged side by side, or still more properly, in circles, in order strictly to express their mutual relations. Those orders which are entirely extinct are printed in italics.

KINGDOM ANIMALIA.

SUB-KINGDOM VERTEBRATA.

CLASS I.—MAMMALIA.

SUB-CLASS *Placentalia*.

		Examples.
Archencephala.		
Order 1. Bimana		Man.
Gyrencephala.		
2. Quadrumana	Catarhini	Old world monkeys.
	Platyrhini	American do.
	Strepsirhini	Lemurs.
3. Carnivora	Digitigrada	Lion, wolf, hyæna, weasel.
	Plantigrada	Bear, racoon, badger.
	Pinnigrada	Seal, morse.
4. Artiodactyla (Even toed, 2 or 4).	Nonruminantia	Hippopotamus, pig.
	Ruminantia	Camel, stag, sheep, cow.
5. Perissodactyla (Odd toed, 1 or 3).	Solipedia	Horse.
	Pachydermata	Rhinoceros, hyrax, tapir.
6. Proboscidea		Elephants.
7. *Toxodontia*		Toxodon.
8. Sirenia		Dugong, manatee.
9. Cetacea		Whale, porpoise.
Lissencephala.		
10. Cheiroptera	Frugivora	Pteropus.
	Insectivora	Bat, vampire.
11. Insectivora		Hedgehog, shrew, mole.
12. Bruta = Edentata		Sloth, armadillo, ant-eater.
13. Rodentia		Rat, hare, squirrel, beaver, porcupine.

SUB-CLASS *Implacentalia*.

Lyencephala.	
Order 1. Marsupialia	Kangaroo, wombat, opossum, dasyurus, thylacinus, etc.
2. Monotremata	Platypus, echidna.

CLASS II.—AVES (*Birds*).

Order 1. Raptores	Eagle, hawk, vulture, owl.
2. Scansores	Woodpecker, cuckoo, parrot.
3. Passeres	Thrush, warbler, sparrow, swallow, crow, lark.
4. Columbæ	Pigeon, dove.

		Examples.
Order	5. Gallinæ	Fowl, grouse, partridge, turkey, peacock.
	6. Cursores	Ostrich, emu, apteryx, bustard.
	7. Grallatores	Crane, heron, plover, snipe, rail.
	8. Palmipedes	Duck, albatross, gull, puffin, pelican.

Class III.—REPTILIA.

Order	1. Chelonia	Turtle, tortoise, etc.
	2. Crocodilia	Crocodile, alligator, etc.
	3. Lacertilia	Lizard, etc.
	4. *Dinosauria*	Megalosaurus, etc.
	5. *Enaliosauria*	Ichthyosaurus, etc.
	6. *Pterodactylia*	Pterodactyle.
	7. Ophidia	Snakes.

Class IV.—AMPHIBIA.

Order	1. *Labyrinthodonta* ?	Labyrinthodon.
	2. Batrachia	Frog, toad, etc.
	3. Saurobatrachia	Proteus, siren, etc.
	4. Ophiomorpha	Cecilia (blind worm).

Class V.—PISCES (*Fish*), nearly after Müller.

Order	1. Dipnoi	Lepidosiren.
	2. Elasmobranchii	Sharks and rays, and all what are commonly called cartilaginous fish, minus the Ganoids, Marsipobranchs, and Pharyngobranchs.
	3. Ganoidei	Sturgeon, lepidostens, etc.
	4. Teleostei	Perch, cod, salmon, and ordinary Osseous fish.
	5. Marsipobranchii	Lampreys, etc.
	6. Pharyngobranchii*	Amphioxus.

Sub-kingdom ANNULOSA.

Div. I. Articulata.

Class I.—INSECTA.

Order	1. Hymenoptera	Saw-fly, ichneumon, etc.
	2. Coleoptera	Beetles, etc.
	3. Neuroptera	Dragon-fly, white ant, etc.
	4. Strepsiptera	Stylops.
	5. Lepidoptera	Butterfly, moth, etc.
	6. Diptera	House-fly, etc.
	7. Orthoptera	Cricket, locust, earwig, etc.
	8. Hemiptera	Bug, cicada, aphis, etc.
	9. Aptera	Flea, etc.

* Agassiz arranges the fish into four orders, according to the structure of the scales; 1. Placoids, which includes the Elasmobranchii, and some others; 2. Ganoids, which correspond to No. 3, and some others; 3. Ctenoids, and 4. ~~Placoids~~, which together Cycloids nearly correspond with the fourth order, the Teleostei.

CLASS II.—MYRIAPODA.

		Examples.
Order 1.	Chilopoda	Centipede.
2.	Chilagnatha	Millipede.

CLASS III.—ARACHNIDA.

Order 1.	Pulmonata	Scorpion, etc.
2.	Amphipneusta	Spiders.
3.	Trachearia	Acarus, etc.
4.	Pycnogonida ?	Pycnogonum.

CLASS IV.—CRUSTACEA.

Order 1.	Podophthalmia	Lobster, crab, etc.
2.	Edriophthalmia	Isopods, amphipods, læmodipods, etc.
3.	Branchipoda	Phyllopoda, cladocera, daphnia, apus, etc.
4.	Copepoda	Cyclops, suctorial crustacea.
5.	Ostracoda	Cythere, cypris.
6.	Cirripedia	Barnacles.
7.	Xiphosura	King-crab, etc.
8.	*Trilobita*	Trilobites.
9.	*Eurypterida*	Eurypterus, pterygotus.

Div. II. Annuloida.

CLASS V.—ANNULATA (*Busk*).

Order 1.	Polychæta	Nereis, serpula, lob-worm.
2.	Oligochæta	Earth-worm.
3.	Discophora	Leech.
4.	Tardigrada ?	Arctiscon.
5.	Sagittida ?	Sagitta.

CLASS VI.—SCOLECIDA (*Busk*).

Order 1.	Trematoda	Fluke.
2.	Tæniada	Tape-worm.
3.	Acanthocephala	Echinorhynchus.
4.	Nematoidea	Thread-worm.
5.	Gordiacea	Hair-worm.
6.	Turbellaria	Planaria.
7.	Rotifera	Rotifer, brachionus, lacinularia.

CLASS VII.—ECHINODERMATA.

Order 1.	Holothuridæ	Sea-cucumbers, trepang, etc.
2.	Echinidea	Sea-urchins, etc.
3.	Ophiuridæ	Sand-stars, etc.
4.	Asteridea	Star-fish, etc.
5.	Crinoidea	Feather-star, stone-lily, etc.
6.	*Blastoidea*	Pentremites.
7.	*Cystidea*	Cystidians.

Sub-kingdom MOLLUSCA.

Class I.—CEPHALOPHORA.

	Examples.
Order 1. Dibranchiata	Squid, argonaut, poulpe, belemnite.
2. Tetrabranchiata	Nautilus, ammonite, etc.
3. Pulmonata	Snail, slug, etc.
4. Pteropoda	Clio, carinaria, etc.
5. Gasteropoda diæcia, or Prosobranchiata	Whelk, periwinkle, cone, cowry, limpet, chiton, etc.
6. Gas. monœcia, or Opisthobranchiata	Tornatella, bulla, doris, aplysia, etc.

Class II.—CONCHIFERA.

1. Lamellibranchiata, or Acephala	Cockle, mussel, oyster, venus, and all ordinary bivalve shells.

Class III.—MOLLUSCOIDEA.

Order 1. Brachiopoda, or Palliobranchiata	Terebratula, (lamp-shell), crania, orbicula, lingula, and other similar bivalve shells.
2. Polyzoa, or Bryozoa	Flustra, eschara, fenestella, retepora, and other similar zoophytes.
3. Ascidioida, or Tunicata	Ascidia, botryllus, salpa, etc.

Sub-kingdom CŒLENTERATA.

Class I.—ACTINOZOA.

Order 1. Alcyonaria	Alcyonium.
2. *Rugosa*	Four-starred corals.
3. Zoantharia	Six-starred corals, sea-anemone, beroe, etc.

Class II.—HYDROZOA.

Order 1. Lucernaroida	Sertularia, and similar zoophytes.
2. Hydroida	Medusa, hydra, etc.

Sub-kingdom PROTOZOA.

Class I.—STOMATODA.

Order 1. Noctilucida?	Noctiluca.
2. Infusoria	Paramœcium, euplotes, vorticella.

Class II.—ASTOMATA.

Order 1. Spongiadæ	Sponge, etc.
2. Foraminifera	Rotalia, nodosaria, nummulites, orbitolites.
3. Thalissicolidæ	Sphærozoum, thalassicolla.
4. Gregarinidæ	Gregarina.

It is less necessary for the geologist to understand the details of the classification of the Vegetable Kingdom, and I shall therefore give only its great sub-divisions, taken from the programme of the Museum of Irish Industry.

VEGETABLE KINGDOM.

Class I.—THALOGENS.

		Examples.
Order 1.	Algæ	Sea-weeds.
2.	Fungi	Mushrooms, etc.
3.	Lichens	Tree and stone mosses, etc.
4.	Characeæ	Chara, etc.

Class II.—ANOGENS.

Order 1.	Hepaticæ	Liverworts.
2.	Musci	Mosses.

Class III.—ACROGENS.

Order 1.	Lycopodiaceæ	Club-moss, etc.
2.	Marsiliaceæ	Pepper-worts, etc.
3.	Equisetaceæ	Horse-tails.
4.	Filices	Ferns.

Class IV.—ENDOGENS.

Order 1.	Glumiferæ	Grass, etc.
2.	Petaloideæ	Banana, orchis, palms, lilies, screw-pines, etc.
3.	Dictyogenæ	Yam, smilax.

Class V.—EXOGENS.

Order 1.	Apetalæ.	
	a. Gymnosperms	Pine, cypress, cycas, etc.
	b. Angiosperms	Spurge, nettle, oak, elm, etc.
2.	Corolliflora	Primrose, convolvulus, heath, etc.
3.	Calycifloræ	Dandelion, campanulæ, rose, pea, etc.
4.	Thalamifloræ	Crows-foot, poppy, geranium, etc.

Of the above classes, I., II., III., form the Cryptogamia, and IV. and V. the Phanerogamia of Linnæus—the Acotyledons and Cotyledons of some authors—while I. and II. constitute the Cellulares, and III., IV., and V., the Vasculares of other authors.

Distribution of Animals and Plants.—Next in importance to the classification is the knowledge of the distribution of organic beings over the globe. This distribution is twofold, vertical and lateral. Both on land and in water, the animals and plants vary as we depart upwards or downwards from the level of the sea. We are all familiar with this variation on the land, everybody being aware that the vegetation undergoes as great a change in ascending vertically upwards from the level of the sea up the sides of a lofty mountain to the regions of perpetual snow, as it does in travelling laterally towards the pole, till we reach the point where perpetual snow comes down to the sea level. With the change in the vegetable life an equal change in the animal life is a necessary consequent effect in all regions of the globe. Even in our own islands we know that ptarmigan and grouse are not to be found in the cultivated plains, nor nightingales nor linnets on the mountain tops.

We are also all of us more or less familiar with the fact of the lateral distribution of terrestrial life. We know, for instance, that plants such as the vine, the apple, the banana, the cocoa-nut, rice, wheat, figs, oranges, currants, do not grow indiscriminately wherever they may be planted; they are confined to certain portions of the globe where the climate is suitable to them. We know also that the polar bear and the lion, the reindeer and the camel, the musk-ox and the giraffe, could not exchange habitats, and could not in a wild state inhabit the same countries. These general facts are so obvious as to be familiar to every one; but their very familiarity, perhaps, prevents their full value and importance from being commonly appreciated. They are the most striking expressions of a general law that reigns throughout the animal and vegetable kingdoms, in the ocean as in the air, in past geological time as well as at the present day—with respect to the most minute and insignificant of living beings, as well as to the largest and most important.

Schouw divided the globe into twenty-five botanical regions, in each of which at least one half of the known species, a quarter of the genera, and some individual families, were peculiar to that region, and found nowhere else. These regions are scattered variously over the globe, but they admit, as shown by Meyen, of an arrangement into zones, the boundaries of which are parallels of latitude, or more properly isothermal lines (Henfrey), each zone surrounding the earth, and including regions in which, although the plants are distinct, yet they are more like and more nearly allied to each other than those of other zones. Starting with the equatorial zone, there is on each side of it a tropical, sub-tropical, warm temperate, cold temperate, sub-arctic, arctic, and polar zone. Not only are the regions of plants in each of these zones similar to each other, but there is another kind of similarity in those of corresponding zones in the opposite hemispheres, so that the plants may be said to be, although entirely distinct, representative of each other.

The evergreen forest trees, for instance, of the northern warmer temperate zone, are represented by other evergreen forest trees in the south warmer temperate zone, each zone still having its distinct regions of plants, as defined above.

Then, if we regard the vertical distribution of plants, and start from the level of the sea in the equatorial zone up the sides of a great mountain chain, we pass in succession through spaces answering to these zones, finding belts of vegetation as we ascend, either the same as, or representative of, all the latitudinal or isothermal zones, till we reach the representative of the polar one, at the margin of perpetual snow. Similarly in all other zones as we ascend from the level of the sea, we pass successively in altitude through the representatives of all the zones that interpose in latitude between the lower one and the pole.

In Britain, for instance, the tops of our mountains are clothed with arctic or sub-arctic plants.

The laws of the geographical limitation of species, vertically and laterally, and the representation by distinct but similar species in corresponding regions thus indicated in the vegetable kingdom, are equally apparent in the animal kingdom.

The lion and the tiger are confined to the old world, but they are represented in the new by the puma and the jaguar; the camel of the one is represented by the llama and alpaca of the other; the wolverine of the one by the glutton of the other; the bison of the one by the buffalo of the other; and so on through a vast number of different genera, or of different species of the same genus among the mammalia. The quadrumana, for instance, are divided into three great groups, the platyrrhini, or broad-nosed monkeys, confined to America, the catarrhini, or straight-nosed monkeys, to Asia, Africa, Europe, and the strepsirhini, or lemur monkeys, confined to Madagascar, which is in this respect like a satellite of the neighbouring continent.

If, again, we enter into more minute details, we find the easily domesticated Asiatic elephant represented in Africa by a different and untamable species, different species of rhinoceros inhabiting different parts of Africa and Asia, different species of oxen, bears, deer, wolves, foxes, leopards, or other large cats, and many other animals inhabiting, and confined to, different districts both of the Old World and of the New. These different species may be looked upon as representative of each other, as often playing similar parts, and performing the same offices in nature; and as regards many of them, we know of no reason why they might not have been transposed,—why, for instance, the puma might not have lived and flourished in the Old World, and the lion in the New; or why the African elephant or rhinoceros might not just as well have lived in Asia, and *vice versâ*.

This law of the occurrence of representative groups in the different quarters of the globe, however, is not universal. There are some groups of animals almost entirely confined to one particular region, with no representatives elsewhere. The Marsupialia and Monotremata, for instance, are confined to Australia and the adjacent islands. with the single exception of the didelphis (opossum), found in North and South America. The Edentata, again, are confined to South America, with the exception of the manis or pangolins, found in South Africa and South Asia. There are, on the other hand, no Insectivora in either South America or Australia.

But then, again, when we come to examine the details of these peculiar zoological provinces, we find that they are little worlds within themselves, in which the law of limited representative specific areas reappears on a smaller scale. In Australia, for instance, the kangaroos, wallibis, opossums, etc., of one part of the country are not the same species as those of another. Even in precisely the same latitudes, with exactly similar climates and kinds of country, as, for example, in the Sydney and Swan River districts, the animals, though closely allied and very similar, are yet nearly all of distinct species.* So in South America there are different species of sloth, armadillo, and ant-eater, in different districts.

Here again, too, we are met with exceptions to the law of representation, in such facts as the absolute restriction of those very peculiar animals, the Dasyurus ursinus (native devil) and Thylacinus Cynocephalus (native tiger), to the small island of Tasmania.

Even with regard to birds, creatures whose powers of easy and rapid locomotion seem to place the whole world at their disposal, we find the same restriction within geographical boundaries, which they rarely or never overstep. The red grouse and the partridge of the British Islands are not known on the continent; the nightingale which makes vocal the summer nights of the south-east of England, as far

* The late lamented Mr. Gilbert once informed me, that with the single exception of the Echidna, he believed there was no species of mammal common to New South Wales and Western Australia, and that the birds were almost equally different.

north as Cambridge and Northampton, rarely or never penetrates into the mild districts of Somerset and Devon. Not to detain the reader with such conspicuous instances as the lammergeyer, confined to the pinnacles of the Alps, and the condor whose home is the still loftier Andes, I must yet point his attention to the yet more remarkable limitation of the oceanic birds. We might sail round the world in the latitude of the Cape of Good Hope or thereabouts, ever surrounded by flights of albatrosses and cape pigeons, that seem sometimes to people the air, but if the navigator turn his vessel towards the north, he soon reaches a latitude where all these beautiful creatures disappear. This takes place not gradually, but at once. The ship may be surrounded by the usual flocks at night, and the next morning not one of them will be seen, nor ever after, till the navigator returns to the line where they were left, and then he finds fresh flocks, as if awaiting his arrival.

Returning for another instance to Australia, I may mention that there are peculiar species of parroquet and other birds in Victoria, South Australia, and Swan River, differing from each other and from those of New South Wales, while many of the latter range along the whole stretch of the eastern coast, from 40° to within 10° or 12° of the equator. The same species in this case seem to cling to one range of high land, even though stretching through different climates, while they do not cross the intervening plains on to other mountain ranges, although they are in the same latitudes, and enjoy the same climates as the eastern coast range.

Perhaps, however, there is no more striking instance in the world of the limitation of species, than that described by Mr. Darwin, and observed by him in the Galapagos islands. Here we have a small cluster of islands all volcanic, and all therefore of the same character, and all nearly under the equator, and therefore enjoying the same climate, and yet not only have they a fauna and flora distinct from that of the rest of the world, but different species are found in the different islands, making the group into a little world of its own, a satellite, as it were, of the great American continent. The animals and plants bear the American stamp, resembling those of America more than those of any other part of the world; they are, however, specifically and even generically distinct. They contained no mammalian animal except one small mouse, but numerous reptiles, snakes, lizards, and tortoises, some of the lizards being marine, and the only living species of their class that inhabit the sea, and the large land tortoises being also of very peculiar forms. Among twenty-six species of land birds, only one is known elsewhere, and some even of these were absolutely confined to particular islands, although some of those islands were within sight of each other.—(*Darwin's Journal*).

Let us now turn to the ocean, and we shall find its inhabitants similarly confined within certain definite boundaries.

The great sperm whale is confined to the equatorial regions of the ocean, extending down the shores of America, so as to double Cape Horn, although he is said never to double the Cape of Good Hope. His limits are singularly contracted in part of the Pacific Ocean, east of the Marquesas islands, and then curiously expanded north and south, so as to include a deeply indented bight or gulf of the North Pacific, and take in New Zealand in the South. The right whale of the north polar sea, and the other species which goes by the same name towards the south pole, have similar singularly waved and indented boundaries towards the tropical regions of the ocean.—(See Maury's Whale Chart, *Phys. Geog. of the Sea.*) The different seals, again, which are so widely distributed as a family all over the earth, have yet very strict, and often very narrow limits to the range of their different species.

Fish are similarly limited. The cod, the turbot, and the sole, with many other ichthyic delicacies of the North Atlantic, are not to be found in other seas; some not even in the Mediterranean, where the thunny and other fishes take their place, which are equally unknown to the Atlantic. The salmon, indeed, enters not only the rivers running into the North Atlantic and Arctic seas, but those of the west coast of North America; but with that exception, this noble fish is unknown in all the rest of the world, occurring in no river even that runs into the Mediterranean or Black Sea. Similar laws of distribution are found to prevail with regard to the fish of all other coasts, while the wider expanses of the open ocean are almost destitute of fish, except an occasional shark or some few widely wandering species, such as the albicore and bonito, and in some places the flying fish. The problem of the distribution of fresh-water fish is perhaps a still more curious one. Such facts as the occurrence of rare fish in different widely separated lakes, such as the different species of Corregonus, the porran of Cumberland, the pollan of Lough Neagh, and the gwynniad of Bala Lake, afford matter for many speculations; while different fish being found in the rivers on opposite sides of a water-shed, as in the case of the so-called cod-perch, found in the rivers flowing west of the Blue Mountains of New South Wales, but not in those flowing east of them, and other similar instances, point to the prevalence of the same general laws that govern the distribution of other forms of life.

It was Professor Edward Forbes who first clearly pointed out that marine life had a vertical, as well as a lateral distribution.

The climates of the sea vary even more rapidly in depth than those of the land do in height. This might have been expected *a priori*, since water is less permeable to heat and light than air is, and exerts a more rapidly increasing pressure than it. The light and heat of the sun, the great vivifying principle of nature, must lose all influence at the depth of a very few hundred feet into the ocean even under the tropics, where, in the air, life ranges through a vertical zone of more than 16,000 feet. Professor Edward Forbes' researches show, that observed facts correspond with such *a priori* considerations.

He divided the sea into five vertical zones as follows:—

1. The Littoral zone,* the space between high and low water-mark, or, where there is no tide, the water's edge.
2. The Circumlittoral zone, from low water-mark to about 15 fathoms.
3. The Median zone, from 15 to 50 fathoms or thereabouts.
4. The Inframedian zone, from 50 to about 100 fathoms.
5. The Abyssal zone, from 100 fathoms to the greatest depth to which life, whether animal or vegetable, can continue to struggle for existence.

These zones are applicable to all coasts over the whole globe, since in every part of it life will be found to vary, and generally to diminish, as we descend into the sea, in the same way as it does when we ascend into the air. The level of the sea, and a few feet above and below it, is the populous film of the earth; departing from that film in either direction, living beings rapidly become less numerous, and shortly disappear.

Besides these vertical limits, however, all the inhabitants of the sea, as well as the fish, have their lateral boundaries. The Mollusca, the Crustacea, and the Echinodermata, have their provinces and districts, the limits of which they do not transgress. Professor Edward Forbes divided the marine life of the globe, including fish, mollusca, and radiata, into twenty-five provinces, like the botanical provinces, varying greatly in size, and scattered round all the coasts of the world. Like the botanical provinces, too, he grouped them into certain belts surrounding the globe, which he called homoiozoic belts, or belts of similar life. These he made nine, namely, one Central or Equatorial, and then on each side of it four, which he called Circumcentral, Neutral, Circumpolar, and Polar, distinguishing those of the two hemispheres by north and south respectively. The boundaries of these belts correspond more or less precisely with isothermal lines, modified by the warm and cold oceanic currents.

The Great Central belt occupies the whole region of the tropics, with the exception of a great indentation on the west coast of South America, where a cold current runs from the Antarctic Ocean up to the coast of Peru. Throughout the Indian and Pacific Oceans it has but one province, the Indo-Pacific, but includes the Panamian province about the Bay of Panama, and the Caribbean and West African provinces in the Atlantic Ocean.

* The word "zone" here has a different meaning from that in which it was used in speaking of the distribution of vegetable life, where it was applied to what Professor Forbes called homoiozoic belts.

Proceeding from this Great Central belt towards the north, we have the North Circumcentral, which stretches from the south of Morocco to the north of France, including the Lusitanian and Mediterranean * provinces, but is in other parts much narrower, and includes the Carolinian, Californian, and Japonian provinces. Next comes the North Neutral, including our own large Celtic province, and the much narrower Virginian,† Oregonian, and Mantchourian provinces. Then comes the North Circumpolar belt, including the Boreal province (which stretches from Norway to Nova Scotia), and the Sitchian and Ochotzian‡ provinces of the Pacific, and lastly the North Polar belt, which has one province, the Arctic, co-extensive with it.

In the southern hemisphere we have the South Circumcentral belt, generally wider than the north one, especially on the west coast of South America, including the Peruvian, Urugavian, South African, and Australian provinces; and then the others, which are known only on the shores of South America, the South Neutral, including the Araucanian and East Patagonian provinces; the South Circumpolar, containing the Fuegian provinces;§ and the South Polar, the Antarctic province.

In order that the reader may form a somewhat more definite notion of the facts of this distribution, in its vertical and lateral range, I will give here Professor Edward Forbes' "Diagram of Zones of Depth." In this the fish are marked by capitals, the vegetables by italics.—*Johnston's Physical Atlas*, second edition.

The reader will remark that the genus Littorina occurs in every one of the provinces; the species, however, are different in each, as in the Arctic and Boreal seas we have obtusata, tenebrosa, green landica; in the Celtic seas, littorea and littoralis; in the Mediterranean, tigrina; in the Indo-Pacific, intermedia, melanostoma, scabra, picta, pulchra, lineolata, punctata, and many others; in the Australian, rugosa, squalida, etc., and we might extend the list to the peruviana in the Peruvian province, the araucana and africana in the Araucanian and South African provinces. The very specific names point to the fact of representation, for while under the tropics we have "beautiful," "painted," and "spotted" species, the "obtuse" and the "tenebrose" species of the north are represented by the "rugose" and "squalid" species of the southern hemisphere.

* The Aralo-Caspian is a branch of the Mediterranean, but according to Mr. Woodward (*Manual of the Mollusca*), the Mediterranean is only a branch of the Lusitanian, while the Aralo-Caspian is a distinct province.

† Mr. Woodward unites the Carolinian and Virginian provinces into one, the Transatlantic.

‡ Mr. Woodward unites these two and the Oregonian under his Aleutian province.

§ Under the term Magellanic, Mr. Woodward comprises the Araucanian, Fuegian, and Antarctic, and also suppresses the Urugavian between the Patagonian and Carribean provinces.

Zones.	Fath.	Arctic and Boreal.	Celtic.	Mediterranean.	Indo-Pacific.	South Australian.
LITTORAL.	0	Littorina. Acmæa testudinaria. Purpura lapillus. *Fucus.*	Patella and Littorina. Mytilus edulis. Purpura lapillus. GUNELLUS. *Fucus and Lichina.* *Corallina officinalis.*	Littorina, Fossarus. Patella. Mytilus minimus. Conus mediterraneus. Purpura hæmastoma. *Padina pavonia.*	Littorina, Querya. Haliotis, Conus. Nerita. Nassa, Ricinula. Purpura, Trochi.	Littorina, Patella. Haliotis, Parmophorus. Conus, Trochi. Mytilus. *Moniliformia.*
CIRCUM-LITTORAL.	15	Echinus neglectus. Margarita. Lacuna, Admeta. Cardita arctica. Astarte. MERLUCUS, MERLANGUS. *Laminaria.*	Echinus sphæra. Trochi. Lacuna, Patina. Rissoæ. BLENNIUS, LABRUS. *Laminaria, Zostera.* *Nullipora.*	Aplysiæ. SPAROIDEÆ, JULIS. Holothuriæ, Rissoæ. Trochi, Murex. Triton, Nassa, Cardita. *Caulerpa, Zostera.*	Comatula, Clypeaster. Holothuriæ. Madreporidæ, Astreidæ. Ovula, Melo, Mitra, Strombus. Triton, Murex, Terebra, Corbis. SCARUS, BALISTES. *Sargassum.*	Echinus. Mitra, Marginella. Columbella, Struthiolaria. Phasianella. Mactra, Myadora. Trigonia. *Durvillæa, Macrocystis.*
MEDIAN.	50	Ophiopeltis. Ctenodiscus. Terebratulina. Cuviera. Corallines.	Zoophyta hydroida. MORRHUA. Mangelia, Fusus. Natica, Capulus. Turbinolia, Pectunculus. Pecten.	Ascideæ. Pecten, Modiolæ. Mangelia, Mitra. Neara. *Dictyomenia, Codium.* *Nullipora.*	Cidaris, Astrophyton. Sp. of Murex, Turritella. Dentalium, Cardium. Nucula, Pecten.	Zoophyta hydroida. Turritella, Cardita. Cypricardia, Pectunculus. Nucula, Dentalium.
INFRA-MEDIAN.	100	MOLVA, SEBASTES. *Chimæra.* Ditrupa, Tethya. Comatula. Yoldia arctica. Nucula tenuis.	Brachiopoda. Astrophyton, Cidaris. Oculina, Tethya. Aporrhais pescarbonis.	Cidaris histrix. Turbo sanguineus. Brachiopoda. Echinus monilis. Corallium rubrum. *Nullipora.*		
ABYSSAL.		BERYX, GABIUS. GADUS abyssorum. Primnoa, Cidaris. Brissus, Astrophyton. Alcyonium arboreum. Virgularia finmarkia. Dentalium vitreum.	Ditrupa. Terebratula cranium.	Foraminifera. Dentalium gangulare. Syndosmya profundissima. Pecten Hoskini. Arca imbricata. Idmonea, Poromya.	(SOUTH AFRICAN.) Terebratulina sp. Pectunculus sp. Voluta costata } 150 fathoms.	(ANTARCTIC.) Primnoa Retepora Hornera Foraminifera } 160 to 400 fathoms.

Edward Forbes did not include the Crustacea in his data for marking out the marine provinces of life, doubtless because that had been already done, so far as regards lateral distribution at least, by Milne Edwards.—(*An. des Sc. Nat.*, 2d ser. t. x. p. 129, and last chapter of his *Histoire des Crustacées.*) M. M. Edwards had sketched out regions of Crustacea more or less coincident with those just described, and had shown, moreover, that as we proceed from polar to equatorial regions, the forms of Crustacea become more numerous, more varied and important, and the animals larger and of higher organisation. The same may be said of every kind of life, vegetable and animal. The species of Littorina just mentioned indicate it.

The boundaries of these various provinces or regions are sometimes very well marked. This is especially the case wherever any strong natural feature occurs, such as a very lofty mountain chain or a narrow and deep sea separating two land provinces, or a narrow neck of land, or the meeting of a cold and a warm current of water dividing two marine provinces. At other times adjacent provinces may be more or less blended into each other, so that it is difficult to say where one ends and the other begins.

M. Barrande, in his "Parallèle entre les depôts Siluriens de Bohême et de Scandinavie," has some very instructive remarks on the close approximation of widely distinct marine provinces. Wherever two spaces of sea are separated by a narrow neck of land, uniting countries which stretch far and without interruption through different climates, we may have totally different species within a few miles of each other. This happens at present in the instances of the Isthmus of Suez and Isthmus of Darien.

In the first case, according to the best authorities, there are no species of Fish or Crustacea common to the Red Sea and the Mediterranean with the exception of a few cosmopolitan species; neither are there any species of Mollusca common to the two seas, with a few doubtful exceptions; while with regard to the Zoophytes this is true without any exception at all.

In the second case, on the authority of M. Alcide D'Orbigny, there are 110 genera of Molluscs on the two coasts of South America, of which 55 are common to the Pacific and Atlantic Oceans; 34 peculiar to the Pacific, and 21 peculiar to the Atlantic. There is, therefore, a generic correspondence to the extent of one half; that half being probably the most important, and containing the greatest number both of species and individuals. But these 110 genera contain 628 species, and of these *one only* is to be found common to the Atlantic and Pacific Oceans.

The shells, then, and other animal remains now being deposited in the Gulf of Mexico and the Bay of Panama in the one case, or in the Levant and the Red Sea in the other, will be entirely different specifically, though only 100 miles apart, while there will be a generic resemblance and identity, and a peculiarity of *facies*, to use a term of Von Buch's, which will always serve to show their close or accurate contemporaneity.

Species of animals and plants vary indefinitely in their range. Some, whose original constitution fitted them only for some peculiar combination of conditions that can occur in but one narrow locality, will of course be confined to that locality, since if they exceed its limits they will necessarily perish. Others, more hardy or more flexible in constitution, flourish equally well under many various circumstances, or will adapt themselves, before perishing, to new conditions which may be gradually brought into their province, or which they may find as they extend themselves into other provinces. Some species seem to be cast in a rigid mould admitting of no variation: every individual is so like its brethren that no mistake could ever be made in the recognition of any one of them. Other species, again, seem to be endowed with an original power of variation and aptitude for assuming every possible change of size, colour, form, and external marking, without losing their real specific characters. The dog (*Canis familiaris*) is a conspicuous instance of this infinite variety in one species, but it may be seen occasionally in many other species of animals and plants, though hardly perhaps to so great an extent. Some species of shells, however, assume variations of form, colouring, and marking, almost equal to the varieties in the external characters of dogs.

In many cases, perhaps in all, the power of great variation is co-existent with that of great range in distribution, both vertical and lateral. Some few species of plants and animals range, like man and the dog, over the whole earth, and can exist at all heights at which life is possible if terrestrial, at almost all depths if marine. These species are called cosmopolitan.

What is a species? has long been a *questio vexata* among biologists. If, however, we adopt the idea of a species being the descendants of a single pair, successive generations of that species being possible among those descendants and them only, we shall find the facts of the distribution of species harmonise well with this idea, while it is difficult to account for them on any other. A single pair being brought into existence, either by direct creation or by the operation of some utterly unknown physiological law, in a locality favourable to their existence, increase and multiply, and spread in every direction from that centre as far as circumstances (of food, heat, light, etc.) allow of their extension. These centres are called specific centres. Edward Forbes, however, showed that there was something more than this; that there were not only specific but generic centres; that species so nearly resembling each other as to allow of being grouped under a common name (as Conus, *cone*, for all the different species of cones in the world) were in many instances grouped together in one connected area, so that the part of the earth inhabited by them might be circumscribed by a continuous boundary (enclosed in a ring fence, as it were), and that in that area there was a central portion where the number of species of the genus was at a maximum, and from which it diminished gradually in every direction towards the circumference of the area. This generic circumscription is still more remarkable than that of a species, and appears quite incapable of any other explanation than that given to it by Professor Edward Forbes, namely, that it is a manifestation of the ideas of the Divine Mind.

These generic areas vary in extent like the specific areas, some being limited to a small part of the earth's surface, others spreading nearly over the whole of it; some having a very narrow vertical range, others a wide one. Even when we take still larger groups, such as families and orders (which are in fact but larger and larger genera) we still find traces of the same law; as, for instance, in the concentration of the Marsupials in Australia, of the Edentata in South America, and so on.

No one, I think, can read for the first time of these wonderful laws and dispositions in the life of the globe, even imperfectly as they are here presented, and take them in connection with the equally singular laws of migration of animals, without pausing to reflect for a moment on their value and significance. What a fulness and completeness of life in all its forms is here opened to our view, no single spot capable of supporting it being left barren; no conceivable collocation of physical conditions without its biological adaptation and utilisation. What an order, what forethought, and arrangement, and contrivance, what a mutual action and reaction, what an irresistible energy animates the globe, and what a varied polity rules the vegetable and animal kingdoms around unconscious man!

Perhaps, however, the reader will object to me that I am wandering rather widely from the subject of Geology, and that all this description of the distribution of the present life of the globe has no reference to the past—that it is not Palæontology. Such an objection, however, would be a complete mistake. We have only to substitute in the foregoing descriptions the idea of *time* for that of *space*, in order to make them as applicable to the past ages of the globe as to the present. In order to account for the facts of the present distribution of life, we were compelled to introduce the element of time, inasmuch as we attributed the populousness of the present specific areas to the multiplication of individuals by successive generations. Let us follow that idea a little further.

Suppose a new species of animal introduced by a single pair in any locality, and that their numbers in a few generations begin to multiply considerably. If they be vegetable feeders they will begin to diminish the numbers of some species of plants, and might in some cases gradually exterminate one or more species. Species of plants might in this way become extinct and make room, as it were, for the introduction of new species. But by diminishing their food these new animals might lessen the numbers, and either repress within narrower limits, or altogether starve out, some other species of animal less powerful than they, but dependent on the same vegetable food. If the new species of animal were flesh-eating, it would of course begin at once to prey on those around it, lessen the numbers of all, and perhaps exterminate some; in either case making room for its own multiplication, or the introduction of other species. Or the order of things might be reversed. Many of the physical changes we have previously spoken of—the conversion of land into sea, or of sea into land, or of deep sea into shallow, or *vice versa*—might so alter the conditions of the locality as to render the life that previously inhabited it no longer possible, and thus necessitate, as it were, the introduction of new species, either new altogether or new to that locality, and spreading into it from some neighbouring locality. Some of these physical changes, again, such as the union of lands or seas previously separated, would give passage to species from one territory to the other that might either directly or indirectly exterminate those previously inhabiting them.*

It follows from these considerations that if we allow a sufficient lapse of time to admit of the requisite physical changes, all the less powerful species, and all those fitted only for certain narrow localities, must eventually become extinct, and the whole earth be inhabited only by those hardy and robust tribes that were able to become cosmopolitan. To guard against such a state of things the frequent introduction of new species seems absolutely necessary, and as a matter of fact we know, from palæontological researches, that this extermination of one species and introduction of another has frequently taken place.

Hence arises a double consideration of the subject of the specific and generic distribution of life:—First, that of the contemporaneous distribution at any one period; secondly, that of the successive distribution of life, either for the whole globe or for any part of it, during successive periods of time. The problem thus becomes a very complicated one, and one for the solution of which the collection of data has hardly commenced. Nevertheless, we are met at the very outset with traces and indications of the now prevailing laws having existed in antecedent times. If, for instance, we find Australia inhabited by Marsupial animals, and South America by Edentata, we also find that the fossil mammalia of those countries were principally Marsupial and Edentate respectively. Large sloths and armadillo-like animals formerly inhabited South America, which is the home of the present sloths and armadillos. Large kangaroos and wombats, etc., formerly inhabited Australia, where alone living kangaroos and wombats are to be found. The same rule applies to other fossil animals found in different parts of the globe. Guided by these obvious considerations, we should naturally feel inclined to accept it as *a priori* probable that the same laws, which

* In addition to the causes mentioned in the text as conducive to the extinction of a species, or the diminution of the numbers of individuals composing it, may be mentioned those curious epidemic diseases or "murrains" which are common to both animal and vegetable, marine and terrestrial life. Some time previous to the year 1842 all the oysters and mussels on the south shore of Tasmania, near Storm Bay, were suddenly killed by some such disease.

regulate the distribution of life upon the globe now, prevailed during all antecedent geological time. We shall see hereafter how far observed facts support this conclusion or oblige us to modify it.

There are two sets of facts by which the present distribution of animals and plants is most remarkably linked with their past distribution.

There are now some apparent exceptions to the law of generic and specific areas, in the fact of outlying species or genera occurring in detached localities, separated by an intervening space from the main area. The existence of these detached localities would militate strongly against the idea of the spread of species and genera from certain centres, if it were not that it can be shown in many instances to be true, and is highly probable in others, that these detached areas were in former ages of the globe included within the main area, and that the fact of their detachment is owing to certain species or genera having perished and become extinct in the intervening spaces, their remains being now found fossil in those spaces.

Another set of facts is still more remarkable. The animals and plants of Australia are very peculiar, and many of them such as are found nowhere else living in the world. Now, some of the marine shells and some of the land animals and plants more resemble those found fossil in rocks deposited during an early geological period (the Oolitic) in our part of the world, than they do any other ordinal or generic types.* It is possible, therefore, that the fauna and flora of Australia are, as it were, the remnant † of that which, during the Oolitic period, was common to the whole globe, but which has everywhere else been superseded by the introduction of new generic and ordinal forms.

Again, the existing fauna and flora of North America

* See Sketch of Physical Structure of Australia.

† The student must be guarded against the idea of their being in any way the direct descendants, though they may be considered the representatives of Oolitic species. Why the Oolitic types should have been preserved in Australia, and new species introduced there, fashioned on those types, while in other parts of the world new types were used, is a mystery we are yet unable to fathom.

have remarkable generic and ordinal analogies with those which prevailed in Europe during a recent Tertiary age. There is perhaps a closer relation between those recently extinct European genera of animals and plants and the existing North American ones, than there is between the latter and the present European genera. It is possible, therefore, that the present European fauna and flora may be of more recent date than those of North America; that the North American ones having formerly been common to the two continents, those which inhabited Europe became extinct from some of the causes alluded to before, and our present species have been introduced to supply their place.*

In this way, the facts of the existing distribution and limitation of animals and plants become accounted for, and acquire, moreover, a deep historical interest, an interest as vivid to the palæontologist as that given by the study of warring and waning races of mankind to the historian and ethnologist.

* See the Testimony of the Rocks, by the late much lamented Hugh Miller, to whom geologists are under so deep a debt of gratitude.

CHAPTER X.

FOSSIL ANIMALS AND PLANTS.

I HAVE determined to lay before the student in this chapter a classified catalogue of fossil animals and plants, in order, first, to give him an idea of the richness and extent of the domain of palæontology, and, secondly, to furnish him with a reference as to the nature of any particular fossil he may find mentioned in this or other works, and also to place before him the main facts of the distribution of fossils in time. This latter subject will anticipate somewhat that which properly belongs to the third part of this work, but its utility will countervail, I hope, any breach of logical sequence.

I have taken Pictet's Palæontology as my guide with respect to fossil animals, having merely rearranged or transposed some of the matter to make it suit the classification previously given a little more closely.

I have not, however, attempted to do this throughout, and the student will take any variation in the two classifications as a hint that systems, however necessary, are, after all, more or less arbitrary and imperfect, representing often rather the limited powers of the human mind than the infinite variety and superabundance of nature. I have also ventured so far to disturb Pictet's arrangement as to place the extinct genera of each family or order by themselves, preferring to mark their geological history more strongly than their zoological relations.

For the plants, I have only given an abstract of those mentioned in Bronn's Index Palæontologicus, with very few additions.

ABSTRACT OF FOSSIL GENERA.

Under each family are mentioned, first the existing genera, and then those that are extinct. The letters following the names of the genera refer to the periods in which the species lived, viz.—Pri Primary; Sec Secondary; Ter Tertiary; or S Silurian; D Devonian, including the Old Red Sandstone; C Carboniferous; P Permian; T Trias, including the Muschelkalk and St. Cassian beds; L Lias; O Oolitic; W Wealden; Cr Cretaceous; E Eocene; M Miocene; Pl Pliocene; Ps Pleistocene; l and f species which are both living and fossil. The small letters, l, m, u, before a letter, mean lower, middle, and upper. The numbers following a letter refer to the number of known species, but when that number is over ten, it must often be taken rather as a rough approximation than an accurate statement.

The species are all *extinct* species, except those mentioned under the last head of living and fossil (l and f).

Class I.—MAMMALIA.

According to the new classification of Professor Owen, to which I have adjusted Pictet's matter.

Order 1. Bimana.—The only genus and species, Man, has been found fossil in several situations. One specimen of a fossil human skeleton is to be seen in the British Museum, in a hard coral limestone from the consolidated beach of Guadaloupe. Human bones have also been found fossil in recent Tertiary deposits, partly of volcanic origin, at Le Puy in Velay, and in various caverns, and elsewhere, associated with the remains of extinct species. Some doubt still remains in all these cases, as to how far the human remains may have been buried there naturally, or whether they may not have been buried by human agency, and are therefore not fossil according to our definition. If buried by human agency, their chronological significance is greatly deteriorated, if not altogether lost.

Order 2. Quadrumana, divided into three families.

a. Catarhini, or monkeys of the old world: Macacus, E 1, Pl 1 or 2; Semnopithecus, Pl 1 or 2; and the extinct genus Pliopithecus (or Protopithecus), E 1 or 2.

b. Platyrhini, or monkeys of South America: Cebus, Pl 1; Callitrix, Pl 1; Jackus, Pl 2; and an extinct genus also called Protopithecus, Pl 1.

c. Strepsirhini, or Lemurs, monkeys of Madagascar: none known fossil.

Order 3. CARNIVORA, divided into three families.

a. Digitigrada: Canis,* E 1, M and Pl 2 or 3, Ps 6 or 8; Viverra (civet), M 4 or 5, Ps 2 or 3; Gulo (glutton), Ps 1; Galictis, Ps 1; Mephitis (skunk), Ps 1; Mustella (marten), M and Pl 7 or 8, Ps 1 (l and f); Putorius (polecat), Pl and Ps (l and f) 1 or 2; Lutra (otter), M and Pl 2, Ps 1 (l and f); Hyæna, Pl 6, Ps 4; Felis,† M and Pl 11, Ps 12. To these must be added the extinct genera—Cynodon, E 5; Galecynus, Pl 1; Palæocyon, Ps 1; Speothos, Ps 1; Palæonyctis, E 1; Soricictis, M 2; Palæomephitis, Pl 1; Plesiogale, M 1 or 2; Plesictis, M 2; Palæogale, M 2; Putoriodus, M 1; Potamotherium, M 1; Thalassictis, M 2; Galeotherium, M 1; Machairodus, M 3, Pl 2 or 3, Ps 1 or 2; Pseudælurus, M 1.

b. Plantigrada: Ursus (bear), Pl 2, Ps 2; Procyon (racoon), Ps 1; Nasua (coati), Ps 1 or 2; Meles (badger), Ps 2; and the following extinct genera, provisionally placed here—Tylodon, E 1; Arctocyon, E 1; Amphicyon, M 9 or 10; Hyænodon, E 4, M 2.

c. Pinnigrada: Phoca (seal), M and Pl 6 or 8; Trichecus (morse), Pl 1 or 2.

Order 4. ARTIODACTYLA (even-toed, 2 or 4), may be divided into two families.

a. Nonruminantia: Hippopotamus, Pl and Ps 5 or 6; Sus (pig), M 5 or 6, Pl 3, Ps 4; Dicotyles (peccary), Ps 5; and the following extinct genera—Hyops, Ps 1; Palæochoerus, M 2; Chæromorus, M 3; Entelodon, M 2; Elotherium, M 1; Chæropotamus, E 3; Hyotherium, M and Pl 4; Bothriodon, M 5; Hyopotamus, E 4; Anthracotherium, M 7; Hyracotherium, E 2; Microchærus, E 1; Acotherulum, E 1; Heterohyus, E 1; Anoplotherium, E and M 4; Eurytherium, E 4; Chalicotherium, M 2 or 3; Tapinodon, M 1; Xiphodon, E 3; Dichobune, E 5 or 6;

* Some of these more resemble wolves, some foxes, while one at least is very nearly allied to our domestic dog.

† Some of these were larger than our lion, others resembled the tiger, panther, leopard, puma, lynx, etc.

Aphelotherium, E 1; Oplotherium (Cainotherium), E and M 5 or 6; Hyægulus, E 2; Microtherium, M 2; Adapis, E 1; Dichodon, E 1; Merycopotamus, Pl 1; Stereognathus, u O 1.

b. Ruminantia: Camelus (camel), Pl 2; Auchenia (lama), Ps 2; Camelopardalis (giraffe), M 3; Moschus, Pl 2; Cervus * (stag, including elk, reindeer, red-deer, axis, etc.), M, Pl and Ps 30 or 40; Antilope, M, Pl and Ps 10; Ovis (sheep), Ps 1 or 2; Capra (goat), Ps 2 or 3; Bos (ox), Ps 6 or 8; and the following extinct genera—Merycotherium, Pl 1; Sivatherium, M 1; Bramatherium, M 1; Amphitragulus, M 2; Dremotherium, M 3; Dorcatherium, M 4; Poebrotherium, M 1; Palæomeryx, M and Pl 8; Orotherium, M 1; Leptotherium, Ps 2.

Order 5. PERISSODACTYLA (odd-toed, 1 or 3), divisible into two families.

a. Solipedia: Equus (horse),† Ps 5 or 6; and the extinct genera—Anchitherium, E 2, M 1; Hipparion (Hippotherium), M and Pl 3.

b. Pachydermata: Rhinoceros, M 6, Pl 2, Ps 2; Tapirus, M and Pl 6 or 7, Ps 3; and the extinct genera—Elasmotherium, Pl 2; Harlanus, Ps 1; Platygonus, Ps 1; Coryphodon, E 3; Lophiodon, E 8; Pachynolophus, E 6; Anchilopus, E 1; Lophistherium, E 1; Tapirulus, E 1; Listriodon, M 1; Palæotherium, E 10; Propalæotherium, E 2; Paloplotherium, E 3; to which may be added, with some doubts as to their right place, Macrauchenia, Ps 1; Nesodon, Ps 2.

Order 6. PROBOSCIDEA: Elephas,‡ Ps 10; and the extinct genus Mastodon, M 3, Pl 8, § Ps 3?

* Among these are the great Irish elk, now made into a subgenus, as Megaceros Hibernicus, and the large stag Elaphus primigenius, etc.

† The fossil horse and the fossil ass of Europe greatly resemble the existing species; other species are different. Parts of an extinct species of horse have been found in South America, although no horse existed there when first visited by the Spaniards.

‡ There were three elephants inhabiting Europe, the mammoth, and two others, and several other extinct species have been found in the Sewalik Hills in India by Falconer and Cautley.

§ Of these Mastodons, three are from the Sewalik Hills; the M. giganteum and one or two others are peculiar to North America; the M. augustidens seems to have been nearly cosmopolite.

Order 7. TOXODONTIA: the extinct genus Toxodon, **three species of which have been found in recent Tertiary rocks in South America.**

Order 8. SIRENIA: Manatus? **E 1**; and the extinct genera—Dinotherium, **M 2 or 3**; Halitherium, **E 2, M 2, Pl 1**; Trachytherium? **M 1.**

Order 9. CETACEA, divided into six families.

*a. Zeuglodontidæ:** the extinct genera—Zeuglodon, **E 3 or 4**; Squalodon, **M 1**; Balænodon, **M 1**; Smilocamptus, **M 1.**

b. Delphinidæ: Delphinus (dolphin), **M 3 or 4, Pl 3, Ps 1**; and the extinct genera—Stereodelphis, **Pl 1**; Champsodelphis, **M 2**; Arionus, **Pl 1.**

c. Monodontidæ: Monodon? (narwhal) **Ps 1 or 2?**

d. Heterodontidæ: Ziphius, **Ps 1**; Dioplodon, **Pl 2**; Choneziphius, **Pl 1.**

e. Physeteridæ: Physeter, **Pl 2, Ps 1.**

f. Balænidæ: Rorqualus, **Pl 2**; Balæna? **E 1?** and the following extinct genera, of which the family is uncertain—Cetotherium, **Ps 1**; Hoplocetus, **M 1.**

Order 10. CHEIROPTERA, divided into two families.

a. Frugivora: none known fossil.

b. Insectivora: Dysopes, **Ps 1**; Phyllostoma, **Ps 5**; Rhinolophus, **Ps 1 or 2**; Vespertilio, **E 1, M 2 or 3, Pl 1, Ps several, of which some are l and f.**

Order 11. INSECTIVORA, divided into four families.

a. Echinoididæ: Erinaceus (hedgehog), **M 5, Ps 2**; Centetes, **M 1**; and the extinct genera—Galerix, **M 1**; Echinogale, **M 1.**

b. Glisoricidæ: Cladobates, **M 1**; and the extinct genus Oxygomphus, **M 1.**

c. Soricidæ: Sorex (shrew), **M 4 or 5, Ps several, of which some are l and f**; Mygale, **M 2**; and the extinct genera—Mysarachne, **M 1**; Plesiosorex, **M 1.**

d. Talpidæ: Talpa (mole), **M 3 or 4, Ps 2, l and f**; and the extinct genera—Dimylus, **M 1**; Palæospalax, **Ps 1**; Geotrypus, **M 2**; Galeospalax, **Ter 1**; Hypocygnis, **M. 1.**

* Pictet makes a distinct order of this family. Professor Owen speaks of it as cetaceous in the programme of his recent lectures, and I have therefore placed it in that order, before the other five families.

Order 12. EDENTATA, divisible into four families.

a. Tardigradæ: (sloths), none fossil.

b. Gravigradæ: extinct genera—Megatherium, Ps 1 (or 2?); Megalonyx, Ps 1 (or 2?); Mylodon, Ps 3; Scelidotherium, Ps 7; Cælodon, Ps 2; Sphenodon, Ps 1; Ochotherium? Ps 1.

c. Dasypidæ: Dasypus (armadillo), Ps 2 or 3; and extinct genera—Glyptodon, Ps 4 (or 7?); Chlamydotherium, Ps 2; Pachytherium, Ps 1; Euryodon, Ps 1; Heterodon, Ps 1.

d. Myrmecophagidæ: (ant-eaters), Crycteropus, 1 (l and f?); and extinct genera—Macrotherium, Ps 1; Glossotherium, Ps 1.

Order 13. RODENTIA, divisible into twelve tribes.

a. Sciuridæ: Sciurus (squirrel), E 2, M 2, Ps 1 (and 1 l and f); Arctomys (marmot), Pl 1, Ps 2 (l and f 1); Spermophilus, M 1, Ps 1; and extinct genera—Plesiarctomys, u E 1.

b. Myoxidæ: Myoxus (dormouse), E 2, M 1 (l and f 1); and extinct genus Brachymys, M 1.

c. Macropodæ: Dipus (jerboa), Ter 1, M 1; and extinct genus Issiodoromys, M 1.

d. Lagostomidæ: Lagostomus, Ps 1; and extinct genus Megamys, Ps 1.

e. Octodontidæ: Echimys, M 1, Ps 1; Nelomys, Ps 1; and extinct genera—Archæomys, M 2; Theridomys, M 4; Lonchophorus, Ps 1; Phyllomys, Ps 1; and ? Adelomys, E 1.

f. Ctenomyadæ: Ctenomys, Ps 2.

g. Cuniculidæ: none fossil.

h. Muridæ: Mus (rat, mouse, etc.), M 4, Pl 1?, Ps 3; Cricetus (hamster), Ps 1; Arvicola, Pl 2, Ps 2 or 3 (l and f); and extinct genera—Cricetodon, M 1; Decticus, M 1; Elomys, M 1.

i. Castoridæ: Castor (Beaver), M 1 (or 2)?, Pl 2 or 3, Ps 2, (1 l and f); Myopotamus, Ps 1; and extinct genera—Steneofiber, M 1; Castoroides, Ps 1; Chaliæomys, M 4, Pl 1; Palæomys, M 1; Osteopera? Ter 1; Omegadon, M 1.

j. Hystricidæ: Hystrix (porcupine), M 1 or 2; Synetherus, Ps 2.

k. *Leporidæ:* Lepus (hare), M 2, Pl 2, Ps 3 or 4 (l and f 1 or 2?); Lagomys, M 1, Pl 1, Ps 4 or 5; and extinct genus Titanomys, M 2 or 3.

l. *Subungulata:* Anæma (guinea pig), Ps 2; Kerodon, Ps 2; Chloromys (agouti), Ps 2; Cælogenys, Ps 2; Hydrochaerus, Ps 2.

Among the Rodentia or the Marsupialia, must also be especially mentioned the Spalacotherium, from the Purbecks.

Order 14. MARSUPIALIA, divisible into two groups.

a. *Sarcophaga* (flesh-eaters): Didelphis (opossum), E 4 or 5, M 3 or 4, Ps 6 or 7; Dasyurus, Ps 3 or 4; Thylacinus, Ps 1; and the extinct genera—Thylacotherium, l O 2; Phascolotherium, l O 1; Microlestes, T 1; Triconodon, u O 2; Galethylax, E 1; Spalacodon, E 1.

b. *Poephaga* (plant-eaters): Phalanger, Ps 1; Macropus, Ps 3; Hypsiprymnus, Ps 1; Phascolomys, Ps 1; and the extinct genera—Diprotodon, Ps 1; Nototherium, Ps 1; and Plagiaulax, u O 2.

Order 15. MONOTREMATA, none fossil.

CLASS II.—BIRDS.

Pictet's classification taken as it stands.

Order 1. RAPTORES, divisible into two families.

a. *Diurnal:* Cathartes (turkey-buzzard), M 1, Ps 1; Vultur, Ps 1; Nisus (sparrow-hawk), Ps 1; Falco, Pl 1; Butteo (buzzard), Ps 1; Aquila (eagle), Ps 1; Pandion (osprey), E 1; and extinct genus Lithornis, E 1.

b. *Nocturnal:* Strix (owl), E 1, P 1, Ps 1 or 2.

Order 2. PASSERES, divisible into seven families.

a. *Dentirostres:* Motacilla (warbler), Ps 1; Turdus (thrush), M 1, Ps 2, and some others in Brazil.

b. *Fissirostres:* Hirundo (swallow), Ps 1; Cypselus, Ps 1; Caprimulgus (goat-sucker), Ps 1.

c. *Coracidæ:* Corvus (crow), Ps 4 or 5.

d. *Tenuirostres:* Dendrocalaptes, Ps 1.

e. *Syndactyli:* the extinct genus Halcyornis, E 1.

f. *Scansores:* Picus, Ps 1; Coccyzus, Ps 1; Capito, Ps 1; Psittacus (parrot), Ps 1.

Order 3. GALLINACEÆ, divisible into two families.

a. Columbidæ: Columba (pigeon), Ps 1; ? Dodo, recently extinct.

b. Gallinæ: Tetrao (grouse), Ps 1; Coturnix (quail), Ps 1; Perdix (partridge), M 1, Ps 1 or 2; Phasianus (pheasant), Ps 1; Gallus (cock), Ps 2 or 3; Numida, Ps 1; Tinamus, Ps 1.

Order 4. CURSORES: Struthio (ostrich), Ps 1 or 2, (of sub-genus Rhea in South America); and extinct genera—Dinornis, Ps 7; Palapteryx, Ps 3; Apterornis, Ps 1.

Order 5. GRALLATORES, divisible into four families.

a. Pressirostres: Otis (bustard), Ps 1; Microdactylus, Ps 1.

b. Cultirostres: Phœnicopterus (flamingo), M 1; Ciconia, M 1; Ardea (heron), E 1; Tantalus, Ps 1.

c. Longirostres: Numenius (curlew), E 1; Scolopax (woodcock), E 1, M 1, Ps 1 or 2.

d. Macrodactyli: Fulica (coot), Ter 1; Rallus (rail), Ps 1 or 2; and nearly extinct genus Notornis, l and f 1.

Order 6. PALMIPEDES: divisible into four families.

a. Longipennidæ: Larus (gull), Ps 1; Sterna (tern), Ps 1; the supposed Cimiliornis from the chalk is now believed to be a Pterodactyle.

b. Totipalmidæ: Pelicanus, E 1, Ps 1; Phalacrocerax (cormorant), Ter 1.

c. Lamellirostres: Cycnus ? (swan), Ps 1; Anser (goose), Ps 1; Anas (Duck), E 1, Ps 1 or 2; Mergus, M 1.

d. Mersatores: Colymbus (diver), Ps 1.

New Order? The Gastornis Parisiensis, from the Eocene, lately described by Professor Owen, seems to have been a large bird, with intermediate affinities between the Gallinaceæ, Grallatores, and Cursores.

CLASS III.—REPTILES.

Pictet's matter adjusted to Professor Huxley's classification.

Order 1. CHELONIA, divisible into four families.

a. Land tortoises: Testudo? tracks in D, P or T, and O; carapace in M 4 or 5, Pl 1 or 2, Ps 2 or 3; and the extinct genera—Colossochelys, (18 feet long), M 1; and Ptychogaster, M 2; Testudinites, Ps 1.

b. *Pond tortoises:* Emys, u O 20? W. 1, E. 6 or 8, M. 10, Pl 2 or 3, Ps 1 or 2 (l and f); Platemys, W 1, E 2; Chelydra, M 2; and extinct genera—Palæochelys, Ter 2 or 3; Eurysternum, u O 1; Tretosternon, u O 1; Apholidemys, E 1; Protemys, Cr 1.

c. *River tortoises:* Trionyx, L 1, E 10 or 12, M 5 or 6, Pl 2, Ps 1.

d. *Sea Tortoises* (turtles): Chelonia, T 1? u O 1, W 2, Cr 3 or 4, E 13 or 14, M and Pl 2 or 3; Sphargis, M 1; and extinct genera—Idiochelys, u O 1; Aplax, u O 1.

Order 2. CROCODILIA, divisible into three groups.

a. *Procœli:** Crocodilus, u Cr 1, E 10 or 12, M 6 or 8, Pl 1 or 2, Ps 2, besides those in India and America.

b. *Amphicœli:* † the extinct genera—Teleosaurus, O 24, (divided into the sub-genera, Mystriosaurus, Macrospondylus, Pelagosaurus, Glaphyorhyncus, Aelodon, and Gnathosaurus).

c. *Prosthocœli:* ‡ the extinct genera—Steneosaurus (or Streptospondylus), O 3 or 4; Cetiosaurus, O 2, W 2. To these may be added as doubtful Crocodilia, the extinct genera—Succhosaurus, W 1; Goniopholis, W 1; Macrorhyncus, W 1; Pholidosaurus, W 1; Pœcilopleuron, O 1; Racheosaurus, O 1; Pleurosaurus, O 1.

Order 3. LACERTILIA: Lacerta (lizard), E 1, M 5 or 6, Ps 1 (l and f 1 or 2); and the extinct genera—Protorosaurus, P 2; Thecodontosaurus, P 1; Palæosaurus, P 2; Cladyodon, T 1; Mosasaurus, Cr 2; Geosaurus, O 2; Leiodon, Cr 1; Raphiosaurus, Cr 1; Coniosaurus, Cr 1; Dolichosaurus, Cr 1; Homæosaurus, u O 1; Saphæosaurus, u O 1. The following genera are too incompletely known to say which of the two preceding orders they belong to—Deuterosaurus, P 1; Rhopalodon, P 2; Dicynodon, P 4; Phytosaurus, T 1; Menodon, T 1; Termatosaurus, T 1; Rysosteus, T 1; Rhyncosaurus, T 1; Macromiosaurus, L 1; Lariosaurus, L 1; Glaphyorhyncus, O 1; Thaumatosaurus, O 1; Ischyrodon, O 1; Brachytænius, O 1; Atoposaurus, u O 2; Anguisaurus, u O 1; Machimosaurus, u O 1; Sericodon, u O 1; Neustosaurus, Cr 1; Mesoleptes, Cr 1; Polyptychodon, Cr 2; Macrosaurus, Cr 1; Hyposaurus, Cr 1.

* Having vertebræ concave in front, and convex behind.
† Neither surface of the vertebræ convex.
‡ Vertebræ hollow behind, and convex in front.

Order 4. DINOSAURIA: the extinct genera—Megalosaurus, O 1; Hylæosaurus, W 1; Iguanodon, W 1; Pelorosaurus, W 1; Regnosaurus, W 1; Plateosaurus, T 1.

Order 5. ENALIOSAURIA, divisible into two families.

a. Ichthyosauria: the extinct genera—Ichthyosaurus, L 12, O 1, Cr 1; Plesiosaurus, L 11, O 6, Cr 3 or 4.

b. Simosauria: the extinct genera—Spondylosaurus, O 2; Pliosaurus, m O 3; Nothosaurus, T 7 or 8; Pistosaurus, T 1; Conchiosaurus, T 1; Simosaurus, T 1; Sphenosaurus, P 1.

Order 6. PTERODACTYLIA: the extinct genera—Pterodactylus, l O 1, u O 9 or 10, W 1, Cr 2 or 3; Ramphorhynchus, L 1, u O 3; Ornithopterus, u O 1.

Order 7. OPHIDIA: Coluba, M 1, Pl 3 or 4, Ps 1 or 2; and extinct genera—Palæophis, E 4; Paleryx, E 2; and some other doubtful remains of serpents.

CLASS IV.—AMPHIBIA.

Order 1. LABYRINTHODONTA: the extinct genera—Labyrinthodon (or Mastodonsaurus), P 1, T 4 or 5; Capitosaurus, T 2; Metopias, T 1; Trematosaurus, T 1; Zygosaurus, P 1; Odontosaurus, T 1; Archegosaurus, C 4; Rhinosaurus, L 1; Telerpeton, D 1.

Order 2. BATRACHIA: Rana (frog), Ter several; and the extinct genera—Asphærion, Ter 1; Palæobatrachus, Ter 1; Latonia, Ter 1; Pelophilus, Ter 1; Palæophrynos, Ter 2.

Order 3. SAURO-BATRACHIA: Salamander, M 1 or 2; Triton, M 3; and extinct genus Andrias, M 1.

Order 4. OPHIOMORPHA: none known fossil.

CLASS V.—FISH.

Pictet uses the primary divisions of Muller, but in the details adopts an entirely different classification. The following is a mere abstract of Pictet, without any attempt at remodelling his classification.

A.—TELEOSTEI; none older than Cretaceous.

Order 1. CTENOIDEA; divided into eleven families.

a. Percidæ: Perca, E and M 3; Labrax, E 3; Apogon, E 1; Lates, E 5; Enoplosus, E 1; Serranus, E 2; Pelates, E 1; Dules, E 2; Holocentrum, E 2; Myripristis, E 2; Beryx, Cr 8; and the extinct genera—Cæloperca, E 1; Cyclopoma, E 2; Eurygnathus, E 1; Smerdis, E 6; Podocephalus, E 1; Brachygnathus, E 1; Percostoma, E 1; Synophrys, E 1; Acanus, E 5; Pachygaster, E 2; Podocys, E 1; Pristigenys, E 1; Allocotus, Ter 1; Berycopsis, Cr 1; Homonotus, Cr 1; Holopteryx, Cr 1; Sphenocephalus, Cr 1; Acrogaster, Cr 1; Rhacolepis, Cr 3; Stenostoma, Cr 1.

b. Scienoidea: Pristipoma, E 1; Odonteus, E 1; Pogonias, Ter 1.

c. Sparoidea: Dentex, E 6; Pagrus, E 1; Chrysophrys, Ter 2; Sargus, E 1, M 3; Pagellus, Cr 2, E 1; and the extinct fossil genera—Sargodon, Ps 1; Sparnodus, E 5; Capitodus, M 5; Soricideus, M 1; Asima, M 1.

d. Cottoidea: Cottus, M or Pl 4; Cristiceps, E 1; and the extinct genera—Callipteryx, E 2; Petalopteryx, Cr 1.

e. Chromidæ: the extinct genus Pycnosternix, Cr 3.

f. Theutidæ: Acanthurus, E 2; and the extinct genera —Naseus, E 2; Ptychocephalus, E 1; Pomophractus, E 1; Calopomus, E 1.

g. Squammipennidæ: Ephippus, E 2; Scatophagus, E 1; Zanclus, E 1; Platax, Cr 1, E 6; Holacanthus, Ter 1; Pomacanthus, E 1; Toxotes, E 1; and the extinct genera—Semiophorus, E 2; Macrostoma, E 1.

h. Gobioideæ: Gobius, E 2 or 3.

i. Lophioideæ: Lophius, E 1.

j. Aulostomidæ: Fistularia, E 2; Aulostoma, E 1; Amphisilus, E 2; and the extinct genera—Urosphen, E 1; Ramphosus, E 1.

k. Mugilidæ: Mugilus, E 1; and the extinct genus Calamopleurus, Cr 2.

Order 2. PLEURONECTES: Rhombus (turbot), Cr 1, E 1; and Solea (sole), Ter 2.

Order 3. CYCLOIDEA ACANTHOPTERYGIA. This order has seven families.

a. Scomberidæ: Scomber, Cr 1; Thynnus, E 2; Orcynus, E 2; Cybium, E 2, M 1; Lichia, E 1; Trachinotus, E 1; Vomer, Cr 1, E 2; Zeus ? 1; and the extinct genera—Ductor, E 1; Goniognathus, E 1; Anenchelum, E 6; Lepidopides, Ter 3 or 4; Nemopteryx, E 2; Xiphopterus, E 1; Carangopsis, E 4; Palimphyes, E 5; Archæus, E 1; Gasteronemus, E 2; Amphisteum, E 1; Isurus, E 1; Pleionemus, E 1; Acanthonemus, E 2; Palæorhyncum, E 7; Hemirhyncus, E 1; Cœlopoma, E 2; Bothrosteus, E 3; Phalacrus, E 1; Rhoncus, E 1; Cechemus, E 1; Scombrinus, E 1; Cœlocephalus, E 1; Naupygus, E 1; Enchodus, W 1, Cr 3.

b. Xiphioidea: Tetrapturus, Cr 1, E 1; and the extinct genera — Cœlorhyncus, E 2; Phasganus, E 1; Acestrus, E 1.

c. Sphyrenoidea: Sphyræna, Cr 1, E 3; and the extinct genera—Sphyrænodus, E 3, M 2; Hypsodon, Cr 2, E 1; Saurocephalus, Cr 4; Saurodon, Cr 1; Pachyrizodus, Cr 1; Cladocyclus, Cr 1 and ? 1; Isodus, Cr 1; Rhamphognathus, E 1; Mesogaster, Cr 1, E. 1.

d. Trachinidæ: Trachinus, Ter 1.

e. Blennidæ: the extinct genera—Spinacanthus, E 1; and Laparus, E 1.

f. Atherinidæ: Atherina, E 2.

g. Labridæ: Labrus, E 2; and the extinct genera—Anchenilabrus, E 1; and Platylemus, E 1.

Order 4. CYCLOIDEA MALACOPTERYGIA, divided into three suborders, but the families only are given here.

a. Gadoidea: Gadus? (cod), Ter 1; and the extinct genera—Rhinocephalus, E 1; Goniognathus, E 1; Merlinus, E 1; Ampheristus, E 1.

b. Cyprinidæ: Cyprinus (carp), Ter 1; Tinca (tench), Ter 3; Gobio (gudgeon), Ter 1; Leuciscus (roach, dace, etc.), Ter 14; Aspius, Ter 4; Rhodeus, Ter 2; Cobitis (loach), Ter 3; Acanthopsis, Ter 1; Scardinius, Ter. 1.

c. Cyprinodonta: Lebias, Ter 5.

d. Scopelidæ: the extinct genus Osmeroides, Cr 6.

e. Esocidæ: Esox (pike), Ter 3; and the extinct genera —Holosteus, E 1; Sphenolepis, Ter 2; Istieus, Cr 4; Rhinellus, Cr. 2.

f. Halecoidæ: Salmo, none fossil; Osmerus, Cr 1, Ter 1; Mallotus, 1 sp. (both living and fossil in Greenland); Alosa, Ter 1; Clupea (herring), Cr 8, Ter 14; Engraulis (anchovy), E 1; Megalops, E 1; and the extinct genera—Acrognathus, Cr 1; Antolepis, Cr 1;

Tomognathus, Cr 2; Spaniodon, Cr 1; Chirocentrites, Cr 3; Halec, Cr 1; Elopides, E 1; Cælogaster, E 1; Platinx, E 2.

g. Murenidæ: Anguilla (eel), E 8; Ophisurus, E 1; Sphagebranchus, E 1; Leptocephalus, E 3; and the extinct genera—Rhyncorhinus, E 1; Enchelyopus, E 1.

Order 5. SILURIDÆ: Pimelodus, Ter 1; and Coccodus, Cr 1.

Order 6. PLECTOGNATHI; containing three families.

a. Sclerodermati: Ostracion, E 1; and the extinct genera—Acanthoderma, E 1; Acanthopleurus, E 2; Glyptocephalus, E 1.

b. Gymnodonti: Diodon, E 1, Pl 2; and Trigonodon, M 1.

c. Blochioidea: the extinct genus Blochius, E 1.

Order 7. LOPHOBRANCHII; Syngnathus, E 1; and the extinct genus Calamostoma, E 1.

B.—GANOIDEA.

Order 1. GANOIDEA CYCLIFERA; containing four families.

a. Amiadæ: the extinct genera—Notæus, E 2; and Cyclurus, Ter 3.

b. Leptolepidæ: the extinct genera—Leptolepis, L 7, m O 1, u O 12; Tharsis, m O 6; Thrissops, m O 7; Melagurus, m O 7; Oligopleurus, m O 1; Coccolepis, m O 1.

c. Cœlacanthi: the extinct genera—Cœlacanthus, C 3, P 3, T 2; Undina, O 2; Macropoma, Cr 2; Ctenolepis, l O 1; Gyrosteus, L 1; Glyptolepis, D 3; Isodus, C 1; Phyllolepis, O R S* 1, C 1; Hoplopygus, C 1; Uronemus, C 1.

d. Holoptychidæ: the extinct genera—Holoptychius, O R S 8, C 9; Actinolepis, D 1; Gyroptychius, D 2; Platygnathus, D 3; Dendrodus, D 5; Lamnodus, D 3; Cricodus, D 1; Colonodus, C 1; Centrodus, C 1; Asterolepis, D 8, C 1; Bothriolepis, D 2; Psammosteus, D 4, C 2; Osteoplax, C 1.

Order 2. GAN. RHOMBIFERA, containing five families, of which

a. Polypteridæ has no extinct, and only one living genus, none fossil.

* O R S means Old Red Sandstone. The part where these fossils are found I believe not to be Devonian but Lower Carboniferous.

b. *Lepidostidæ:* Lepidosteus, E 1; and the extinct genera—Aspidorhynchus, L 2, m O 7, Cr 1; Belonostomus, L 2, l O 1, m O 7, Cr 3; Prionolepis, Cr 1; Notagogus, u O 7; Propterus, m O 4; Nothosomus, L 1, O 1; Ophiopsis, O 5 or 6; Æthalion, O 5 or 6; Lepidotus, L 12, O 15, Cr 1, E 1; Semionotus, L 7, O 2, Cr 1; Centrolepis, L 1; Pholidophorus, L 13, O 20; Libys, O 1; Dictyopyge, O 1; Tetragonolepis, T 1, L 14, O 2; Dapedius, L 7; Amblyurus, L 1; Dorypterus, P 1; Caturus, L 2, O 21, Cr 1; Pachycormus, L 10, O 5; Saurostomus, L 1; Amblysemius, O 2; Sauropsis, L 1, O 4 or 5; Thrissonotus, L 1; Strobilodus, O 1; Oxygonius, W 1; Macrosemius, O 3; Disticholepis, O 1; Eugnathus, L 14, u O 1; Conodus, L 1; Ptycholepis, L 2; Lophiostomus, Cr 1—the above are all homocercal; the following are heterocercal—Saurichthys, T 11; Megalichthys, D 1, C 2; Pygopterus, C 5, P 3; Acrolepis, C 1, P 3; Amblypterus, C 10, T 4; Eurynotus, C 3; Elonichthys, C 3; Palæoniscus, C 19, P 9; Urosthenes, C 1; Plectrolepis, C 1; Catopterus, C 2; Graptolepis, C 1; Orognathus, C 1; Pododus, C 1.

c. *Acanthodia*, heterocercal: the extinct genera—Acanthodes, O R S 1, C 2; Cheiracanthus, D 6; Diplacanthus, D 6; Cheirolepis, D 8; Holacanthodes, D 1.

d. *Dipteridæ*, heterocercal: the extinct genera—Dipterus, D 2; Osteolepis, D 7; Diplopterus, O R S 4, C 2; Tripterus, D 1; Glyptopomus, D 1; Stagonolepis, D 1.

e. *Pycnodontidæ*, homocercal: the extinct genera—Pycnodus, O 29, Cr 11, E 3, M 1; Gyrodus, O 22, Cr 7, E 2; Microdon? Cr 2; Mesodon, O 2; Periodus, E 1; Gyroconchus, O 1; Acrotemnus, Cr 1; Scrobodus, O 1; Sphærodus, O 9, Cr 5, Ter 6 or 8; Phyllodus, Cr 1, E 6, M 4; Pisodus, E 1; Phacodus, Cr 1; heterocercal—~~Playtosomus~~, C 1, P 9; [Platysomus] Globulodus, P 1; Placodus, T 5; Tholodus, T 1; Colobodus, T 1; Asterodon, T 1; Nephrotus, T 1; Cenchrodus, T 1; Charitodon, T 1; Hemilopas, T 1.

Order 3. **HOPLOPLEURIDÆ**: the extinct genera—Sauroramphus, Cr 1; Eurypholis, Cr 3; Dercetis, Cr 5.

Order 4. GANOIDEA LORICATA, divided into three families.

a. Cephalaspidæ, heterocercal: the extinct genera—Cephalaspis, u S 2 or 3, D 3 or 4; Auchenaspis, u S or D 1; Pteraspis, u S or D 2; Coccosteus, D 8, C 1?; Pterichthys, D 12; Placothorax, D 2; Polyphractus, D 1; Menaspis, P 1; Macropetalichthys, S 1.

b. Sturionidæ: Accipenser (sturgeon), E 1; and extinct genus Chondrosteus, L 1.

c. Spatularidæ: none fossil.

C.—PLACOIDEA.

Order 1. HOLOCEPHALI: the extinct genera—Ischyodon, O 9, Cr 2; Ganodus, O 10; Elasmodus, E 1; Psaliodus, E 1; Edaphodon, Cr 3, E 2, M 1.

Order 2. PLAGIOSTOMÆ, divisible into seven families, of which the first four are Sharks, the last three Rays.

a. Squalidæ: Carcharias, Cr 3, E 1; Lamna, Cr 4, E 2, M and Pl 2 or 3; Odontaspis, Cr 8, Ter 9; and the extinct genera—Glyphis, E 2, M 1; Carcharodon, Cr 2, E 4, M and Pl 16; Carcharopsis, Cr 1; Chilodus, Cr 2; Galeus, E 1; Corax, Cr 6, Ter 4; Galeocerdo, Cr 2, Ter 5; Ællopos, O 2; Hemipristis, M 3; Notidanus, O 3, Cr 2, Ter 4; Sphyrna, Cr 1, M 4; Spinax, Cr 3, M 1; Otodus, Cr 7, Ter 20; Meristodon, W 1; Oxyrhina, Cr 8, Ter 15; Oxytes, Ter 1; Sphenodus, O 3, Cr 1; Gomphodus, Cr 1; Ancistrodon, Cr 2; Scylliodus, Cr 1; Thyellina, L 1, Cr 1.

b. Hybodontidæ: the extinct genera—Hybodus, C 2, T 10, O 21, W 7, Cr 9, Ter 1?; Cladodus, D, 1 C 9; Sphenonchus, L 1, O 1, W 1; Diplodus, C 2; Glossodus, C 2.

c. Cestraciontidæ: the extinct genera—Strophodus, T 4, O 10, Cr 3; Acrodus, T 6, L 6, O 1, W 1, Cr 6; Thectodus, T 4; Wodnika, P 1; Petrodus, C 1; Orodus, C 4; Ctenoptychius, D 2, C 8; Centrodus, C 1; Ptychodus, Cr 15; Psammodus, C 3; Chomatodus, C 5, T 1; Helodus, C 11; Campodus, C 1; Cochliodus, C 5; Ceratodus, T 18, O 2; Chirodus, C 1; Ctenodus, D 7, C 4; Conchodus, D 1; Pæcilodus, C 8; Climaxodus, C 1; Pleurodus, C 2; Petalodus, C 8; Polyrhizodus, C 2; and Dictæa, P 1.

d. Squatinidæ: Squatina, O 1, Cr 2, Ter 1; and the extinct genera — Radamas, P 1; and Xenacanthus, C 1.

e. Pristidæ: Pristis, T 1? Ter 5; and the extinct genus Squaloraya, L 1.

f. Raiadæ: Raia, Ter 3; Torpedo, E 1; and the extinct genera—Spathobatis, O 1; Arthopterus, L 1; Asterodermus, O 1; Euryarthra, O 1; Cyclarthrus, L 1; Cyclobatis, Cr 1; Byzenos, P 1.

g. Myliobatidæ: Trygon, E 2; Myliobates, Ter 30 or 40; Œtobates, Ter 8; Zygobates, Ter 5; and the extinct genus Janassa, P 3.

In addition to the above mentioned genera of fish, there are the following genera of Ichthyodorulites, or fish defences, spines of fins, etc.—

Onchus, S 2, D 3, C 6; Dimiracanthus, D 1; Hoplacanthus, D 1; Narcodes, D 1; Byssacanthus, D 3; Climatius, D 1; Parexus, D 1; Odontacanthus, D 2; Cosmacanthus, D 1, C 1; Homacanthus, D 1, C 1; Ctenacanthus, D 2, C 8; Ptychacanthus, D 1, C 1; Pleuracanthus, D 2, C 2; Oracanthus, C 2; Tristychius, C 2; Asteroptychius, C 3; Physonemus, C 2; Sphenacanthus, C 1; Platycanthus, C 1; Dipriacanthus, C 1; Erismacanthus, C 1; Orthacanthus, C 1; Cladacanthus, C 1; Cricacanthus, C 1; Lepracanthus, C 1; Gyracanthus, C 5; Memacanthus, C 1, T 4; Leptacanthus, C 2, O 4; Gyropristis, P 1; Leiacanthus, T 3; Asteracanthus, O 6; Priscacanthus, O 1; Myriacanthus, O 5; Aulacanthus, E 1.

To these M. Pictet adds Cololites, the supposed intestines of fish, which are, however, as probably tracks of Annelids or Mollusca.

Fish have two forms of tail, the one *homocercal*, that in which the caudal fin is equally spread round the termination of the vertebral column, as in the cod, perch, etc.; and the other *heterocercal*, where the vertebral column is, as it were, continued into the upper lobe of the caudal fin, the extremity of the body in reality being slightly bent up, and the larger lobe of the caudal fin placed underneath it, as in the dog-fish, shark, and sturgeon.

It is a very remarkable fact, that in *all* fish, whether osseous or cartilaginous, found in rocks more ancient than the Lias, the tails are heterocercal, while in the Lias and more recent rocks, and at the present day, the majority of fish have homocercal tails.

Sub-kingdom ANNULOSA.

Class I.—INSECTS.

The great divisions of this class being the same as those in the classification given in the last chapter, I have merely adjusted them to the order there pointed out.

Order 1. Hymenopteræ, six families.

a. Tenthredinidæ: several extinct species of the living genera Tenthredo, Celandria, Cryptus, etc.; and two of an extinct genus, Cephites—(Tertiary.)

b. Pupivora: several extinct species of the living genera Ichneumon, Agatis, Anomalon, Pimpla, etc.—(Tertiary.)

c. Heterogyna: 40 extinct species of the living genus Formica (ant); and 9 of the allied genus Ponera, besides the extinct genera Imhoffia, 1 sp.; Attopsis, 3 sp., etc.—(Tertiary.)

d. Fossores: extinct species of Pompilus and Crabro—(Tertiary.)

e. Diploptera: extinct species of the living genera Vespa (wasp) and Polistes—(Tertiary.)

f. Mellifera: several undetermined species of Apiaria; some of Xylocopa, Osmia, and Bombus; and the extinct genus Anthophorites, 4 sp.—(Tertiary.)*

Order 2. Coleoptera, divided into five sub-orders, each of which contains families and tribes. I shall only mention the families and genera—

a. Carabidæ: extinct species of the living genera Cicindela, Cymindis, Brachinus, Polystichus, Dromius, Lebia, Scaritis, Clivina, Harpalus, Ophonus, Feronia, Calathus, Anchomenus, Badister, Chlænius, Agonum, Carabus, Nebria (Tertiary); and the extinct genera Thurmannia, Carabites (Lias); Glenopterus, (Tertiary); besides other incompletely known species of this family from Solenhofen, the Lias, and Purbeck rocks, and the amber of Prussia.

b. Hydrocantharidæ: extinct species of Dytiscus (Tertiary); Colymbetes, Laccophilus (Lias); Gyrinus (Lias and Tertiary); and the extinct genus Gyrinites (Lias).

* The extinct insects of this family occur partly in Tertiary shales at Œningen, etc., and partly in the amber or fossil gum of the north of Prussia.

c. Brachelytra: extinct species of Staphylinus, Philonthus, Inedius, Lathrobium, Stenus, Stylicus, Protactus, Omalium, Anthophagus, Aleochara, Tachinus, Tachyporus, and Mycetoporus (all Tertiary); and others incompletely known (Purbeck and Tertiary).

d. Sternoxidæ: many extinct species of the old genera Buprestis and Elater, from the Liassic, Oolitic, and Tertiary rocks; some placed in new sub-genera.

e. Malacodermata: extinct species of the existing genera Cyphon, Scirtes, Lampyris (glow-worm), Telephorus, Dasytes, Ebæus, Malachius, Clerus, Ptinus, Atractoceras, and Cerpes—(chiefly Tertiary, some Lias and Purbeck.)

f. Clavicornidæ: extinct species of the genera Scydmænus, Hister, Silpha, Scaphidium, Choleva, Nitidula, etc., Cryptophagus, Dermestes, Byrrhus (Tertiary); Parnus (Wealden); and the extinct genus Petrophorus (Lias).

g. Palpicornidæ: various extinct species of the genera Hydrophilus, Hydrobius, Elophorus (Liassic to Tertiary); and the extinct genera Wollastonia, 1 sp. (Lias); and Escheria, 1 sp. (Tertiary?)

h. Lamellicornidæ: extinct species of the genera Gymnopleurus, Sisyphus, Onthophagus, Copris, Geotrupes, Melolontha, Cetonia, Platycerus, etc. (Tertiary); and Scarabæidæ, etc. (Oolitic).

i. Melasoma: extinct species referred uncertainly to the existing genera Blaps, Pimelia, etc. (Oolitic); and to Tenebrio, Lepidium, etc. (Tertiary).

j. Taxicornidæ: extinct species of Anisotoma and Boletophagus (amber).

k. Stenelytridæ: extinct species of the genera Cistela, Helops, etc.—(Tertiary.)

l. Trachelidæ: an extinct species of Cantharis? (Wealden); and others of Meloe, Mordella, etc. (Tertiary).

m. Curculionidæ: many extinct species of the existing genera Bruchus, Apion, Rhynchites and Weevils; of the genera Brachycerus, Cionus, Miniops, etc. (from Tertiary rocks); and extinct genera Curculionides, and Curculionites (from Carboniferous and Oolitic rocks.

n. Xylophaga: extinct species of the genera Scolytus, etc., Cerylon, etc., Colydium, Trogosita, etc. (Purbeck and Tertiary); and Prototoma (Lias).

o *Longicornidæ:* extinct species of Prionus (Oolitic and Tertiary); Cerambyx, etc., Lamia, etc., Leptura (Tertiary).

p. *Chrysomelidæ:* some little known extinct species from the Lias and Oolite, and some of the genera Donacia, etc., Cassida, etc., Chrysomela, Galleruca, Phalacrus (Tertiary).

q. *Fungicolæ:* extinct species of Lycoperdina (amber).

r. *Aphidiphaga:* extinct species of Coccinella and Scymnus (Tertiary).

s. *Pselaphidæ:* extinct species of Pselaphus, Bryaxis, and Euplectus (amber).

Order 3. Neuroptera.

a. *Termitenidæ:* extinct species referred to Termites have been found (from the Carboniferous to recent Tertiary rocks), and one to the genus Embia (in amber).

b. *Psocides:* extinct species of Psocus have been found in amber.

c. *Ephemeridæ:* an extinct species of this family in the Lias, and many of the genera Palingenia, Bætis, etc., in amber.

d. *Libelludæ* (or dragon-flies): extinct species of the genera Agrion, Œshna, and Libellula (perhaps forming extinct genus Heterophlebia) have been found in Lias, and many other of the above named and allied genera in Tertiary rocks.

e. *Perlidæ:* extinct species referred to Semblis, Perla, etc.—(found in amber.)

f. *Phryganidæ:* undetermined but extinct species of Phryganea found in the Wealden rocks, many others of that and allied genera in Tertiary rocks.

g. *Planipennidæ:* extinct species of the genus Chauliodes have been found in amber, and others like it, and also some like Hemerobius in Lias and Wealden; other species of these and allied genera in Tertiary rocks, and the extinct genus Dictyophlebia (in Carboniferous).

h. *Panorpatidæ:* extinct species of Bittacus in amber, and the extinct genus Orthophlebia (Lias and Wealden.)

Order 5. Lepidoptera: fossil butterflies and moths have been found sometimes beautifully preserved in the Tertiary rocks; extinct species belonging to the genera Satyrus, Cyllo, Vanessa, Zygena, Sesia, Bombyx, and Noctua, etc.; extinct species of the genera Sphinx and Tinea, or Tineites, are also found in the Oolites of Solenhofen.

Order 6. DIPTERA: an extinct species referred to Culex (Wealden); and several referred to the great genus Tipula, and its sub-genera Tanypus, Chironomus, Sciara, Rhyphus, Scimulia, and to the genera Asilus, Enepis, etc., are Oolitic and Wealden, while many others of these and of the allied genera, Musca, etc., are Tertiary.

Order 7. ORTHOPTERA: extinct species of Forficula, and of Blattus (cockroach), Mantis, Gryllus (cricket), Locusta, Acheta, Gryllotalpa, etc., are found in Tertiary rocks, while others of these or of the allied extinct genera Blattina, Acridites, Gryllacris, and Gryllites, occur in Carboniferous, Liassic, and Wealden rocks.

Order 8. HEMIPTERA: extinct species of the genera Cimex (bug), Coreus, Alydus, Lygæus, Capsus, Tingis, Redavius, Belostoma, Cicada, Asiraca, Cicadella, Aphis, Monophlebus, etc., are found in Tertiary rocks, while some of the existing genera Cimex, Nepa, Cicada, Ricania, Cercopis, Aphis, and the extinct genera Protocoris, Pygolampis, Ditomoptera, are Oolitic or Wealden.

Order 9. APTERA. Insects of this Order have only been found in amber; extinct species belonging to the genera Petrobius, Forbicina, Lepisma, Glessaria, Podura, etc.

CLASS II.—MYRIAPODA.

A few fossil fragments are known; one extinct species of Geophilus from the Oolitic shales of Solenhofen, and several of the genera Iulus, Scolopendra, etc., from Tertiary rocks.

CLASS III.—ARACHNIDA.

An extinct species of scorpion called Cyclophthalmus, occurred in the Carboniferous rocks near Prague, and some spiders in the same rocks near Coalbrookdale. Others forming the extinct genus Palpipes, occur in Oolitic rocks, while many are found in the Tertiary amber of Prussia. Other Arachnida similar to Chelifer, but called Microlabis, occur in the Carboniferous rocks, and the freshwater tertiaries and amber contain many of the genera Chelifer, Phalangium, Acarus, etc.

CLASS IV.—CRUSTACEA.

This great class is more interesting and important to the palæontologist than the three preceding ones, and I shall therefore give it in greater detail, especially the part relating to the trilobites. I shall transpose Pictet's great groups into the order of the classification in the last chapter.

Order 1. PODOPHTHALMIA.

a. Decapoda: Cancer (crab), E 8, M 1, Pl 1, (l and f); Carpilius, Ter 1; Xantho, M 2; Platycarcinus, Ter 2 or 3; Portunus, Ter 3 or 4; Podophthalmus, Cr 1, Ter 1; Eriphia, Ter 1; Gonoplax, Ter? 1; Macrophthalmus, Ter? 3; Grapsus? Cr 1? Ter 2; Sesarma, Ter 1; Ebalia, Pl 1; Ixa, Ps 1; Dromia, Ter 2; Ranina, Ter 3; Pagurus (hermit-crabs), O 1? Ter 2 or 3; Scyllarus, Cr 1, E 1; Palinurus, E 1; Astacus (cray-fish), Sec 4 or 5? Ter 2 or 3; Holoparia, Ter 2; Homola, O 1; Galatea? T 1; Calianassa, Cr 9; Gebia? T 1; Palæmon? Cr 1; and the extinct genera —Xanthopsis, E 3 or 4; Podopilumnus, Cr 2; Notopocorystes, Cr 3 or 4; Basinotopus, E 1; Ogydromites, O 1; Prosopon, O 3, Cr 1; Eryon, O 20; Archæocarabus, E 1; Palinurina, O 3; Pemphix, T 2; Litogaster, T 2; Cancrinos, O 1; Meyeria, Cr 2; Orphnea, O 6?; Brisa, O 2; Hoploparia, Cr 2, E 2; Palæastacus, Cr 2; Glyphæa, O 8; Eryma, O 9; Clytia, O 3; Enoploclytia, Cr 3; Bolina, O 2; Undina, L 2; Broma, O 2; Magila, O 3; Aura, O 1; Coleia, L 1; Antrimpos, O 5 or 6; Bylgia, O 2; Drobna, O 2; Koelga, O 8; Œger, O 5; Udora, O 4; Dusa, O 2; Hefriga, O 2; Bombur, O 2; Blaculla, O 2; Elder, O 2; Rauna, O 2; Saga, O 2; Mecochirus, O 9; Gitocrangon, D 1; and some others less known—(all Secondary.)

b. Stomapoda: Squilla, E 1.

Order 2. EDRIOPHTHALMA.

a. Læmodipoda: none fossil.

b. Amphipoda: Typhis, E 1; and extinct genus Gampsonyx, C 1.

c. Isopoda: Oniscus (woodlouse), Ter 1; Porcellio, Ter 1; and Sphæroma, O 1? M 1?; and the extinct genera Palæoniscus,* Ter 1; Archæoniscus, W 1; Urda, O 4; Reckur, O 1; Norna, O 1; Sculda, O 1; Alvis, O 1.

* This being the name of a well-known genus of fossil fish, should be altered.

Order 3. **Branchiopoda.**

a. Cladexera: none fossil unless the extinct genus, Daphneia, C 1, should be placed here.

b. Phyllopoda: Apus, C 1, T 1; Estheria, W 2; and an extinct genus Dithyrocaris, D 3.

Order 4. **Copepoda.** None fossil.

Order 5. **Ostracoda,** or Cyprides.

The following extinct species of the marine genus Cythere have been found, u S 2, D 11, C 1, P 10, O 7, Cr 28, Ter numerous; of the freshwater genus Cypris, as follows—C 1, T 1, W 9, Ter 11. Species of Cythere have been made into the genera Bairdia, Cythereis, and Cytherella, Beyrichia, and Leperditia, and species of Cypris into Candona; but Pictet does not admit these genera. He gives, however, the living genus Cypridina, as having extinct species, S 1, D 6, C 8; and many among Secondary and Tertiary rocks, probably confounded with Cythere. He also gives the extinct genera Cyprella, C 1, and Cypridella, C 1.

Order 6. **Cirripedia**—(Barnacles.)

a. Sessilia: Balanus, C 1? Ter 20 to 30, besides some l and f. Both extinct and living species of the following genera are also found fossil in Tertiary rocks—Acasta, Chthamalus, Coronula, Creusia, Clitia, Ochtosia, Prygoma, and Tubicinella.

b. Pedunculata: doubtful species of the genus Anatifa, and extinct species of Pollicipes, O 5, Cr 22, Ter 8; Scalpellum, Cr 11, Ter 2; Loricula, Cr 1.

M. Pictet introduces the genus Aptychus here, but there is now little doubt that the curious triangular plates so named are portions of the Cephalopod, whose shell is the Ammonite.—(*Woodward's Manual.*)

Order 7. **Xiphosura:** Limulus (kingcrab), O 2, Cr 1?; and the extinct genera—Halycina, T 3, and Bellinurus, C 1 or 3.

Order 8. **Trilobites.** Extinct before the close of the Palæozoic epoch.

These Crustacea must have had small soft feet on the under surface of the body, which have never been preserved. Their covering consists of a shelly coat or shield divided into three parts, head, thorax, and pygidium, each separated into three lobes by two longitudinal indentations running down the body. The thorax and pygidium, especially the former, were composed of a number of rings that moved upon each other like those of the lobster, and thus enabled the animal to coil itself up.

Most, if not all, had compound eyes, consisting, like those of the present Crustacea, of a number of facets or lenses, covering a curved surface. They passed through a metamorphosis in proceeding from the larval to the mature condition.

They are divisible, according to Pictet, who nearly follows Barrande, into twelve families as follows:—

a. Harpides, containing one genus, Harpes, l S 3, u S 7, D 2.

b. Paradoxides, containing the genera—Remopleurides, l S 6; Paradoxides, l S 16 or 20; Hydrocephalus, l S 2; Sao, l S 1; Arionellus, l S 1; Ellipsocephalus, l S 2; Olenus, l S 1 or more; Conocephalites, l S 11 or more; Peltura, l S 1, u S 1; Triarthrus, C? 1.

c. Calymenidæ: Proetus, l S 1, u S 30 or 40, D 12; Phaeton, u S 3; Philipsia, u S 2? D 2, C 12;* Cyphaspis, u S 9, D 3; Arethusina, u S 2 or 3; Harpides, l S 1; Phacops, l S 10 or 12, u S 21, D 7; Dalmania, l S 17, u S 10, D. 7; Calymene, S about 20; Homalonotus, l S 5 or 6, u S 6, D 11.

d. Lichasides: Lichas, l S 9, u S 11, D 1.

e. Trinucleides: Trinucleus, l S 12 or more; Ampyx, S 10 or more; Dionide, l S 1.

f. Asaphides: Asaphus, l S 16 or 20; Symphysurus, l S 3; Ogygia, l S 6.

g. Æglinides: Æglina, l S 4.

h. Illænides: Illænus, l S 17, u S 2; Nileus, S 1.

i. Odontopleurides: Acidaspis, l S 5, u S 16, D 3, but there are believed to be 50 species altogether; Cheirurus, l S 15, u S 13, D 2; Placoparia, l S 2; Sphærexochus, l S 2, u S 2; Staurocephalus, u S 1; Deiphon, u S 1; Zethus, S 2; Dindymene, l S 2.

j. Amphionides: Amphion, l S 2; Cromus, u S 4; Encrinurus, u S 3.

k. Brontides: Bronteus, l S 2, u S 35, D 10.

l. Agnostides: Agnostus, l S 21.

The last genus differs from all the others in having the general form of the head and pygidium very much alike. There are also some other genera not well known.

* Of these, four make M'Coy's genus Griffithides.

Order 9. EURYPTERIDÆ. Extinct before the Carboniferous period. This order includes the genera Eurypterus, D 4, and Pterygotus, u S and D several sp., some of them six feet long.

They are Crustacea more resembling lobsters, etc., in their general form, but very different in their details, having no true claws, but pincers at the ends of the antennæ, and recalling to mind the larval condition of some Crustacea.

CLASS V.—ANNELIDA.

This class is the same as the Annulata of the classification before given. Pictet's divisions of it are different, but the fossils are so few, that I merely give an abstract of his work :—

Order 1. TUBICOLA, containing the living genera Serpula, 8 or 10 Palæoz., some Triassic, 30 or 40 Upper Secondary, and still more Tertiary; Filograna, 1 Permian; Spirorbis, 8 Palæoz., 5 or 6 Mesoz., and some Tertiary; Vermilia, 1 Perm., 6 or 7 Mesoz., and some Tertiary; Galeolaria, 2 or 3 Oolitic; Terebella, some Oolitic; Ditrupa, 1 Tertiary; and the extinct genera—Serpularia, 2; Serpulites, 1; Spiroglyphus, 1 (all Palæoz.); and Cyclogyra, 1 Tertiary.

Order 2. DORSIBRANCHIATA; traces have been found in Palæozoic rocks, attributed uncertainly to the genera Aphrodita, Leodice, Nereis, etc.; and in Cretaceous rocks to Scolica.

Order 3. ABRANCHIATA; equally vague traces have been referred to the living genera Hirudella and Tubifex; and extinct genera called Entobia, Talpina, Vermiculites, and Trachyderma.

Of the group called SCOLECIDÆ, Class VI. of the Annulosa in Professor Huxley's classification, none are known fossil, nor, as they are mostly internal parasites, are they ever likely to be known.

In accordance with his classification, the Annulosa are closed by

CLASS VII.—ECHINODERMATA.

Order 1. HOLOTHURIDÆ has no known fossil representatives.

Order 2. ECHINIDÆ. Pictet adopts Agassiz's first classification, and divides this order into three families.

a. Spatangoidea, subdivided into two tribes.

α. Holasteria : the extinct genera — Collyrites, O 25, Cr 6; Ananchytes, Cr 5 or 6; Holaster, O 1? Cr 21; Hemipneustes, Cr 1.

β. *Brissidæ:* Schizaster, E 6, M 1, Pl and Ps 2; Spatangus, E 4, M 4, Pl 2, Ps 3; Eupatagus, E 10, M 1; Amphidetus, E 2, M 1, Pl and Ps 2 or 3, of which 1 l and f; Brissus, E 4, M 2, Pl and Ps 2, of which 1 l and f; Brissopsis, E 4, M 2, Pl 3; and the extinct genera—Echinospatagus (Toxaster), Cr 14; Micraster, Cr 5; Epiaster, Cr 8; Hemiaster, Cr 30, E 12, M 1, Pl and Ps 2 or 3; Pericosmus, E 1, M 1, Pl 1; Periaster, Cr 3, E 2; Macropneustes, E 4, Pl 1; Gualteria, E 1; Prenaster, E. 2.

b. *Clypeasteroidea*, subdivided into four tribes.

α. *Asterostomia:* the extinct genera—Asterostoma, ? 1; Archiacia, Cr 3; Claviaster, Cr 1.

β. *Nucleolitea:* Echinolampas, Cr 1, E 19, M 5 or 6, Pl 3 or 4; Cassidulus, Cr 3, E 2, Ps 1; Nucleolites, O 20, Cr 21, E 2; and the extinct genera—Conoclypus, Cr 2, E 11, M and Pl 3; Amblypygus, E 3; Pygurus, O 11, Cr 10, E 1 or 2; Pygorhynchus, E 12; Pygaulus, Cr 8; Catopygus, Cr 11; Clypeus, O 13.

γ. *Scutellia:* Echinocyamus, Cr 1, E 9, M 2, Pl 4, Ps 3; Fibularia, Cr 1, Ter 2; Clypeaster, M and Pl 14; Laganum, E 2; Echinarachnius, E 2, Pl 2; Lobophora, E 1, M 4; and the extinct genera—Lenita, E 2; Scutellina, E 5; Scutella, E 1, M and Pl 9; Runa, E or M 1, Pl 1.

δ. *Galeritia:* Echinoneus, l and f 1; and the extinct genera—Hyboclypus, O 5; Nucleopygus, Cr 8; Desoria, O 2, l C 1; Pyrina, Cr 6; Globator, Cr 2; Caratomus, Cr 10; Galerites, Cr 15; Discoidea (subdivided into Holectypus, O 14, Cr 3; and Discoidea proper, Cr 14); Pygaster, O 5, l Cr 2.

c. *Cidaridæ:* subdivided into six tribes.

α. *Echinometrea:* the genera Echinometra, Acrocladia, and Podophora, have no true fossil representatives.

β. *Latistellea:* Echinus, O 20, Cr 7, E 3, M 2, Pl 8, of which 1 l and f; Heliocidaris, O 1; Tripneustes, M 2; Salmacis, E 1, Ps 1; Diadema, L 5, O 28, Cr 30 or 40, E 2; and the extinct genera—Polycyphus, O 3, Cr 2 or 3; Magnosia, O 1; Glypticus, O 3, Cr 1; Temnechinus, Pl 4; Pedina, O 7, Cr 1; Codiopsis, Cr 2; Cælopleurus, E 3; Eucosmus, O 1; Arbacia, O 3, Cr 9, M 1, Pl 1; Echinopsis, Cr 4, E 3; Cyphosoma, Cr 20; Hemidiadema, Cr 1; Acropeltis, O 1; Acrocidaris, O 5; Goniopygus, Cr 7.

γ. *Saleniena:* the extinct genera—Salenia, Cr 21; Peltastes, Cr 7; Goniophorus, Cr 2; Acrosalenia, O. 10; Milnia, O. 1.

δ. *Angustistellea:* Cidaris, T 25, L 3, O 24, Cr 20, E 3, M 1, Pl 1; Rhabdocidaris, O 7, l Cr 3; and the extinct genera—Hemicidaris, T 3, O 27, Cr 6; Diplocidaris, O 6; Porocidaris, O 1, E 2, M 1.

ε. *Archæocidaria:* the extinct genera—Archæocidaris, D 3, C 9, Pl 1; Perischodomus, C 1.

ζ. *Palæechinea:* the extinct genera—Palæechinus, u S 1, C 6; Melonites, C 1.

Order 3. Ophiuridæ: Ophioderma, L 3; Ophiura, L 1, Cr 3, E 1; and the extinct genera—Acroura, T 1, O 2, Cr 1; Aplocoma, T 1; Aspidura, T 1; Ophicoma, Cr 1; Ophiurella, O 2; Geocoma, O 1; Protaster, u S 1, D 1.

Order 4. Asteridæ: Uraster, l S 2, u S 3, C 1, L 3, Pl 1 (l and f); Solaster, O 1; Palmipes, Cr 1; Pentaceros (Oreaster and part of Goniaster), Cr 7; Astrogonium (part of Goniaster), O 5, Cr 6, E 3; Stellaster, Cr 3; Pentagonaster (Goniodiscus and part of Goniaster), Cr 20; Crenaster, L 2, O 7, Cr 1, E 4, M 1; Luidia, L 1; and the extinct genera—Palæaster, S 1 or 2; Tropidaster, L 1; Artraster, Cr 1; Pleuraster, T 1, O 1; Cœlaster, Cr 1; Lepidaster, u S 1.

Order 5. Crinoidea, divisible into seven families.

a. *Comatulidæ:* Comatula, O 6 or 7; Decameros, Cr 3; and the extinct genera—Pterocoma, O 1; Glenotremites, Cr 1; Saccosoma, O 3; Marsupites, Cr 3; Astylocrinus, C 1.

b. *Cupressocrinidæ:* the extinct genus Cupressocrinus, D 8.

c. *Polycrinidæ:* the extinct genus Eucalyptocrinus, u S 5 or 6, D 1.

d. *Haplocrinidæ:* the extinct genera—Haplocrinus (Eugeniacrinites), D 2; Coccocrinus, D 1; Ceramocrinus, D 1; Myrtilocrinus, D 1; Epactocrinus, D 1 Gasterocoma, D 1.

e. Anthocrinidæ: the extinct genera—Anthocrinus, u S 1; Crotalocrinus, u S 1.

f. Cyathocrinidæ: all extinct genera, divisible into four tribes.

α. Cyathocrinea: Rhodocrinus, l S 1, u S 1, D 2, C 10; Acanthocrinus, D 1; Poteriocrinus, l S 2, u S 3, D 2, C 20; Thysanocrinus, m S 4; Dendocrinus, m S 1; Cyathocrinus, D 2, C 3 or 4, P 1; Dimerocrinus, u S 2; Ichthyocrinus, u S 5; Lecanocrinus, S 4; Woodocrinus, C 1; Scyphocrinus, D 1; Mespilocrinus, C 2; Enallocrinus, u S 2; Tribrachiocrinus, C 1.

β. Actinocrinea: Ctenocrinus, D 3; Pradocrinus, D 1; Saccocrinus, S 1; Periechocrinus, u S 2; Sagenocrinus, u S 1; Actinocrinus, C 20; Batocrinus, C 2; Amphoracrinus, C 3; Dorycrinus, C 1; Melocrinus, D 5; Phillipsocrinus, C 1.

γ. Carpocrinea: Forbesocrinus, C 1; Taxocrinus, u S 2, D 2, C 3; Graphiocrinus, C 1; Carpocrinus, u S 1; Schizocrinus, l S 2; Heterocrinus, l S 3; Closterocrinus, S 1; Macrostylocrinus, S 1; Lyriocrinus, S 1; Scypocrinus, l S 1.

δ. Platycrinea: Platycrinus, C 30; Hexacrinus, D 3; Culicrinus, D 1; Marsupiocrinus, u S 1; Adelocrinus, D 1; Dichocrinus, C 8.

g. Pycnocrinidæ, divisible into four tribes.

α. Eugeniacrinea: the extinct genera—Eugenicrinus, O 9; Tetracrinus, O 1; Plicatocrinus, O 2.

β. Encrinea: the extinct genera—Encrinus, T 4 or 5; Dadocrinus, T 1; Calathocrinus, T 1; Flabellocrinus, T 1.

γ. Apiocrinea: the extinct genera—Guettardicrinus, O 1; Apiocrinus, O 8; Millericrinus, O 20; Conocrinus, Cr 3, E 2; Cyclocrinus, O 2; Balanocrinus, O 1.

δ. Pentacrinea: the living genus Pentacrinus (including Chladocrinus and Extracrinus), T 5, L 10, O 6, Cr 12, E 5, M 1; and the extinct genus Isocrinus, O 2.

Order 6. Blastoidea: the extinct genera—Pentremites, u S 1 (N. America), D 4, C 25; Eleacrinus, D 1; Codonaster, C 2; Zygocrinus (Astrocrinites), C 1; Phyllocrinus, Cr 1.

Order 7. Cystidea: the extinct genera—Pseudocrinus, u S 4; Apiocystites, u S 2; Callocystites, S 1; Prunocystites, u S 1; Echinoencrinites, l S 4, u S 2; Caryocrinus, u S 1; Hemicosmites, l S 5; Calliocrinus, u S 1; Caryocystites, l S 6; Echinosphærites, l S 5, D 1; Heterocystites, S 1; Sphæronites, l S 1; (Protocrinus, S 1; Glyptosphærites, S 1); Stephanocrinus, S 2; Cryptocrinus, l S 2; (Sycocrinus, C 3); Agelacrinus, l S 5; Hemicystites, S 1; Calix, S 1.

SUB-KINGDOM MOLLUSCA.*

CLASS I.—CEPHALOPHORA.

This class is usually called Cephalopoda, and confined to the two first orders. I shall, however, adopt the classification given in the last chapter, and transpose Pictet's matter so as to harmonise with it.

Order 1. DIBRANCHIATA, called by Pictet Cephalopoda Acetabularia, and divided into two sub-orders:—(1.) *Octopoda*, containing the living shell-less Octopus or Poulpe, and similar genera, of which none are known fossil, and the shell-bearing Argonauta, of which one species, A. hians, is living on the coast of China, and fossil in Pliocene rocks in Italy. (2.) *Decapoda*, containing the living Squids or Calamaries and other cuttle-fish, which have no external shell, but have some an internal *bone*, and others an internal chambered shell. This sub-order is divided into five families.

a. Sepiadæ, containing the living genus Sepia, of which 1 or 2 species occur fossil in Oolitic rocks; and the extinct genus Belosepia, E 2.

b. Spirulidæ: the living genus Spirula, none fossil; and the extinct genera—Beloptera, E 2; Belemnosis, E 1; Spirulirostra, M 1.

c. Loligidæ: the living genus Loligo contains 1 extinct species, Lias; and the extinct genera—Teuthopsis, L 3; Beloteuthis, L 1; Leptoteuthis, O 1.

d. Teuthidæ: the living genera having extinct species are—Enoploteuthis, O 1; and Ommastrephes, O 2; and the extinct genera are—Acanthoteuthis, O 1 or 2; Belemnosepia, L 10 or 12.

e. Belemnitidæ: all extinct before the Tertiary epoch. Conoteuthis, Cr 1; Belemnoteuthis, O 1; Helicerus?

* The student is recommended to Woodward's Manual of the Mollusca, as an admirable condensed account of this kingdom, both living and extinct.

1; Belemnites, L 15, O 22, Cr 16; and Belemnitella, Cr 4.*

Order 2. TETRABRANCHIATI (called by Pictet Cephalopoda tentaculifera). They inhabit the first large chambers of a long tapering shell, either straight or variously curved, divided into chambers by partitions (*septa*), the edges of which are either plane or corrugated, traversed by a tube (*siphuncle*). They are divided by Pictet into five families as follows:†—

a. Nautilidæ: siphuncle internal, margins of the septa simple (plane) or gently undulated.

(*a* 1.) Shell regularly involute; contains the only living genus of the order, namely, Nautilus, species of which have existed from the earliest times to the present day. They are u S 2, D 7 and more, C 38, P 2, T 9 or 10, L 9 or 10, O about 20, Cr 32, E 11, M 2; and there are 2 or 4 living species; the extinct genus Nautiloceras has C 3 and T 1.

(*a* 2.) Shell regularly involute while young, afterwards projected across: Lituites, l S 4, u S 3; Hortolus, l S 1, u S 4.

(*a* 3.) Shell arched, not involute: Aploceras, C 6 or 7.

(*a* 4.) Shell straight: Orthoceras, l S 20 or 30, u S about 25, D 50 or 60, C 28, P 1, T 8 or 9; Gonioceras, l S 1; Actinoceras, l S 4, u S 1, C 1; Ascoceras, u S 7.

(*a* 5.) Shell turbinated: Trochoceras, l S 12.

To these M. Pictet adds, as uncertain as to their exact place, the genera — Endoceras, l S 14 or 15; Cameroceras, l S 3, D 1; Melia, l S 3, u S 2, D 9, C 6 or 7, T 2 or 3.

b. Gomphoceratidæ: shell fusiform, apex contracted. Gomphoceras, l S 2, u S 1, D 4, C 4; Sycoceras, l S 1, D 1; Campulites or Phragmoceras, u S 5, D 2; Oncoceras, l S 1, u S 1.

c. Clymenidæ: septa simple or sinuous, siphon close on the inner margin of the shell. Trocholites, l S 3, D 17 or 18; Clymenia, D 20 or more; Subclymenia, C 1; Aturia, E 3, M 1 (including the Nautilus zigzag, and similar species).

* The great genus Belemnites is divisible into five groups:—1. *Acuarii* (Oolitic and Neocomian); 2. *Canaliculati* (Lower Oolite); 3. *Hastati* (Oolitic and Cretaceous); 4. *Clavati* (Lias); 5. *Dilatati* (Neocomian).

† I give an abstract of Pictet's classification, but in many respects that in Woodward's Manual of the Mollusca seems to me preferable.

d. Gyroceratidæ: septa simple, siphon on the external margin. Cryptoceras, D 1, C 1; Gyroceras, u S 1, D 14; Cyrtoceras, l S 7, u S 1, D 27, C 3.

e. Ammonitidæ: siphon on external margin of shell, septa with corrugated margins, forming two sub-divisions.

(*e* 1.) Margins of septa indented, but not ramified. Goniatites, shell involute, D 50 or 60, C 50 or 60, T 26 (Muschelkalk and St. Cassian), Cr 2?; Ceratites, shell involute, lobes of septa denticulated, T 26 (Muschelkalk and St. Cassian), Cr? 5 (? Ammonites); Bactrites, shell straight, D 4 or 5; Baculina, Cr 1.

(*e* 2.) Margins of septa variously indented, ramified, and foliated (all the species belong to the Secondary epoch). The great genus Ammonites, which has between 500 and 600 species, is divided into 20 groups, as in the following table. These groups, however, would not include all the species of the genus, either of Europe or of other parts of the world.

Name of Group.	Exemplar Species.	Rocks in which they occur.
1. Arietes.	A. bisulcatus.	Lower Lias.
2. Falciferi.	A. serpentinus.	Lias to Oxfordian.
3. Cristati.	A. inflatus.	Neocomian and Cretaceous.
4. Amalthei.	A. cordatus.	Lias to Oxfordian.
5. Pulchelli.	A. crenatus.	Oxfordian to Cretaceous.
6. Clypeiformi.	A. requienianus.	Oolitic and Cretaceous.
7. Dentati.	A. denarius and Jason.	Oolitic and Cretaceous.
8. Gemmati.	A. aon.	Triassic.
9. Flexuosi.	A. radiatus.	Neocomian.
10. Compressi.	A. Beaumontianus.	Upper Neocomian and Cretaceous.
11. Armati.	A. perarmatus.	Middle and Upper Oolitic.
12. Angulicostati.	A. Milletianus.	Neocomian and Cretaceous.
13. Capricorni.	A. planicosta.	Liassic.
14. Heterophylli.	A. Guettardi and heterophyllus.	Liassic to Cretaceous.
15. Ligati.	A. Mayorianus.	Neocomian and Cretaceous.
16. Planulati.	A. biplex.	Upper Lias to Portland Oolite.
17. Coronarii.	A. Humphresianus.	Upper Lias and Lower Oolite.
18. Macrocephali.	A. microstoma.	Middle Lias to Lower Cretaceous.
19. Globosi.	A. globus.	Triassic.
20. Fimbriati.	A. subfimbriatus.	Triassic to Cretaceous.

(*e* 2 *continued*)—The genus Crioceras, Cr 6 or 7, differs from Ammonites, as the whirls of the shell do not touch each other;

Scaphites, Cr 18 or 20, when young, like an Ammonite, when older, part of the shell projects across, and then turns into a boat shape; Ancyloceras, O 8, Cr 50, like a Scaphite, but the young part like Crioceras; Anisoceras, Gault 1, like the preceding, but the young part irregularly spiral; Toxoceras, O 4, Cr 15, like an oblique horn, not involute; Hamites, Cr 40 or 50, having the form of a hook; Ptychoceras, Cr 5 or 6, like a hook with its arms squeezed together; Baculites, Cr 10, straight, like a stick; Turrilites, Cr 30, regularly spiral, like a turritella; Helicoceras, O 1, Cr 8, like a Turrilite, but the whirls separated; Heteroceras, Cr 5, the young part like a Turrilite, then projected like an Ancyloceras.

Besides the shells, beak-shaped teeth, like those of living cuttle-fish, have been found in the same beds which include the Ammonitidæ, and are referred to the genera called Conchorhynchus, Rhyncoteuthis, and Palæoteuthis.

The triangular bodies referred to the genus Aptychus, or Trigonellites, which M. Pictet and D'Orbigny class with the Cirripedia, are now believed to be the opercula of some of the Ammonitidæ.

Order 3. PULMONATA. The only order of the class which breathe air; they are either terrestrial or fresh-water, none being marine—divisible into four families.

a. *Limacidæ:* shell internal or wanting, one or two extinct species of Limax and Testacella (recent Tertiary).

b. *Colimacidæ*, all testaceous and terrestrial: Vitrina, Ter 2; Helix, E 30, M 35, Pl 30 (several both l and f); Anastoma, E 3 or 4; Bulimus and Achatina, E 17, M 10, Pl several (some l and f); Pupa, C 1? E 13, M 10, Pl 3 or 4 (several l and f); Clausilia, E 4, M 3, Pl 2; Succinea, E 1, M 3, Pl 2 or 3.

c. *Auriculidæ:* Auricula (sub-genera Scarabus, Conovulus, Carychium, Acme), E 10, M 9, Pl 8 (several l and f).

d. *Lymneadæ:* Lymnæus, W 2 or 3, E 27, M 22, Pl 5 or 6 (many M and Pl are l and f); Chilina, M 1; Physa, E 8, Pl and Ps 2 or 3 (l and f); Planorbis, L 1? W 2 or 3, E 22, M 20, Pl 10 (several l and f); Ancylus, E 2, M 3, Ps several (l and f).

Order 4. PTEROPODA, including those sometimes called HETEROPODA, or NUCLEOBRANCHIATA. I join the data given by Woodward and Pictet. The two first families are Heteropoda.

a. Firolidæ: fragment referred to a Carinaria (Ter.)

b. Atlantidæ: the extinct genera—Porcellia, D 5, C 3, T 3 (St. Cassian); Bellerophon (divided by some into Bucania, Carinaropsis, Crytolites, and Bellerophon), l S 12 or 14, u S 10 or 12, D 15, C 20; Bellerophina, Cr 1; Maclurea, l S 5.

c. Limacinadæ: Limacina, Ter 1.

d. Hyalidæ: Hyalæa, Ter 5; Cleodora, Ter 2; Cuviera, Ter 5; and the extinct genera—Theca (Creseis), S 6; Pterotheca, l S 3; Conularia, S 6, D 5, C 3 or 4; Coleoprion, D 1; Pugiunculus, S 5.

e. Cliidæ: Clio, none fossil.

Order 5. GASTEROPODA DIŒCIA (sexes distinct), or PROSOBRANCHIATA (having the gills or branchiæ forward); all testaceous—divisible into twenty-three families.

a. Cyclostomidæ, the only terrestrial family: Cyclostoma, E 12, M 15, Pl 17 (some l and f); and the extinct genus Ferussina, M 4.

b. Paludinidæ, all freshwater: Paludina, L 4? E 30, M 18, Pl 10 (some l and f); Valvata, E 1, M 1 (several l and f); Nematura, E 1; Ampullaria, the fossil species are referred by Pictet to Natica.

c. Melanidæ, freshwater: Melania, L 2, W 9, E 11, M 14; Melanopsis, E 12, M 12, Pl 2 or 3 (several l and f).

d. Littorinidæ, this and all following families are marine: Rissoa, P 3, T 9, O 13, Cr 2, E 5, M and Pl 40 or 50 (several l and f); Cochlearia, T 1; Turritella, many species so called, some perhaps rightly from Pal and l Sec rocks, O 5 or 6, Cr 30 or 40, E 30 or 40, M and Pl 40 or 50 (some l and f); Scalaria, O 3, Cr 19 or 20, E 20, M and Pl 30 or 40 (several l and f); Littorina, S 1? C 3, O and Cr 10 or 12? Ter 5 or 6 (some l and f); Planaxis, M 2 or 3.

e. Pyramidellidæ: Chemnitzia,* l S 2, u S 1? D 20 or 30, C many, P 5 or 6, T 20, L many, O 20, Cr 5 or 6, E 6, M

* Pictet unites to Chemnitzia many species described as Loxonema, and other genera, by other authors. If we look to the form of the shell only as sufficient for the determination of genera, he may doubtless be justified in this course; since, however, among living genera there are some which, by the external shell alone, could not be distinguished, while the animals are in reality very different, not only in genus, but even in family, it would seem wise rather to raise than diminish the importance of any appreciable differences in shells, more especially when the fossils occur in localities widely

5 or 6; Eulima, C 2, T 5, O 4, Cr 5, E 5, M and Pl 10 or 12 (several l and f); Pyramidella, Cr 2, Ter 10; Niso, Ter several (some l and f); Actæon, O 6, W 1, Cr 16, E 8, M and Pl 20; Volvaria, E 2; Ringicula, E 2, M and Pl 10; Pedipes, E 3, M 1; and the extinct genera—Loxonema, the S, D, C, P, and T species of Chemnitzia; Turbonilla, Ter many, referred to other genera by other authors; Macrocheilus, D 5, C 5; Nerinæa, O 50 or 60, Cr 20 or 30; Avellana, Cr 19 or 20; Acteonella, u Cr 10; Acteonina, C 1, T 4, O 46, Cr 6 or 8; Varigera (Tylostoma), Cr many; Pterodonta, Cr 4.

f. Naticidæ: Natica, u S 3 or 4, D 8, C 16, P 3, T 16, L 2, O 40 or 50, Cr 40 or 50, E about 100, M and Pl 60 (some l and f); Narica, Cr 3; Sigaretus, E 8, M and Pl 14; Velutina, Pl 3 (of which 1 and f); and the extinct genus Deshayesia, M 2.

g. Neritidæ: Nerita (and Neritina), O 25, Cr 10, E 20 or 30, M and Pl 30; Neritopsis, T 4 or 5, O 13, Cr 10, M 1; and the extinct genera—Neritoma, O 2; Pileolus, O 5, Cr 1, E 1.

h. Trochidæ: Turbo, l S 4, u S 8, D 30, C 15, P 5 or 6, T 20 or 30 (Muschelkalk and St. Cassian), L 20, O 50 or 60, Cr 50 or 60, E 30 or 40, M and Pl 30 or 40 (some l and f); Phasianella, D 5 or 6, C 1? T 8, L 5, O 20, Cr 10, E 10, M and Pl 2 or 3 (l and f); Delphinula, T 1, O 15, Cr 10, E 12, M 3 or 4; Trochus (including Monodonta and some other less known genera), S 5 or 6, D 10, C 8 or 10, T 50 (St. Cassian), L 30, O 40 or 50, Cr 50 or 60, E 30 or 40, M 50 or 60, Pl 15 or 20 (of which several l and f); Phorus, Cr 4, E 6, M 10, Pl 2 or 3; Solarium,* T some (St. Cassian), O 5 or 6, Cr 28, E 15 or 20, M and Pl 20 or 30, (some l and f); Pitonellus, D 1, L 4, Cr 2, E 2, M 3 or 4; Stomatia, D 4, C 1, T several, L and O 4 or 5, Cr 2; and the extinct genera—Euomphalus, S 12 to 20, D 20 or more, C 20, P 1, T 3 or 4 (St. Cassian), besides other allied species described, as of the genera Schizostoma, Straparolus, etc., from Sec rocks; Serpularia, D and C a few; Scalites, S, D, and C a few (both perhaps sub-genera of Euom.); and Helicocryptus, O 1, Cr 1.

different geologically or geographically. Independently of our probably being nearer the truth in so doing, the practical utility of this course is obvious. If, for instance, we include Loxonema, etc., under Chemnitzia, we lose the advantage we should otherwise possess of knowing, when we speak of a Loxonema as found in the British Islands, that it must have been found in a Palæozoic rock.

* Pictet unites Euomphalus with Solarium, see previous note.

i. Haliotidæ: Scissurella, Pl 2 (l and f); Haliotis, M 2, Pl 1 (l and f); and the extinct genera—Pleurotomaria, l S 1? u S 6, D 30, C 50, P 6, T many, L 50, O 60, Cr 30, E 3; Murchisonia, l S 10, u S 5, D 14, C 12, P 2, T several (St. Cassian); Catanostoma, D 1; Trochotoma, L and O 15; Cirrus, D 1, C 2, L and O 3; and Polytremaria, C 2.

j. Ianthuridæ: no fossil representative.*

k. Cypreadæ: Cypræa, u Cr 2, E 15, M and Pl 30 or 40 (some l and f); Ovula, u Cr 3 or 4, E 4, M and Pl 7; Erato, Pl 2 (1 l and f); Marginella, u Cr 1, E 8, M and Pl 20 (1 l and f).

l. Olividæ: Terebellum, E 6, M 3; Oliva, E 7, M and Pl 20; Ancillaria, u Cr 1, E 11, M and Pl 26.

m. Strombidæ: Strombus, Cr 4 or 5, E 4, M and Pl 20; Pterocceras, L 1, O 20, Cr 20, E 1; Rostellaria (and Alaria), O 30, Cr 40, E 20, M and Pl 20 (some l and f); Struthiolaria, Pl 1 or 2.

n. Conidæ: Conus, u Cr 5, E 30, M and Pl 80 (in Europe alone).

o. Volutidæ: Voluta, u Cr 20 or 30, E 30, M and Pl 50 or more; Volutella, Ps 1; Mitra, Cr 9, E 30 or 40, M and Pl 60 or 70 (some l and f).

p. Muricidæ: Murex, Cr 2, E 30, M and Pl 60 or 70 (some l and f); Typhus, M and Pl 15; Ranella, M and Pl 20 (some l and f); Triton, u Cr 1, E 14, M and Pl 30 or 40; Fusus (and Trophon), O 10, Cr 30 or 40, E 100, M and Pl 150 (some l and f); Pyrula, Cr 13, E 6, M and Pl 14; Trichotropis, M some, Pl 1 (l and f); Fasciolaria, u Cr 2 or 3, E 3, M and Pl 25; Turbinella, E 2, M and Pl 15; Cancellaria, u Cr 1, E 11, M and Pl 30 or 40; Pleurotoma (and Mangelia), u Cr 2, E 100, M, Pl, and Ps, nearly 200 (some l and f); and the extinct genera—Spinigera, O 3, Cr 1; Borsonia, M 3; Cordieria, E 4.

q. Buccinidæ: Harpa, E 3, M 1; Dolium, M 2 or 3; Oniscia, M 1 or 2; Cassis, E 7, M and Pl 15 (some l and f); Cassidaria, u Cr 1, E 8, M and Pl 10 (2 or 3 l and f); Columbella, M and Pl 20; Purpura, M and Pl 20 (some l and f); Ricinula, M and Pl 4; Monoceras, Pl 4; Buccinum, Cr 1, E many, M and Pl more; Nassa, Cr 1,

* Professor Edward Forbes entertained doubts whether many of the so-called Turbo and similar holostomatous univalves, were not in reality Oceanic snails belonging to this family.

E several, M and Pl many; Terebra, E 2 or 3, M and Pl 20 (some l and f); Cerithium, T 13 (St. Cassian), L and O 120, Cr nearly 100, E 150, M and Pl 110 (some l and f); Triforis, E 1; and the extinct genera—Collumbellina, Cr 3 or 4; Purpuroidea, O 12; Ceritella, O 12.

r. *Vermetidæ:* Vermetus, Cr 2, E 6, M and Pl 6 or 7; Cæcum, E 1, Pl 5 (some l and f); Siliquaria, E 7, M and Pl 5 (1 l and f); and the extinct genus Nisea? l Cr 3.

s. *Crepidulidæ:* Capulus, u S 1, D 6 or 7, C 4,* T 3, L 2, Cr 7, E 11, M and Pl 10 (some l and f); Dispotea, Ter 4 or 5; Calyptræa, Ter 2 or 3; Infundibulum, Cr 2, E 7, M and Pl 13 (some l and f); Crepidula, M and Pl 4 (1 l and f); and the extinct genera—Bucchia, Pl 2; and Spiricella, M 1.

t. *Fissurellidæ:* Parmophorus, E 2, M 2; Emarginula, T 1, O 10, Cr 10, E 5, M and Pl 9; Rimula, O 3, E 2, Pl 1 (l and f); Fissurella, D 1, C 1, O 3, Cr 4, E, M, and Pl 10 (1 l and f).

u. *Patellidæ:*† Patella (including Acmæa, Metoptoma, etc.), l S 3, D 10, Cr 12, T 7, L 4, O 26, Cr 16, E 5 or 6, M and Pl 14 (some l and f); Siphonaria, Ter 3; Gardinia, Ter 1.

v. *Chitonidæ:* Chiton (and Chitonellus), D 6 or 7, C 9, P 1, L 1, O 1, E 1, M, Pl, and Ps 7 or 8 (1 or 2 l and f).

w. *Dentalidæ:* Dentalium, D 2, C 4 or 5, T 6, L 3, O 4, Cr 12 or 15, E 17, M and Pl 18 (some l and f).

Order 6. GASTEROPODA MONŒCIA (sexes united): Opisthobranchiata (having the branchiæ backwards). Mostly naked, but some have an internal, and a few an external shell. Sea slugs.

I give Woodward's classification, which appears to me much better than Pictet's. He divides them into two sections—*A.* Tectibranchiata, those in which the branchiæ are covered by a shell; and *B.* Nudibranchiata, which are destitute of a shell, except in the embryo state, and have therefore no fossil representatives. The section *A* is divided into five families.

A.—TECTIBRANCHIATA.

a. *Tornatellidæ:* Tornatella, 70 sp. in Trias, Lias, etc.; and the extinct genera—Cinulia, Cr 20; Globiconcha, Cr 6; Varigera, Cr 8; Tylostoma, Cr 4; Pterodonta? Cr 8.

* These ancient species of Capulus form the genera Pileopsis and Acroculia of English authors. On this see previous note, p. 357.

† Pictet, following Cuvier, places the Patellidæ and Chitonidæ in a separate order called Cyclobranchiata.

b. Bullidæ: Bulla, O 14, Cr 2, Ter 40; Scaphander, Ter 6; Philine, Ter 6.

c. Aplysiadæ: small bodies found fossil in Tertiary rocks have been referred to Aplysia.

d. Pleurobranchidæ: Umbrella, O 2?, Ter 2; Tylodina, Ter 1.

e. Phyllidiadæ: none fossil.

B.—NUDIBRANCHIATA: no hard parts, and therefore none fossil. Doris, Tethys, Æolis, Glaucus, etc.

CLASS II.—CONCHIFERA.

The ACEPHALA, or LAMELLIBRANCHIATA of some authors. Ordinary Bivalve shells. Pictet and D'Orbigny divide them into those whose natural position is upright, Orthoconchidæ, and those which lie on the side, Pleuroconchidæ. This division corresponds nearly with that into Dimyaria and Monomyaria. The Orthoconchs or Dimyaria may be subdivided into those which have a sinus in the impression of the mantle (Sinupallealia), and those which have none (Integropallealia).

A.—ORTHOCONCHS.

Order 1. The sinupalleal Orthoconchs have, according to Pictet, twelve families.

a. Clavagellidæ: Aspergillum, Ter 2; Clavagella, Cr 5, E 6, M Pl and Ps 4; Gastrochæna, O 11, Cr 7, Ter 12 or 14.

b. Pholadidæ: Septaria, E 1, Ps 1 (l and f); Teredo, O 1, Cr 7, Ter 6 or 8; Pholas, O 6, Cr 7, E 6, M Pl and Ps 14 (some l and f); and the extinct genus Teredina, Cr 2, Ter 1.

c. Solenidæ: Solen D 2 or 3, C 1 or 2, O 1? E 5, M and Pl 10 (6 l and f); Siliqua, Cr 3, E 1; Solecurtus, O 1? Cr 10, Ter 7.

d. Myacidæ: Panopæa, P 1, T 3 or 4, L 20, O 30 or 40, Cr 20 or 30, E 5, M and Pl 7 or 8 (1 l and f); Pholadomya, D 1? C 1? P 1? L and O 110, Cr 30, E 7, M and Pl 5; Glycimeris, Pl 2; Mya, Pl 6 (of which 1 l and f); Lutraria, M and Pl 7 (3 l and f).

e. Mactridæ: Mactra, O 2 or 3? Cr 6, E 7, M and Pl 20 (several l and f).

f. Corbulidæ: Corbula, O 9, Cr 18, E 30, M and Pl 20; Neæra, Cr 1 or 2, Ter 8; Potamomya, O 2? Ter 8; Poromya, Cr 3, Ter 2.

g. Anatinidæ: Anatina, S 1? D 2? L 1, O 20, Cr 20, Ter 6; Thracia, L 6, O 13, Cr 16, Ter 7; Periploma, O and Cr a few; Lyonsia, (1 or 2 l and f); Pandora, Ter 2 or 3; and the extinct genus Ceromya * (and Gresslya), O 35.

h. Mesodesmidæ: Mesodesma, Ps some l and f; no extinct species?

i. Amphidesmidæ: Scrobicularia, O 4? Cr 5, Ter 1 or 2; Cumingia, Ter 1 l and f; Syndosmya, Pl 2 or 3 (l and f); Amphidesma, some, so called but wrongly, in Primary and Secondary rocks, Ter 3 or 4.

j. Tellinidæ: Tellina, D 2? C 2? O 4 or 5, Cr 15, E 20 or 30, M and Pl 20 (some l and f); Acropagia, Cr 5 or 6, E 12, M and Pl 7 (1 l and f); Fragilia, M 2 or 3 (1 l and f); Psammobia, Cr 4 or 5, E 6, M and Pl 10 (some l and f); Sanguinolaria, (Pictet refers all the fossil sp. to other genera); Capsa, M and Pl 1 or 2 (1 l and f); Donax, L 1, Cr 2, E 12, M and Pl 10 (some l and f); and the extinct genus Isodonta, O 1.

k. Petricollidæ: Saxicava, O 1? Cr 1? E 5, m Pl and Ps 7 (some l and f); Petricola, Cr 3 or 4, E 2, Pl 5 (1 l and f); Venerupis, O 2, Cr 1, E 2, M and Pl 4 (1 or 2 l and f); Coralliophaga, E 1, M 1, Pl 1; and the extinct genus Pachymya, Cr 1.

l. Cytheridæ: Tapes (Pullastra), Cr 8, E 5,† M and Pl 9 (some l and f); Venus, O 2 or 3, Cr 20, E 10, M Pl and Ps 20 (many l and f); Cytheræa, O 2 or 3, Cr 9, E 28, m Pl and Ps 30 (many l and f); Dosinia (Artemis), M and Pl 2 or 3 (l and f); Cyclina, M 1; and the extinct genera Thetis, D 1? Cr 5; and Grateloupia, M 4.

A 2. The Integropalleal Orthoconchs have also twelve families, of which the first ten have two nearly equal muscular impressions, the eleventh (Mytilidæ) very unequal ones, and the last (Tridacnidæ) one impression only.

a. Cyclasidæ, (freshwater): Cyclas (and Pisum), W 10 or 12, E 20, m Pl and Ps 5 or 6 (mostly l and f); Cyrena, O 8, W 30 or 40, E 22, M and Pl 10 (some l and f); Glauconome, E 2; Gnathodon, Ps 3 (1 l and f).

b. Cyprinidæ: Cyprina, O 6, Cr 20 or 30, E 4, M and Pl 3; Cypricardia, O 8 or 10, Cr 5 or 6, E 2, M 1.

* Many Liassic and Oolitic shells described as Lutraria, Unio, Tellina, Amphidesma, etc., are placed by Pictet under this genus.

† One of these is said by M. Deshayes to be undistinguishable from T. decussata still living; if it be the same species, this is one of the most anciently descended animals now living on the globe.

c. *Cardidæ:* Cardium, u S 1? D 20? C? T 2 or 3, O 30, Cr 50, E 30, m Pl and Ps 50 or 60 (some l and f); Isocardia, C 2, T 10, L 2, O 18 or 20, Cr 15, Ter 15 (some l and f); and the extinct genera—Unicardium, O and Cr, many usually placed under other genera; Conocardium* (Pleurorhycorchus), D 3 or 4, C 10; Cardiomorpha, S 5 or 6, D 3 or 4; Cardiola, u S 2; Lunulacardium, D 5 or 6; Hettangia, L 12.

d. *Lucinidæ:* Corbis, O 20 or 30, Cr 6 or 8, Ter 3 or 4; Lucina, D 4, C 3, T 2, O 30 or 40, Cr 18 or 20, E 35, m Pl and Ps 30 or 40 (some l and f); Diplodonta, M 4 or 5 (1 l and f); Scacchia, Ps 1 (l and f); Ungulina, E 1; Cyrenella, E 1; Erycina (and Kellya), E 10, m Pl and Ps 15 (some l and f); Cardilia, E 2; and the extinct genus Edmondia, Cr 20.

e. *Astartidæ:* Crassatella, Cr 20, E 24, M and Pl 10; Astarte, P 2, T 3, L 8 or 10, O 70 or 80, Cr 37, E 6, M and Pl 40 (several l and f); Circe, Pl 1 (l and f); Cardita (with Venericardia and Hippopodium), T 7, L 1, O 10 or 12, Cr 20, E 50, m Pl and Ps 50 (some l and f); and the extinct genera—Opis, T 1, O 30,† Cr 13; Pachyrisma, O 1; Megalodon, S 2? D 10, C 2? Pleurophorus, P 1; Myoconcha, P 2 or 3, T 2, O 11, Cr 3 or 4; Cardinia,‡ S 3? D 19 (many described as Pullastra, Corbula, etc), C 12 or 15, T 4, L 20, l O 3.

f. *Unionidæ* (freshwater): Unio (including Anodon§), D 1 (Anodon), W 9, Cr 1 or 2, E 9, m Pl and Ps 20 (3 l and f).

g. *Cælonotidæ:* the extinct genera—Grammysia,‖ S 3, D 2; Leptodomus,¶ S 8; Dolabra, S 2, D 4, C 3; Modiolopsis, S many (often described as Cypricardites,

* This genus requires re-examination. In well-preserved specimens there is a curious thin fringe or hood projecting over the contracted end of the shell, which is very easily detached from it, and remains on the stone when the shell falls away. Dr. Melville informs me that it has been suspected to be a brachiopodous shell. It has obviously so little relation to Cardium, that its being placed in the same family is a mere temporary arrangement. For the same reason, Phillips' name of Pleurorhyncus seems far better than Conocardium.

† Most of these have been described as Cardita, etc.

‡ Some have been called Unio, others Anthracosia.

§ What advantage is to be gained by suppressing easily distinguishable groups, such as Anodon, and mingling them up with a huge assemblage like Unio?

‖ Including Orthonotus of Salter.

¶ Including proposed genera called Allorisma, Sanguinolites, Myacites, etc.

Pterinea, Modiola, etc.); Anodontopsis, S 5; Lyrodesma, S 1; Cleidophorus, S 1; Tellinomya, S several (some called Orthonotus).

h. Trigonidæ: Trigonia, T 2, L 5, l O 20, m O 6 or 8, u O 14, Cr 30 or 40,* Ter 2? and the extinct genera—Myophoria, T 15; Schizodus (including Sedgwickia and part of Axinus), C several, P 6 or 8.

i. Arcacidæ: Arca (including Cucullæa and Byssoarca), S 15, D 12†, C 12, P 5, T 16, L 10, l O 20 or 30, m O 20, u O 15 or 20, Cr 50 or 60, E 40, m Pl and Ps 30 (some l and f); Pectunculus, Cr 20, E 12, M Pl and Ps 40 (some l and f); Limopsis, O 5, Cr 3, Ter 16; Nucula, S 5 or 6, D 16, C 11, P 3, T 18, L 8, O 11, Cr 20 or 30, Ter 30 (some l and f); Leda, T 10, L 6, O 10, Cr 5, E 10, M and Pl 10 (several l and f); and the extinct genera—Stalagmium, Ter 2; Isoarca, O 7, Cr 6; Cucullela, S 15; Nuculina (Pleurodon), Ter 1; Nucunella, Ter 2; Orthonota, S 3 or 4.‡

j. Solenomyadæ: Solenomya, doubtful whether any fossil.

k. Mytilidæ: Pinna, C 6 or 7, P 1? T 1, L 4, O 12, Cr 17, Ter 8 (1 or 2 l and f); Mytilus, D 12, C 5 or 6, T 11, L 12, O 20 or 30, Cr 30 or 40, Ter 30 or 40, (some l and f). Lithodomus, O 10 or 12, Cr 16, Ter 5 (1 l and f); Dreissena, Ter 13.

l. Tridacnidæ: Tridacna,§ Ps 1 l and f.

B. PLEUROCONCHES. Pictet makes eight families of these, namely:

a. Chamidæ: Chama, Cr 4 or 5, l Ter 18, m and u Ter 6 or 7, l and f 1 or 2; and the extinct genus Diceras, O 6 or 8, Cr?

b. Etheridæ: Etheria, none fossil.

c. Malleaceæ: Malleus, none fossil; Avicula, S 6 or 8, D 20 or 30, C 15 or 20, P 3, T 6 or 8, L 7 or 8, O 15 or 20, Cr 20 or 30, Ter 8; Vulsella, Cr 1? Ter 2? Crenatula, none fossil; Perna, T 1, O 12, Cr 10, Ter 3 or 4 (l and

* Two species of this interesting genus (the second T. uniophora found by myself in 1844), still linger round the coasts of Australia, while it is entirely extinct in every other portion of the globe.

† These are usually called Cucullæa. Pictet thinks some of them may be Nucula, others Cælonotidæ. Some of those quoted as from D, are probably really from C.

‡ Confined to America, according to Pictet.

§ The Tridacna generally lies in a horizontal position on the coral reefs, and would therefore seem to belong to the Pleuroconches. They occur fossil in raised fringing reefs in the island of Timor, etc.

f 1); and the extinct genera—Bakevellia, P 5; Pterinea, D 14; Pteroperna, O 3; Myalina, C 3; Monotis, P 3, T 6, O 3; Trichites, O 5, Cr 2; Posidonomya (and Posidonia), S 1, D 7 or 8, C 8 or 10, T 4, L 3, O 9; Gervilia, T 3, O 16, Cr 10; Inoceramus* (and Catillus), O 12, Cr 22.

d. Limidæ: Lima (including Plagiostoma), T 10, L 12, O 30 or more, Cr 40 or 50, Ter 10 or 12 (l and f 6 or 8); and the extinct genus Limea, O 4, Ter 2.

e. Pectinidæ: Pedum, none fossil; Pecten,† D 12, C 24, P 3, T 15 or 20, L 10, O 24, Cr 30 or 40, Ter 60 or more (l and f 10 or 12); Hinnites, T several, O 10, Cr 3, Ter 4, l and f 1; Janira, Cr 20 or 30, Ter 12 (l and f 2 or 3); Spondylus, Cr 20, Ter 20; Plicatula, T 1, L 4, O 8, N 5, Cr 3 or 4, Ter 15.

f. Ostracidæ: Ostræa, T 4, L 10, O 20 or 30, Cr 20, Ter 50 or 60 (l and f 5 or 6); Gryphæa, T 2 or 3, L 2, O 5, Cr 1 or 2, Ter 1 or 2; Exogyra,‡ u O 4, Cr 10 or 12; Placuna, none? fossil; Anomia, O 3, Cr 10 or 12, Ter 6 or 8, l and f 4 or 5; and the extinct genera—Placunopsis, O 4; Pulvinites, O 1, Cr 1.

Class III.—MOLLUSCOIDEA.

Order 1. Brachiopoda. These differ from ordinary bivalve shells in the following particulars. They have no distinct branchiæ (gills), the mantle performing the respiratory function, hence they have been called Palliobranchia. They have no foot, but ciliated arms (brachia), often supported on internal shelly processes. They are differently placed in the shell, the median line of the animal cutting through the middle of each valve, while in the Conchifera it corresponds with the division between the valves. The valves of the Brachiopoda are accordingly front (ventral) and back (dorsal), while in the Conchifera they are right and left valves. It results that while in the Conchifera the valves are almost always equal (equivalves), they are usually inequilateral; the Brachiopoda, on the contrary, being

* Pictet refers the Inoceramus of the Silurian and Devonian periods to Posidonomya, but says nothing of those which seem certainly Inoceramus in the Carboniferous limestone.

† Pictet ignores the genus Aviculopecten of M. Coy, with its multitude of species, made, perhaps, chiefly out of distorted and imperfect specimens.

‡ Gryphæa and Exogyra can hardly be separated from Ostræa by any good generic characters. They are, however, useful groups, and I have therefore mentioned their species separately instead of under Ostræa, as is done by Pictet.

always equilateral, and almost always inequivalve. They are divided into nine families, of which the five first have their valves united by an articulated hinge, and the four last are not so united.

a. Terebratulidæ: Terebratula (including Waldheimia, Eudesia, and Epithyris), D 10, C 7 or 8, P 3, T 15, L 10, l O 50, m O 15, u O 8, Cr 40, E 6, M and Pl 4; Terebratella, L 1, O 5, Cr 16, Ter 2 (1 l and f?); Terebratulina, Cr 12, E 12, M 1 (l and f); Morrisia, Cr 1; Argiope, Cr 3; and the extinct genera—Trigonosemus, u Cr 5; Terebrirostra, Cr 5; Magas, Cr 1; Stringocephalus, D 3.

b. Thecideidæ; the living genus Thecidea, T 1? O 9, Cr 7, M 1.

c. Spiriferidæ: the extinct genera—Spirifer, l S 5 or 6, u S 30, D 50 or 60, C 60 or 70, P 12, T 10;* Cyrtia, u S 2, D 3, C 3 or 4, P 1, T 1; Spiriferina, L 12; Spirigera, u S 8, D 15, C 8, P 1, T 5; Spirigerina, u S 6, D 5 or 6; Retzia, u S 3, D 3, C some; Uncites, D 2; Koninckia, T 1.

d. Rhynconellidæ; Rhynconella, l S 11, u S 20, D 12, C 12, T several, L 10, l O 27, m and u O 12, Cr 40; and the extinct genera—Atrypa, l S 20, u S 80†, D 56, C 22, P 1; Camarophoria, C 2 or 3, P 3; Pentamerus, l S 5 or 6?‡, u S 12, D 4, C 1? Porambonites, u S 6.

e. Productidæ: the extinct genera—Orthis, l S 30 or 40, u S 40 or 50, D 20 or 30, C 12; Orthisina, l S 6, D 3, C 1, P 2; Strophomēna, l S 20, u S 10 or 12, D 6, C 2 or 3; Leptæna, l S 20, u S 30, D 15 or 20, C 3, L 5§; Producta (and Strophalosia), D 5, C 50, P 10; Chonetes, u S 3, D 12, C 15, P 1; Davidsonia, D 2.

f. Calceolidæ: the extinct genus Calceola, D 1.

g. Cranidæ: the living genus Crania, l S 2, u S 2, D 1, C 1, L 1, l O 2, m O 6, Cr 14, M 1.

h. Orbiculidæ: the living genus Orbicula, E 3, P 2 (l and f); and the extinct genera—Trematis, l S 1, u S 5 or 6; Orbiculoidea, u S 3, D 4, C 7, P 1, T 2, o L 3, O 6, l Cr 3; Siphonotreta, l S 5, u S 1; Acrotretra, l S 3.

* The Spirifers of the Lias are called Spiriferina by D'Orbigny and Pictet.

† Many of these numbers are called Rhynconella, etc., by other authors.

‡ Many of these would now probably be classed as u S, the position of their localities being better known.

§ Provided these species really belong to Leptæna.

i. Lingulidæ: the living genus Lingula, l S 12, u S 5, D 4, C 6, P 1, O 4, Cr 4, Pl 2; and extinct genus Obolus, l S 2, u S 2.

M. Pictet places in connection with the Brachiopoda the very singular group of shells known as the RUDISTÆ,* divisible into two families, both absolutely restricted to the Cretaceous period.

a. Caprinidæ: the extinct genera—Hippurites, Cr 12 (Chalk marl, Turonien 10, White Chalk, Senonien 2); Caprina, Cr 3 (Upper Green sand, Cenomanien, and Chalk marl); Caprinula, Cr 3 (Chalk marl); Caprinella, Cr 2 (Lower Green sand, Urgonien).

b. Radiolidæ: the extinct genera—Radiolites, Cr 35 (from Lower Green sand to White Chalk); Biradiolites, Cr 4 (Chalk marl 3, White Chalk 1); Caprotina, Cr 24 (from Lower Green sand to White Chalk).

Order 2. POLYZOA or BRYOZOA. Pictet divides these into two groups—*A.* The Cellulina or Escharidæ; *B.* The Centrifuginæ or Tubuliporidæ.

A. The CELLULINA may be divided into three families:

a. Cellarioidæ, of which the genera Electra, Electrina, Caberea, Reteplectrina, have no fossil species; and the living genera—Canda, M 3 (l and f); Cellaria, Cr 4, P 3 (2 l and f); Tubucellaria, N 1 (l and f); and several sub-genera Cr.

b. Escharoidea, of which Lanceopora and Terebripora have no fossil species; and Vincularia, Cr 42; Eschara, O 1, Cr 89, E 7, M 2, P 1; Lunulites, Cr 11, E 6, M 3, P 2; Retepora, l S 1, D 3, C 6,† E 2, M 5 or 6; Cellepora, Cr 20, Ter 30; Vincularina, Cr 6, M 2; Porina, Cr 4, Ter 8; Escharifora, Cr 6; Discoporella, M 3; Steginipora, Cr 4; and thirty-seven sub-genera, containing several species, each described by D'Orbigny from Cretaceous and Tertiary rocks.

c. Flustrinoidæ: Siphonella, Cr 30, M 1; Flustrella, Cr 20; Flustrina, Cr 17; and ten sub-genera, containing thirty or forty species from Cretaceous and Tertiary rocks.

B. The CENTRIFUGINÆ have three families—

a. Radicellæ: Crisia, M 5; Unicrisia, Cr 1, M 1.

b. Operculinæ: Nodelea, Cr 8; and the extinct genera—Melicertites, O 2, Cr 12; Elea, O 2 or 3, Cr 6, besides several sub-genera.

* Mr. Woodward places them among the Conchifera dimyaria.
† These Palæozoic Reteporæ are probably Fenestellæ.

c. Tubuliporidæ: Fasciculipora, O 1, Cr 6, Ter 1; Frondipora, M 1; Berenicea, O 10, Cr 12, Ter 10; Idmonea, O 1, Cr 20, E 9, M 5; Tubulipora, Cr 40, E 2; Stomatopora, O 10, Cr 9, E 1, M 3, Pl 1; Hornera, E 2, M 3, Pl 2, Ps 2; and the extinct genera—Theonoa, O 3, Cr 2; Fascipora, Cr 1; Spiropora (Cricopora) O 1, Cr 3, E 1; Diastopora, O 2, Cr 5; Cavea, Cr 10, Ceriopora, Cr 5; Heteropora, O 1, Cr 1; together with a great number of other genera and sub-genera both living and extinct.

To these M. Pictet appends the following extinct genera—Fenestella, l S 1, u S 6, D 5, C 15, P 1, and some sub-genera all Palæozoic; Synocladia P 1; Glauconome, u S 1, D 2, C 5, P 1; Ptilodyctia, l S 5, u S 2, and some sub-genera; Seriatopora, S 1, and sub-genera; and Oldhamia, Cambrian 2, l S 1?

GRAPTOLITES: Professor Huxley is of opinion that the family of Graptolites ought to be placed here. Pictet gives the following genera—Graptolithus, l S 10 or 12, u S 10 or 12; Rastrites, S 3; Diprion, l S 12, u S 3; Cladograpsus, l S 2 (America); Didimograpsus, l S 6; Gladiolites, u S 1.

Order 3. ASCIDIOIDEA or TUNICATA have no known fossil representatives, as they have no hard parts that are likely to be preserved.

SUB-KINGDOM CÆLENTERATA.

CLASS I.—ACTINOZOA.

Order 1. ALCYONARIA, divisible into two* families.

a. Alcyonidæ: Alcyonium, P 1; Distichopora, E 1.

b. Gorgonidæ: Isis, Cr 1, M 1; Mossea, E 1; Corallium, Cr 1, M 1; Virgularia, E 1; Pavonaria, u Cr 1 (l and f?); and the extinct genus Graphularia, E 1.

Order 2. RUGOSA, the Palæozoic type of stony corals, divided by Pictet into three families.

a. Stauridæ, all extinct: Stauria, u S 1; Holocystis,† Cr 1; Polycælia, P 1; Metriophyllum, D 2.

b. Cyathaxonidæ: Cyathaxonia, u S 2, C 5.

* Pictet makes three families, placing the Graptolites as the end of the order.

† This is the only exception to the Palæozoic period of the order; it perhaps requires revision.

c. Cyathophyllidæ: the genus Zaphrentis, S 4, D 8, C 17; (and the sub-genera Amplexus, D 3, C 5; Menophyllum, C 1; Lobophyllum, D 1, C 2; Anisophyllum, D 1; Baryphyllum, D 1; Hadrophyllum, D 2; Hallia, D 2; Aulacophyllum, u S 1, D 2; Trochophyllum, C 1; Combophyllum, D 2); the genus Cyathophyllum, u S 8, D 30, C 10; (and the sub-genera—Endophyllum, D 2; Campophyllum, D 2, C 1; Streptolasma, l S 3; Pachyphyllum, D 2); the genus Omphyma, u S 5; (and sub-genera—Goniophyllum, u S 2; Chonophyllum, D 2; Ptychophyllum, u S 2, D 1; Heliophyllum, D 1); the genus Acervularia, u S 2, D 9; (and sub-genera—Aulophyllum, C 2; Smithia, D 4; Phillipsastræa, D 1, C 2; Syringophyllum, u S 1, D 2; Eridophyllum, u S 1, D 1; Spongophyllum, D 1); the genera—Strombodes, u S 8 or 9; Lithostrotion, D 1, C 22; (and sub-genera—Clisiophyllum, u S 2, C 5; Chonaxis, C 1); the genera—Petalaxis, C 2; Axophyllum, C 3; Lonsdalia, C 5; Cystiphyllum, u S 4, D 3.

The above are separated as an order from the other stony corals on the authority of Professor Huxley.

Order 3. ZOANTHARIA.—This order ranges from the Palæozoic epoch to our own times; the Rugosa being detached, the remainder form, as divided by Pictet, six sub-orders.

Sub-order Z. APORA, divisible into four families.

a. Turbinolidæ: the living genera—Cyathina,* Cr 9, Ter 5 (1 l and f); Paracyathus, E 4, M 1, Pl 2; Placocyathus, Cr 1; Sphenotrochus, E 5, M 3; Desmophyllum, M 1, Pl 1; Flabellum, E 7, M 5, Pl 9, Ps 1; and the extinct genera—Discocyathus, O 1, Cr 1; Conocyathus, M 1; Trochocyathus, O 2, Cr 6, E 11, M 25; Thecocyathus, O 1, Cr 1, E 1; Delthocyathus, M 1; Turbinolia, E 9; Smilotrochus, Cr 1; Platytrochus, E 2; Ceratotrochus, E 1, M and Pl 3; Discotrochus, E 1; Dasmia, E 1.

b. Oculinidæ: Oculina, O 1, E 2; Stylophora, E 1, M 1; and the extinct genera—Astrhelia, M 3; Synhelia, Cr 3; Diphlelia, E 3, M 1; Enallhelia, O 3, Cr 2; Evhelia, O 1.

c. Astreidæ: Eusmilia and Euphyllia have no fossil species; Lophosmilia, Cr 1; Caryophyllia, M 1; Mussa, M 1;

* I have disregarded in this and other genera the divisions into sub-genera.

Eunomia (including Calomophyllia, Dasyphyllia, etc.), T 2, L 1, O 18, Cr 5, M 1; Oulophyllia, O 3, M 1; Mæandrina, O 7, Cr 9, M 2; Diphoria, Cr 2; Hydnopora, Cr 2, M 1; Cladocora, Cr 2, M 4, Pl 2; Astræa, Cr 8, M 8 (and six other genera ending in "Astræa"); and the following extinct genera—Cylicosmilia, E 1; Placosmilia, Cr 6 or 8; Trochosmilia, O 2, Cr 25, E 5, M 1; Parasmilia, Cr 7; Cælosmilia, Cr 2; Diploctenium, u Cr 6; Peplosmilia, Cr 1; Axosmilia, L 1, O 1; Placophyllia, O 2; Stylosmilia, O 1, Cr 3; Dendrosmilia, E 1; Aplosmilia, O 3; Barysmilia, Cr 4; Dactylosmilia, Cr 2; Pachygyria, O 6, Cr 2, M 1; Stylina, O 20 or 30; Convexastræa, T 1, O 2; Stylocænia, Cr 1, E 3, M 1 (and twenty-five other genera or sub-genera ending in cænia, and including a multitude of species from Oolitic, Cretaceous, and Tertiary rocks); Montlivaltia (including several sub-genera of D'Orbigny), T 5, L 4, O 20, Cr 13, E 2, M 1; Thecosmilia, O 8, Cr 2; Isastræa, T 1, O 4, Cr 10; Thamnastræa, T 2, O 22, Cr 25 (and twelve! other extinct genera ending in "astræa"! besides the six living ones mentioned before);* Cryptangia, M 3 (and four other genera ending in "angia").

d. Fungidæ: Cycloseris, Cr 4 or 5, E 3; and the extinct genera—Micrabacia, Cr 1; Anabacia, O 3; Genabacia, O 1; Cyclolites, Cr 11, E 5, M 1; Palæocyclus, u S 4; Trochoseris, and four other "seris," O 4, Cr 1, E 4, M 1.

Sub-order Z. PERFORATA, divisible into 2 families.

a. Madreporidæ: Endopachys, E 1; Balanophyllia, E 4, Pl 3, Ps 1, l and f; Dendrophyllia, E 1, M 4; Madrepora, E 3, M 2; Turbinaria, M 1; Astereopora, E 3; and the extinct genera—Eupsammia, E 5, M 1; Stephanophyllia, E 1, M 1, Pl 2; Discopsammia, Pl 3; Lobopsammia, E 2; Stereopsammia, E 1.

b. Poritidæ: Porites, M 1; and the extinct genera—Litharæa, E 6, M 1; Microsolena, O 8; Pleurodictyum, D 1.

Sub-order Z. TABULATA, divisible into four families.

a. Milleporidæ: the extinct genera—Heliolites, l and u S 3, u S 2, D 2; Fistulipora, C 2, P 1? Plasmopora,

* I pretend to no authority on a subject of which I have no knowledge, but I cannot believe in the necessity for this multiplication of species and genera, and beg leave to protest against the cumbrous nomenclature of MM. D'Orbigny, and Edwards, and Haime. Who could recollect a score of words all ending in "cænia," or "astræa"?

u S 3, D 1? Propora, u S 2, C 1? Lyellia, S 1; Axopora, E 3; Battersbya, D 1.

b. *Favositidæ:* Pocillopora, M 1; and the extinct genera —Favosites, S 8, D 9, C 1; Emmonsia, S 2, C 1; Roemeria, D 1; Michelinia, D 2, C 5; Koninckia, C 1; Alveolites, u S 6, D 7, C 2; Chætetes, l S 1, u S 3, D 2, C 3, P 1; Monticulipora, l S 10, u S 1, D 2; Dania, S 1; Beaumontia, D 2, C 2; Dekayia, l S 1; Labecheia, u S 1; Cænites, u S 5; Halysites, S 1, u S 1; Syringopora, u S 5, D 5, C 6; Thecostegites, D 3; Chonostegites, D 1; Fletcheria, u S 1.

c. *Seriatoporidæ:* Seriatopora has no fossil species; the extinct genera—Dendropora, D 1; Rhabdopora, C 1; Tachypora, D 1.

d. *Thecidæ:* the extinct genera—Thecia, u S 1; Columnaria, l S 1, u S 1.

The soft Zoantharia such as the Actinia (Sea-anemone), Beroe, etc., may possibly be the origin of some of the round circular marking and stains, or semiconcretionary patches, occasionally observable in some rocks.

Class II.—HYDROZOA.

Order 1. Lucernarioda, the living genus Sertularia has one species Ps, both l and f, and one extinct genus Websteria, E 1, possibly belongs to this group, as may also *Oldhamia*, mentioned in the Polyzoa.

Order 2. Hydroidea. The Medusæ and allied genera may contribute with the Actiniæ to the markings mentioned above.

Sub-Kingdom PROTOZOA.

Class I.—STOMATODA.

Order 1. Noctilucidæ, none fossil.

Order 2. Infusoria. Many fossil, but Pictet omits them on the plea of its being very doubtful with respect to most of them how far they belong to the animal kingdom, with which he alone concerns himself. I shall omit them solely from want of space, and from their being a peculiar subject requiring special apparatus, and therefore not coming within the range of the ordinary student's occupation, while those who wish to study them will have recourse to the requisite authorities. For some notice of them see *ante*, p. 115.

CLASS II.—ASTOMATA.

Order 1. SPONGIADÆ, divided by Pictet into three families.

a. Spongidæ, none fossil.

b. Clionidæ: Cliona, S 1? Cr 4, E 2, M 1; Talpina? Cr 2; Dendrina? Cr 1.

c. Petrospongidæ, all extinct: Coscinopora, Cr 25; Guettardia, Cr 3, E 1; Ocellaria (Ventriculites), Cr 10; Cephalites, u Cr 3; Cribrospongia, O 2, Cr 1; Cæloptychium, u Cr 1; Retispongia, u Cr 2; Thalamospongia, l Cr 1; Palæospongia, l S 1; Porospongia, O 5; Goniospongia, O 9; Eudea, T 5, O 12, Cr 2; another group (called Scyphia, Manon, etc.), P 1, T 3, O 12, Cr 17; Perispongia, O 2; Cnemidium, O 7, Cr 5; Sephonia (Choanites), Cr 20; Hippalimus, Cr 2; Verticillites, Cr 2; Ptychotrochus, Cr 1; Lymnorea (and four sub-genera), T 12, O 5, Cr 2 or 3; Chenendopora (generally described as Tragos and Manon), O 6, Cr 7; Forospongia, O 2, Cr 2; Jerea, O 1? Cr 13; Marginospongia, Cr 2; Pleurostoma, Cr 1; Hemispongia, Cr 1; Verrucospongia, T 1, Cr 4; Sparsispongia, D 3, T 1, O 1, Cr 2; Conis, Cr 1; Bothroconis, P 1; Stellispongia, T 3, O 11, Cr 8; Cupulospongia, P 2, T 1, O 17, Cr 28; Mæandrospongia, Cr 1; Plocoscyphia, Cr 9; Amorphospongia, P 1, T 9, O 10, Cr 25; Turonia, Cr 1; Stromatopora, l S 1, u S 2, D 5, C 1, T 1.

Order 2. FORAMINIFERA, divided by D'Orbigny into seven families.*

a. Monostegidæ: the living genera—Orbulina, M and Pl 1 (l and f); Oolina, Cr 2, M and Pl 2; and the extinct genera—Fissurina, E 1, M 1; Ovulites, E 2; Acicularia, E 1; Dactylopora, E 2; Conodictyum, O 2; Goniolina, O 1.

b. Cyclostegidæ: Orbitolites, E 2; and the extinct genera—Cyclolina, Cr 1; Orbitolina, Cr 4; Orbitoides, E 4.

c. Stichostegidæ: the living genera—Glandulina, L 10, Cr 6, M 13, Pl 1; Nodosaria, L 2, Cr 17, E 4, M 11 Pl 16; Orthocerina, E 1; Dentalina, P 2, L 5, Cr 20, E 10, M 24, Pl 3; Frondicularia, L 7, Cr 20 or 30, E 1, M 16, Pl 3; Lingulina, L 1, Cr 1, M 3, Pl 1; Marginulina, L 3, O 2, Cr 14, E 2, M 12 or 14; Vaginulina, L 2, O 3, Cr 14, M 4; Webbina, L 1, Cr 2.

* These are called orders by D'Orbigny and Pictet, as they make the Foraminifera a class; the rank of these groups is so arbitrary that it makes very little difference what we call them.

d. *Helicostegidæ*, subdivided into two groups—*d* 1, *Nautiloidæ:* Cristellaria, L 10, O 8, Cr 20 or 30, E 3, M and Pl 30 or 40; Robulina, L 2, Cr 2, E 10, M and Pl 18 or 20; Nonionina, Cr 3, E 6, M and Pl 12; Operculina, Cr 2, E 5, M 9; Polystomella, M 15, Pl 1; Peneroplis, E 2, M 1; Dendritina, M 4; Spirolina, Cr 2, E 6, M 2; Orbiculina, M 2; Alveolina, Cr 3, E 6, M 3; and the extinct genera—Flabellina, Cr 11, M some; Fusulina, C 2 (one of the few Palæozoic forms); Nummulites,* E 50, M 1; Assilina, E 5; Siderolina, Cr 2; Hauerina, M 1; (these three closely allied to Nummulites). *d* 2. *Turbinoidæ:* Rotalia, L 1, O 1, Cr 14, E 20, M and Pl 20 or 30; Globigerina, Cr 6, E 1, M and Pl 11; Planorbulina, Cr 2, M and Pl 2 (1 l and f); Truncatulina, Cr 4, E 2, M 5; Anomalina, Cr 2, M 6; Rosalina, Cr 5, E 4, M and Pl 12; Valvulina, Cr 6, E 7, M 2; Bulimina, Cr 18, M and Pl 10; Uvigerina, Cr 1, E 1, M and Pl 6 or 8; Clavulina, Ter 4; and the extinct genera—Siphonina, M 1; Placopsilina, L 1, Cr 3; Verneuilina, Cr 2; Pyrulina, Cr 1, Pl 1; Faujasina, Cr 1; Chrysalidina, Cr 1; Gaudryina, Cr 4, E 1, M 1.

e. *Entomostegidæ:* The living genera—Astigerina, E 1, M 2; Amphistegina, Cr 1, M 2; Heterostegina, M 2; Cassidulina, M 2.

f. *Enallostegidæ:* Dimorphina, M 2; Guttulina, Cr 4, E 2, M and Pl 6; Globulina, Cr 2, E 7, M and Pl 16; Polymorphina, L 1, Cr 3, E 5, M and Pl 20; Virgulina, Cr 1, M 2; Bigenerina, M 2; Textularia, C 1, P 2, Cr 20, E 1, M and Pl 14; Bolivina, Cr 2, M 1; Sagrina, L 1, Cr 1; and the extinct genera—Aulostomella, Cr 1, M 1; Allomorphina, Cr 1, M 1; Chilostomella, E 1, M 1; Cuneolina, Cr 3.

g. *Agathistegidæ:* Biloculina, Cr 1, E 5, M and Pl 9; Spiroloculina, E 3, M 12; Triloculina, Cr 1, E 8, M and Pl 12; Articulina, E 1, M 2; Sphæroidina, E 1, M 1; Quinqueloculina, Cr 1, E 14, M 26, Pl 8; Adelosina, Cr 1, M 2, Pl 1; and the extinct genus Fabularia, E 2.

* These remarkable fossils, some of which are as large as a crown-piece, compose the mass of whole formations belonging to the commencement of the Tertiary period. The stone of which the Pyramids are built is composed of them.

VEGETABLE KINGDOM.

The following is an abstract of the plants given in Bronn's "Index Palæontologicus" (1849). In this the arrangement is different from that in Pictet, since Bronn begins with the lowest and works upwards. He uses the terms Cellulares and Vasculares (see *ante*, p. 310). A great number of families which have no fossil representatives are omitted, as it is designed to give an abstract of the fossils only.

CLASS I.—CELLULARES.

A. FUNGI.

Coniomycetes, none.

Hyphomycetes: Nyctomyces, m Ter 1; Sporotrichites, Ter 1; Rhizomorphites, Ter 1.

Gasteromycetes: Hysterites, Ter 2; Xylomites, L 1, O 1, Ter 1; Excipuletes, C 1.

Pyrenomycetes: Sphæria, Ter 4.

Hymenomycetes: Polyporites, C 1.

B. ALGÆ.

Confervoidæ: Confervites, T 1, W 1, Cr 1, Ter 3.

Characeæ: Chara, Ter 4 or 5.

Ulvaceæ: Codites, O 2; Caulerpites, C 1, P 13, O 11, Cr 2, Ter 6; Hellia Ter 3.

Florideæ: Rhodomelites, C 1, Cr 1; Chondrites, D 2 or 3, C 3, O 5, Cr 8, Ter 3; Sphærococcites, D 2, C 1, P 1, T 1, L 3, O 2, Ter 4; Halymenites, O 12, Cr 1; Baliostichus, O 2; Munsteria, O 4, Cr 1, Ter 3; Delessertites, E 7; Cylindrites, Cr 3; Sphæreda, O 1; Tympanophora, O 2; Solenites, O 2; Astrocladium, L 1; Algacites, O 2.

Fucaceæ: Encoclites, O 1; Haliserites, O 1, Cr 1; Zonarites, P 1, E 1; Laminarites, C 1, Ter 2; Cystoseirites, O 1, Ter 4; Sargassites, Cr 1, E 1; Fucus, C 2; Fucites, Ter 1; Fucoides, Cambrian 1 or 2? C 2.

C. LICHENES. Ramallinites, L 1, Ter 1.

D. HEPATICÆ. Jungermannites, Ter 3.

E. MUSCI FRONDOSI. Muscites, Ter 7.

CLASS II.—VASCULARES.

Division I.—MONOCOTYLEDONES.

A. CRYPTOGAMIA.

Equisetaceæ: Calamites, D 7, C 34, P 4, T 4, O 1; Calamitea, P 4; Medullosa, P 3; Equisetites, D 2, C 5, P 1, T 12, O 2, W 2; Equisetum, M 2; Schizoneura, D 1.

Asterophylliteæ: Asterophyllites, D 2, C 22; Huttonia, C 1; Volkmannia, C 7; Sphenophyllum, C 12; Annularia, C 11; Trizygia, C 1; Vertebraria, C 2; Phyllotheca, C 1; Columnaria, C 3; Pinnularia, C 1.

Filices: (*Stems*)—Protopteris, C 1, P 1, Cr 1; Zippeia, C 1; Caulopteris, C 8, T 4; Cottaia, T 2; Karstenia, C 2. (*Stalks and leaflets*)—Selenopteris, C 2; Gyropteris, C 1; Anachoropteris, C 2; Ptilorrachis, C 1; Diplophacelus, C 1; Culopteris, C 1. (*Leaves*)—1. *Daneaceæ:* Glockeria, C 1, T 1; Danacites, C 1; Strephopteris, C 1; Tæniopteris, C 1, P 2, T 3, O 6, Ter 1. 2. *Gleicheniæ:* Phialopteris, T 1; Laccopteris, T 1, L 2; Andriania, L 1; Asterocarpus, C 6; Hawleia, C 1; Chorionopteris, C 1; Scoleopteris, P 1. 3. *Sphenopterides:* Sphenopteris, C 75, P 3, T 6, L 4, O 7, W 3, Cr 1; Hymenophyllites, D 1, C 11, T 2, O 3; Trichomanites, C 11; Steffensia, C 2. 4. *Neuropterides:* Neuropteris, C 48, P 1, T 8, L 3, O 3; Odontopteris, C 18, P 3, L 1; Schizopteris, C 4, O 1; Cyclopteris, D* 5, C 30, O 4; Dictyopteris, C 1; Noeggerathia, D 2, C 7, P 2. 5. *Pecopterides:* Ctenis, O 1; Glossopteris, C 3; Sagenopteris, C 1, T 1, L 1, Ter 1; Lonchopteris, C 4, W 2; Woodwardites, C 2; Thaumatopteris, L 1; Dictyophyllum, T 1, L 1, O 1; Camptopteris, L 2; Clathropteris, T 1, L 1; Acrostichites, O 1; Beinertia, C 3; Diplazites, C 2; Asplenites, C 10; Crematopteris, T 1; Anomopteris, T 1; Goeppertia, C 2; Balanites, C 1; Polypodites, C 3, O 3, Cr 1; Polystichites, O 1; Oligocarpia, C 3; Cyatheites, D 1, C 22, T 1, O 2; Hemitelites, C 4, O 2; Alethopteris, C 33, P 1, T 1, O 7; Pecopteris, C 50, P 1, T 4, L 2, O 4, Cr 1, Ter 1; (doubtful) Staphylopteris, T 1; Pachypteris, P 4, O 2; Aphlebia, C 8; Bockschia, C 1, P 1.

Ophioglosseæ, none.

Hydropterides: Bajeria, L 1; Pilularites, L 1; Isoetites, O 1, Ter 1.

Psaroneæ: Psaronius, C 9, P 19; Tubicaulis, C 1, P 3; Tempskyia ?

Stigmareæ:† Stigmaria, D 1, C 11; Arcistrophyllum, D 2; Didymophyllum, D 1.

Sigillareæ: Sigillaria, D 3, C 73; Rhytidophoyos, C 1; Myelopithys, C 1; Diplotegium, C 1.

Lycopodiaceæ: Psilotites, L 2; Lycopodites, D 1, C 22, P 1,

* Not reckoning the C. Hibernica, which A. Brongniart thinks is either a Sphenopteris or a new genus.

† It is now known that Stigmaria are roots of Sigillaria, and perhaps of other allied plants.

T 1, O 2, Cr 1; Selaginites, C 3; Walchia, C 8, T 1, O 1; Knorria, D 10, C 3; Phillipsia, C 1; Lepidodendron, C 19, P 1; Sagenaria, D 2, C 24; Lepidostrobus, C 11; Lepidophyllum, C 7; Aspidiaria, D 2, C 13; Bergeria, C 7; Pachyploeus, D 1; Lepidofloyos, C 1; Lomatofloyos, C 2; Ulodendron, C 10; Bothrodendron, C 3; Megaphytum, C 4; Cyclocladus, C 1; Tithymalites, C 1; Rothenbergia, D 1; Leptoxylum, C 1; Heterangium, C 1.

B. PHANEROGAMIA.

Cyperaceæ: Cyperites, C 1, L 3.

Gramineæ: Aethophyllum, T 2; Echinostachys, T 2; Poacites, C 7, L 3; Culmites, C 1, Cr 1, Ter 1; Arundo, Ter 1; Bambusium, Ter 1; Triticum, Ps 1.

Restiaceæ: Palæoxyris, T 2.

Najadeæ: Zosterites, O 1, Cr 4, Ter 3; Caulinites, Ter 4; Mariminna, Ter 1; Ruppia, Ter 1; Halochloris, Ter 1; Potamogeton, Ter 3; Potamophyllites, Ter 1.

Callaceæ: Aroides, P 1.

Pandaneæ: Pandanocarpum, T 1; Podocarya, O 1; Nipadites, E 13.

Typhaceæ: Typhaeloipum, Ter 1.

Palmæ: Fasciculites, Ter 2; Perfossus, Ter 2; Porosus, C 1; Flabellaria, C 1, Cr 1, Ter 10; Phænicites, Ter 2; Zeuglophyllites, C 1; Palæospathe, C 1; Palmacites, C 5, P 1, W 1; Cocites, Cr 1, E 2; Trigonocarpum, C 6.

Asphodeleæ: Antholites, C 2, Cr 1; Yuccites, D 1; Sedgwickia, W 1.

Smilaceæ: Preisleria, T 1; Artisia, C 1; Rabdotus, C 1; Cromyodendron, C 1; Smilacites, E 1; Dracæna, Cr 1; Majanthemum, Ter 1.

Cannaceæ: Cannophyllites, C 1? O 1; Amomocarpum, E 1.

Musaceæ: Musacites, C 2; Musocarpum, C 3.

Division 2.—DICOTYLEDONES.

A. MONOCHLAMYDEÆ.

Ceratophylleæ: Ceratophyllum, Ter 1; Ceratophyllites, Ter 1.

Cycadeæ: Cycadites, C 2, L 2, O 2, Ter 2; Raumeria, Ter 2; Calamoxylon, C 1; Zamites, C 2, T 1, L 7, O 20; Zamiostrobus, O 1, Cr 3; Pterophyllum, C 1, T 6, L 8, O 10, Cr 2; Nilssonia, T 4, L 6, O 2; Cycadium? C 1; Mammillaria, O 3.

Diploxyleæ: Diploxylon, C 1.

Abietiniæ: Pinites, C 2, T 4, L 3, O 3, Cr 1, Ter 80; Abietites, O 2, Cr 1, Ter 3; Corticites, Ter 1; Elate, Ter 1; Steinhaueria, Ter 3; Cunninghamites, T 1, L 1, Cr 1; Araucarites, C 8, T 1; Pissadendron, C 2; Dammarites, Cr 2; Albertia, T 4.

Cupressineæ: Juniperites, Ter 4; Cupressinites, E 12; Cupressites, P 1, Ter 4; Taxodium, Ter 2; Taxodites, T 2, L 1, Ter 1; Thuites, W 1, Ter 10; Thuioxylum, T 2, Ter 2; Voltzia, P 1; Brachyphyllum, O 1.

Taxineæ: Taxites, Ter 8.

Gnetaceæ: Ephedrites, Ter 1.

Cupuliferæ: Carpinus, Ter 4; Carpinites, Cr 1, Ter 2; Fagites, Ter 4; Phegonium, Ter 1; Plataninium, Ter 1? Dryobalanus, Ter 1; Quercus, Ter 11; Quercites, Ter 2; Quercinium, Ter 3; Rosthornia, Ter 1; Castanea, Ter 1? Corylus, Ter 1.

Salicineæ: Populus, Ter 6; Populites, Ter 1; Salix, Ter 4; Salicites, O 1, Cr 1, Ter 2.

Betulineæ: Alnites, Ter 6; Betulites, Ter 3; Betulinium, Ter 2.

Myriceæ: Comptonia, Ter 3; Comptonites, O 1, Ter 1; Myrica, Ter 4.

Ulmaceæ: Ulmus, Ter 9.

Artocarpeæ: Ficus, Ter 2.

Plataneæ: Platanus, Ter 1.

Laurineæ: Daphnogena, Ter 8; Lurus, Ter 2; Laurinium, Ter 1.

Santalaceæ: Nyssa, Ter 1.

Proteaceæ: Petrophylloides, E 7.

B. CORALLIFLORÆ.

Ericeæ: Dermatophyllites, Ter 9.

Ebenaceæ: Diospyros, Ter 1.

Primulaceæ: Berendtia, Ter 1; Sendelia, Ter 1.

Verbenaceæ: Petraea, Ter 1.

Boragineæ: Cordia, Ter 1.

Gentianeæ: Villarsites, Cr 1.

Apocyneæ: Echitonium, Ter 2; Neritinum, Ter 2; Plumeria, Ter 1; Apocynophyllum, Ter 4.

Viburneæ: Viburnum, Ter 2.

Jasmineæ: Fraxinus, Ter 1.

Oleineæ: Ligustrum, Ter 1?

C. CHORISTOPETALÆ.

Loranthaceæ: Enantioblastos, Ter 1; Viscum, Ter 1.
Umbelliferæ: Pimpinellites, Ter 1.
Magnoliaceæ: Liriodendron, Ter 1.
Nympheaceæ: Nymphacites, Ter 1.
Cucurbitaceæ: Cucumites, E 1.
Sileneæ: Cucubalites, Ter 1.
Crassulaceæ: Sedites, Cr 1.
Halorgeæ: Myriophyllites, C 1? Ter 1; Trapa, E 1.
Calycantheæ: Calycanthus, Ter 1.
Melastomaceæ: Melastoma, Ter 1.
Myrtaceæ: Myrtus, Ter 1.
Tiliaceæ: Tilia, Ter 2.
Malvaceæ: Hightea, E 10; Gossypium, Ter 1.
Acerineæ: Acer, Cr 1, Ter 16.
Coriariceæ: Coriaria, Ter 1.
Sapindaceæ: Cupanoides, E 8; Tricarpellites, E 7.
Euphorbiaceæ: Buxus, Ter 1.
Rhamneæ: Ceanothus, Ter 3; Karwinskia, Ter 1; Rhamnus, Ter 2; Prinus, Ter 1; Carpantholites, Ter 1; Enantiophyllum, Ter 1.
Zanthoxyleæ: Zanthoxylum, Ter 1.
Aurantiaceæ: Wetherellia, E 1; Klipsteinia, Ter 1.
Terebinthaceæ: Rhus, Ter 5.
Juglandeæ: Juglans, Ter 4; Juglandites, Cr 1, Ter 9; Juglandinium, Ter 1; Mirbellites, Ter 1.
Pomaceæ: Pyrus, Ter 1.
Leguminosæ: Cytisus, Ter 2; Dolichites, Ter 2; Desmodites, Ter 1; Phaseolites, Ter 2; Desmodophyllum, Ter 2; Gleditschia, Ter 1; Erythrina, Ter 1; Adelocercis, Ter 2; Bauhinia, Ter 1; Phacites, C 1? O 1; Faboidea, E 25; Leguminosites, E 18; Mimosites, E 2; Xulinospironites, E 2; Cassia, Ter 1; Robinia, Ter 1; Acacia, Ter 2; Fitchelites, M 1; Mohlites, M 2; Cottaites, M 3.
Doubtful: Petzholdtia, Ter 1; Pritchardia, Ter 1? Withamia, Ter 1; Meyenites, Ter 1; Nicolia, Ter? 1? Bronnites, Ter 1? Lillia, Ter 1; Piccolominites, Ter 1; Endolepis, T 2.
Leaves: Credneria, Cr 7; Phyllites, Ter 25.
Fruits: Baccites, Ter 1; Folliculites, Ter 1; Cardiocarpum, C 6; Carpolithes, C 70, P 2, O 5, Cr 8, E 4, M and Pl 12.
Elementary Organs of Plants: Lithodontium, Ter 6 or 8; Lithostylidium, Ter 20; Lithodermatium, Ter 4.

CHAPTER XI.

THE LAWS AND GENERALISATIONS OF PALÆONTOLOGY.

The Kinds of Animals and Plants most likely to occur Fossil.

IN even casting his eyes over the preceding lists, the reader will doubtless be surprised at their completeness—at the number and variety of fossil animals and plants that are already known. Among the animals, there is scarcely a single family or important group—of those at least that had any hard parts capable of being preserved—that has not its fossil representatives. Now, the rocks in which these remains are found are aqueous rocks, principally marine. We should, therefore, naturally expect the inclosed fossils to be the remains of aquatic, principally marine beings. In the vegetable kingdom, at the present day, the vast majority of the species are terrestrial, while in the animal kingdom there is an almost equal majority of aquatic species. Among the Vertebrata, for instance, we have two orders and one sub-order of Mammalia entirely aquatic, a large part of the Reptiles and Amphibia, and the whole of the Fish. In the sub-kingdom Annulosa, the insects, indeed, like the birds among the Vertebrata, are chiefly terrestrial or aerial; but the Crustacea are nearly, and the Echinodermata entirely, aquatic. The exceptions to the aquatic character of the rest of the whole animal kingdom, including the Mollusca and the other sub-kingdoms, are very few and comparatively unimportant, the Pulmonata, or land snails, being the principal one. This at once gives us one reason for the fact of fossil animals being more numerous and more important than fossil plants.

It is to the terrestrial animals, as most important to us economically, and most frequently before our eyes, that we are naturally more accustomed to look as our fellow inhabitants of the globe, but in reality, if we except the birds and the insects, and the terrestrial Mammalia, almost all the infinite variety and abundance of other animals live in the water. We should therefore naturally expect to find, as we do, portions of all the other kinds of the animal kingdom in great plenty, while remains of Mammalia, of Insects, and of Birds, must be comparatively rare. In order to find terrestrial animals or plants, indeed, in a fossil state, it is obvious that we must either hit upon these few that had been accidentally carried down into the water, that had there sunk to the bottom and been buried under such circumstances as to allow of their preservation before they rotted away, or that we must have the land-surfaces on which they lived preserved to us, and find their remains still undestroyed, either buried under aerial accumulations, or under those aqueous rocks which were deposited on the land-surface immediately after its submersion.

It is necessary to take these considerations strictly into account before we found any reasoning upon the negative evidence of the absence of terrestrial animals or plants in a fossil state.

Very important conclusions are doubtless to be drawn from the study of the terrestrial kinds when they do occur fossil; but even then their practical value to the geologist is often small, on account of their rarity. Many of the extinct species and genera of Mammalia, for instance, mentioned in the lists in the last chapter, are founded upon the occurrence of single specimens, or of not more than two or three specimens; fragments of fossil Fish are more numerous, while the

Testacea (or shell-bearing Molluscs), the Crustacea, the Echinodermata, and the Corals, occur by hundreds and thousands, great masses of rock being in some cases made up of them.

We might accordingly take any one of the classes last mentioned to compare among themselves, with the expectation of arriving at some definite conclusion as to their history, by examining the different groups of those found fossil in different formations. Of those classes, however, the Mollusca, from their number, their variety, and the comparative completeness of the preservation of their fossil parts, and the consequent facility of determining their nature and habits, and from their occurring in almost all formations, afford to the palæontologist the most complete and unbroken scale of comparison in his examination of fossils.

British Fossil Animals and Plants compared with Existing.

It will be very useful here if we compare for a moment the living fauna and flora of the British Islands with the fossils that have been found within the same area. The British Islands are included within the Celtic province of Professor Edward Forbes; and considering the diversity in the forms of the land and the distribution of land and water, the variety of "habitat" and "station," and of the climate and surrounding circumstances, we may assume it as affording us not an unfair example of what the terrestrial, fresh water, and marine fauna and flora of a province ought to be. It contains, perhaps, as great an abundance of species as any other region of equal extent out of the tropics, and more than many equally-sized districts within them.

In the following table I have been assisted by my friend and colleague Dr. Kinahan in stating the numbers of living species. The numbers of fossil animals and plants are those given by Professor Morris in his catalogue, a book of which I henceforward shall make the greatest use, and which every working geologist knows to be *indispensable* to his labours.

LIVING AND FOSSIL SPECIES OF THE BRITISH ISLANDS.

	No. of Species Living.	No. of Fossil Species.	Proportion of Living to Fossil.
Plants . . .	1600 flowering. 2800 cryptogamic. 4400	655	6.7 : 1
Zoophytes * .	70	435	1 : 6.2
Polyzoa . .	70	258	1 : 3.7
Testacea † .	513	4590	1 : 8.9
Echinodermata	70	492	1 : 7.0
Crustacea ‡ .	225	298	1 : 1.3
Fishes . . .	162	741	1 : 4.6
Reptiles . .	18	180	1 : 10.0
Birds . . .	332	11	30 : 1
Mammals .	70	110 §	1 : 1.5

Perhaps the most unexpected result of the preceding table is to find that the extinct fossil Mammalia of the British Islands are *more numerous in species by one-half* than the existing Mammals. This at once prepares us for the belief that if our present fauna is a good example of what the population of a province ought to be, the fossil fauna must represent more than one such population.

If we turn to the Mollusca as our best guide, we find that the fossil species known are nearly nine times as numerous as the living species. If, indeed, we excluded the land and fresh-water shells from each side of the comparison, we should find the fossil marine testaceous Mollusca *more than ten times the number* of the living ones. Our conclusion must be, that there are buried in the British Islands the remains of *at least ten* complete populations of Mollusca, each as numerous in species as those now living in the seas around us. But as a matter of fact, while the existing population is almost entirely known from recent most elaborate researches, the extinct populations are yet very imperfectly known; and some great groups and formations exist in which few or no Mollusca have

* Principally Corals, as they are commonly called.

† Under Testacea, all the shell-bearing Molluscs are included.

‡ Under the living Crustacea, the Cirripedia are not included. (Proximate only, probably 300 species are known).

§ Morris gives only 96; the new discoveries raise the number to 108, or 110 at least.

yet been found fossil; and therefore we may feel assured that the number of fossil Mollusca are in reality the representatives, more or less imperfect, of *many more than ten* populations of the past which have died away and become extinct.

These conclusions are confirmed by examining the other aquatic classes of animals, the fossil Fish for instance are nearly five times, the Echinodermata seven times, the Zoophytes more than six times, and the Reptiles ten times more numerous than our living ones, most of these classes having been still more partially, and, as it were, capriciously, preserved than the Mollusca.

"The dust we tread upon was once alive,"

is no poetical exaggeration. We can hardly walk upon the earth over large parts of its surface without shaking the grave of some long extinct animal, while for hundreds and thousands of feet beneath us are successive grave-yards of the past, each crowded with the remains of a once happy and joyous existence. Astronomy opens up to us, indeed, the most sublime views over the immensity of space; but it is space cold, barren, and lifeless, with which we seem to have little interest or connection; while the view which geology affords us into the immensity of past time, is cheered and enlivened by the contemplation of vast populations endowed with a life similar to our own, linked to ourselves by physiological acts such as we are conscious of in our own bodies, and our interest in which is therefore immediate, close, and direct.

It has been said that fossil animals are more important than fossil plants on account of their number and variety. There is also another reason for this comparative value, which is, that it is more easy to arrive at definite conclusions as to the nature and the habits of the once living beings from the examination of a fragment of an animal than from that of a plant. A single scale, or tooth, or fragment of bone, or shell, will often reveal to the comparative anatomist the whole history of an animal which he certainly never saw, and of which, perhaps, the only known traces may be that solitary fragment. The botanist is not in equally favourable circumstances for determining the history of a fossil plant, since a piece of the stem or a leaf or two will rarely do more than enable him to determine which great division of the vegetable kingdom the living plant belonged to; while the parts, such as the flower, on which he mainly depends for more exact and minute determination, are scarcely ever preserved in a fossil state.

Laws of Distribution of Fossils.

I will now endeavour to state the conclusions to be derived from the study of fossils taken in connection with the rocks in which they have been found.

1st, Fossils do not occur indiscriminately, but in groups or assemblages, in such a way that if one or two members of the group be found, the others will generally be associated with them. If we found certain fossil forms very abundant in one particular kind of rock, as the chalk for instance, or that called carboniferous limestone, in any one district, we should find the same fossils in the same kind of rock in the neighbouring districts. Moreover, if, in extending our researches, we met in a rock of a different character with one or two conspicuous members of the assemblage we first found, others of that assemblage would almost invariably be found along with them.

2d, If a great series of stratified rocks be examined in any country, as England for instance, and the fossils of the different sets of strata be collected and arranged in the order of occurrence of the beds of rock, *i.e.*, in their order of superposition, it will be found that the series of fossil groups collected in one part of the country will be the same as the series found in any other part of the country.

If we follow any particular set of strata (A) in its range across a country, we shall find everywhere in it the same assemblage of fossils (*a*); if we pass from that set of strata to another (B), we find a different assemblage of fossils (*b*), those fossils being equally co-extensive with this second set of strata. If, however, in following the (A) set of strata, we find that the beds change their nature, pass from limestone, for instance, into shale and sandstone, we shall find very often a corresponding change in the fossils (*a*); we shall find, that is, no longer the remains of animals that loved a clear sea, but those that lived on muddy or sandy bottoms, or we shall find those that inhabited shallow seas and shores, together perhaps with terrestrial species washed down from the land, instead of those that lived in deep and open seas. Still the rules stated above hold good. So long as we keep to the same set of strata, we have the same assemblage of fossils. Those found in the limestones of one place are found in the limestones of another; those in the shales or sandstones of one locality recur in similar rocks of another place; and so on, any differences depending upon differences in the conditions, or in the accidental circumstances which caused the death and entombment of the animals.

3. If we are enabled to follow any particular set of strata over still wider areas, to trace them across Europe for instance, or to identify them in distant quarters of the globe, as in America or Australia, then we find a difference in the assemblage of fossils contained in them, just such as we should expect to find if we argued from the laws of the geographical distribution and limitation of species at the present day.

Some widely extended, or cosmopolite species, would perhaps range throughout; other closely allied representative species would come in, as they do at present; while a certain percentage of wholly different forms would also make their appearance. Still even these wholly different species would have a generic or family resemblance that would preserve to the assemblage that peculiar "facies," to use Von Buch's phrase, which would generally enable us to identify the group.* This geographical variation in the assemblage of fossils is not calculated to mislead us when properly understood, since it never goes the length of confounding together in one district those which are kept distinct elsewhere. In tracing the set of strata (A), and their included fossils (*a*), we find perhaps a change in the nature of the beds (A), and also a change in the species (*a*); but that change does not introduce any of the species (*b*) which we found in the set of strata (B). On the contrary, a similar change takes place in the fossil group (*b*) itself, which will likewise have in the new district its proportion of cosmopolite identical species, of new but representative species, and of new and entirely different species, with their generic or family identity and peculiar "facies."

4. Returning to the examination of a single province, as, for instance, the British Islands, and comparing our supposed series of fossil groups, arranged in the order of occurrence of the rocks from which they were derived, we shall find further, that we have in the series of fossils, as in the series of rocks, a chronological scale.

*** This "facies" puts us in mind of that vague, undefinable, but clearly recognisable resemblance known among ourselves as a "family likeness."**

We have already seen that, on purely mechanical and physical grounds, a great series of stratified rocks must require a vast indefinite period of time for its formation; the study of the series of fossils included in it would show us that this period of time has been so vast, that great changes have taken place in the life of the district during the time. As we traced the series of strata, bed by bed, in their order of super-position, beginning at the lowest, and gradually ascending, we should find changes of two kinds. First, as we passed vertically from one kind of rock to another, say from limestone to shale or sandstone, we should often find a change in the fossils, just the same as that which we had found in tracing the same beds laterally, a change, namely, from the species that lived in the clear sea to those that lived in sandy or muddy bottoms. But for a certain distance, vertically as well as laterally, this change would be one of conditions only; and whenever a new bed similar in kind to the first recurred in the series, we should find the same fossils recurring. We might thus, through a set (A) of many hundreds, or even thousands of feet thick, find similar fossils in similar beds throughout—certain fossils in the limestones, certain others in the shales, certain others in the sandstones.

There would, however, in all probability still be a certain amount of alteration. The most well-marked and abundant fossils might perhaps occur in all the limestones throughout the series, while certain other species did not range throughout, some being only to be found in the lower beds, and some only in the upper. As we still ascended in the series into another group of rocks (B), we should perceive that those well-marked and abundant species which we had met with below in (A) had altogether disappeared, while a new set of fossils, equally well marked, began to be equally abundant. This change would not be like the one previously mentioned—a change coincident with, and apparently depending on the change in the nature of the rock. We might still have limestones, shales, and sandstones, each containing a distinctive set of fossils, but the limestone fossils in the new set of beds (B) would be different from the limestone fossils in the set (A), and so also would the others found in the shales and sandstones. It not unfrequently happens that some of those species which appeared only in the higher beds of (A) along with its characteristic fossils, are also to be found in the lower beds of B associated with its characteristic fossils. Sometimes, on the other hand, we pass abruptly in crossing a mere line of boundary from one set of fossils (*a*) into another utterly different set (*b*), without a single species in common.

These abrupt transitions from one set to a totally different set, occur only in those places where a great interval of time elapsed, or a great change of conditions took place between the deposition of the two sets of beds, A and B.

Where the deposition of sediment was regular and continuous, the change in the character of the fossils is always most gradual.

This proves to us that the idea of sudden destructions of life, and sudden introductions of new assemblages of animals and plants, is an erroneous one, founded solely on the mistake of assuming our data to be perfect and complete, when they are in fact very imperfect and fragmentary.

We formerly saw reason to conclude that the deposition of sediment in any water, except just at the mouth of a great river, is an exceptional act. The depth and the nature of the bottom in our seas remain unaltered for many years. The old sea-bottoms, which are our stratified rocks, were not one whit more rapidly accumulated than the bottoms of our present seas. We saw (p. 163) that centuries, or perhaps thousands of years, very often elapsed between the formation of two successive beds. This was shown to be probable on physical grounds alone. It is therefore far more philosophical, when we find two totally different sets of fossils in two contiguous sets of beds not very dissimilar in lithological character, to take the change in the fossils to have been the result of that gradual action of time which we know to be able and likely to produce it, than to call into play sudden acts of destruction and creation of which we know nothing, and which we can prove did not occur in many other localities where the thickness of the rocks is greater, and the deposition consequently appears to have been more regular and continuous, and the change in the fossils more gradual.

It may be taken, indeed, as an invariable rule, the result of tolerably wide experience, that the change in the fossils as we ascend or descend in the series of rocks is more gradual in proportion to the number and completeness of the series of beds.

It is in exact harmony with these results of direct observation that, as Professor Edward Forbes showed, species at the present day, which have the greatest vertical range, have also the greatest lateral range; those, that is to say, which can live and flourish under the greatest variety of conditions of temperature, pressure, light, etc., in any one locality, can spread themselves through the greatest number of localities in spite of any variety of those conditions they may meet with. The same philosopher also taught us that it is just those species which have the greatest range in space, vertically and laterally, at any one period of the earth's history, that have also the greatest range in time, or are found fossil through the greatest number of sets of beds, because they have survived a great variety of accidents and physical changes before they became extinct. Just as we find at the present day the range of animals and plants limited by the surrounding circumstances of climate, of food, and of hostile races, so we must believe the duration of species in past time to have been limited by the similar circumstances that surrounded them. And this view gets rid of what Edward Forbes held to be rather a fanciful notion than a scientific truth, namely, that species like individuals, have a term of life, beyond which they cannot survive, impressed upon them from the commencement of their existence, and implanted in their very constitution.

Should any difficulty be felt in conceiving physical changes to have taken place sufficient to produce this amount of change in the life of the globe, I have only to recall to the reader's mind the physical agents at work in the gradual erosion and degradation of our present lands, which is taking place everywhere, and their bodily depression beneath the sea occurring in some places, while in others the bottom of the sea is being elevated into dry land (as shown in Sir C. Lyell's Principles, and alluded to in this little work), and to point out to him that, if sufficient time be allowed, these changes will become universal,—in order to show him the possibility of all our present life on the globe being ultimately destroyed, unless it were kept up and renewed by the introduction of fresh species.

There is an important consequence to be deduced from this gradual destruction of life, by the gradual action of physical changes. The life destroyed in any one locality may still exist for a considerable time in other localities, until those also become affected by similar physical changes. The ultimate destruction of the whole assemblage of animals of any one province, will be brought about by a succession of removals and divisions of its members, each removal being attended by some loss, and so on.

It may follow, therefore, that species which lived in abundance in any one locality during one period of time, may become extinct in that locality during the succeeding period, but yet survive in some other locality.

The fact of particular species, then, being common to the rocks of two distant localities, is by no means a proof of their being *exactly contemporaneous* in point of time. It may prove the very reverse of this. Strict contemporaneity in the rocks of distant localities is probably a very rare occurrence, and one which would be very difficult to prove. Even approximate synchronism can only be established by working out the details of the entire series of rocks in the two localities, and comparing the results arrived at in their totality with each other.* In speaking of the contemporaneous

* These principles have always influenced me from my earliest geological days. In speaking of the Coal Measures of Newfoundland, in my report on

rocks, therefore, of two localities, the student must be prepared for a sufficiently lax use of the term to include great periods of time. Beds deposited in the English Channel before the Romans visited Britain, would be looked upon by future geologists as strictly contemporaneous with beds forming now in the Irish Sea, when the two districts become dry land.

As a corollary of the geographical distribution of species in past time, may be mentioned M. Barrande's doctrine of Colonies, one of the very curious and remarkable results of his labours in the Silurian district of Bohemia. If two neighbouring but distinct faunas, A and B, contemporaneous, or A a little the oldest, be separated by some barrier, physical, climatal, or depending on other geographical conditions, and a breach be at one time effected in this barrier, or a temporary alteration take place in the conditions, some individuals of the fauna B may spread over part of the province of A ; but circumstances not then favouring their retention of these new settlements, these colonists may die and leave a small band of their remains intercalated between beds containing only the remains of A. At some future period, perhaps, circumstances may favour their extension far and wide into the province of A, and become unfavourable to the existence of that fauna, which will therefore become extinct, and the higher rocks deposited will become filled with the remains of B only.

Law of Approximation to Living Forms.

If we examined the whole series of assemblages of fossils at present known, we should find that, with a good many exceptions, either real or apparent, there is a kind of law reigning throughout them, which may be expressed by saying, that the fossils of the oldest or lowest rocks are most unlike the animals and plants of the present day, while, as we ascend in the series, there is a gradual approximation to living forms.

the geology of that country, I limited myself to calling them the *Newfoundland Coal Measures*, leaving their identity, or otherwise, with the coal measures of other districts an open question. Not having found any fossils in them in my necessarily hasty search, the Newfoundland Coal Measures might be tertiary rocks for anything I could say to the contrary. Similarly, in speaking of the Palæozoic rocks and fossils of Australia, I preferred always to speak of them only as Palæozoic, and forbore to discuss the question of their identity in time with the Silurian, Devonian, or Carboniferous periods of Europe, for which I do not think even identity of one or two species (if it occur) altogether sufficient evidence.*

* See Sketch of Physical Structure of Australia (Boone), pp. 21, 22.

In examining the fossils from the earliest rocks, the species, and for the most part the genera, and even the families, are entirely different from any now living. Still, although different, they are yet so nearly allied to them, as to be capable of being placed in the same great Classes, often even in the same Orders of organisation as the existing species and genera are grouped in. When we look at the fossils of newer and newer rocks, we find some of these genera and families, and one or two of the orders very soon disappearing; they are not only extinct now, but they were extinct long before others came into existence which are now equally extinct. This happens not once only, but frequently, as we examine the series of fossil groups. But, together with these short-lived orders, families, and genera, there occur species, chiefly Mollusca, which are so nearly allied to some now living, as to receive the same generic names, such as Nautilus, Turbo, Natica, Terebratula, Rhynconella, etc. These existing generic groups become more and more numerous, until at length the existing become more numerous than the extinct genera, and at last even two or three species make their appearance, which are obviously identical with still existing species. More and more of these existing species then come to light in still newer rocks, at first associated with a vast majority of extinct species, but gradually attaining the preponderance, until, in the newest rocks of all, we find all the Mollusca perhaps belonging to existing species, and only extinct species of the higher orders of animals.

The law of succession reigns throughout. It is not only that our existing fellow-inhabitants of the earth came into being gradually, one by one, at very different dates, some being of vast unknown antiquity, some as it were creations of yesterday; but this was the case throughout all geological time, except, of course, the very earliest. Had any intelligent being lived in one of the later Palæozoic, or in one of the Secondary periods, he could have stated the result of his geological researches in the same terms we use ourselves. There must always have been a mingling of extinct and existing species in the last-formed rocks, some of the existing species of one period becoming extinct in the next, others surviving to a second and third, where they found themselves surrounded by newer and yet newer associates. The chain of existence was an unbroken and continuous one, but made up of links of very various dimensions; or rather, it was a rope, the strands and threads of which were of very different lengths and thickness. The apparent gaps and breaks in this endless succession, when they go so far as to produce an utter want of continuity, we may very reasonably set down as due solely to the imperfection of our records; fresh discovery is daily filling in these gaps, daily discovering fresh links in the chain enough to convince us of the truth of these views, although we may perhaps never hope to obtain anything like a perfect and unbroken series of records.

There is another interesting point connected with the succession of life upon the globe which has made much noise in the world lately, but which I shall treat very briefly.

Arguing from what we now know, it appears that the earliest life on the globe was that of Annelids (sea worms), and Zoophytes (either sertularian or polyzoan), the one certainly, the other probably, rather high up in the scale of animal life.* It seems very difficult to suppose that these existed by themselves. Animal life now is so bound together by links, uniting species to species in such a way that, if you destroy one, you in all probability exterminate another which in some way depended on it, that it seems almost an impossibility to my mind to imagine a world inhabited by only one or two species of animals. Waiving that consideration, however, we have in the next period certainly, a vast variety of animal life of all the sub-kingdoms, except the Vertebrata, while in the succeeding or third known period, we find remains of fishes, and then of reptiles in the fourth. Still, in all the Palæozoic series of rocks, there has yet been no trace found of a mammal or a bird. In the very lowest member of the Mesozoic series, however, namely, the Trias, though in the upper part of that member which is called the Keuper, the tooth of a mammal has occurred, and in some still newer rocks the tracks of gigantic birds and the jaws of several mammals.

Now, it may be, that we have in these facts a true picture of the course of creation; that during the earlier Palæozoic periods no Vertebrata existed; that at length fishes, and then reptiles were introduced, but that long ages still elapsed before birds and mammalia were placed upon the globe. On the other hand this *may be* only the apparent, and not the real course of creation; it may appear to us so, solely from the deficiency and imperfection of our records. A single discovery of a fish scale or a fragment of a reptile in the Lower Silurian or Cambrian rocks would greatly damage the hypothesis; a tooth of a mammal in the Palæozoic rocks would upset it altogether. Negative evidence should never be taken at more than its true value, and the process requires to be indeed an exhaustive one before the non-existence of a thing can be held to be established, because we have not yet been able to find it.

The existence of Mammalia in the Secondary rocks was long combated. First one or two, and then five small under jaws were found in the Stonesfield Oolite. At first these were supposed to be marsupial only, the lowest of the Mammalia, then Professor Owen showed that one at least, the Stereognathus ooliticus, was a placental mammal, probably one of the non-ruminant Artiodactyla, and therefore of the same division as our hippopotami and swine; another placental mammal, Spalacotherium, one of the Insectivora, was found in the Purbeck rocks; and quite recently, by the labours of Mr. Beckles and Mr. Brodie, no less than twelve or thirteen new species of mammals have been found in the same formation. These

*** Dr. Kinahan's recent discoveries of the holes and tracks of highly organised worms in the Cambrian rocks of Bray Head, associated with Oldhamia, come strongly in support of Mr. Salter's annelid tracks in the Longmynd.**

have been determined by Dr. Falconer, Professor Owen, and Sir C. Lyell,* to belong to eight or nine genera, Triconodon, Plagiaulax, etc., some marsupial, others placental. These were all found in one little bed not more than six inches thick, and within a space of twenty-two yards square, and Sir C. Lyell justly observes, that these very beds, which altogether are 160 feet thick, had been diligently explored by many observers—including the Geological Survey—during many years, one specimen only having been at length found by Mr. Brodie, and that it was not till that bed was quarried *expressly for the purpose* by Mr. Beckles, that these new discoveries were made. He also remarks on the bearing of these discoveries on the value of negative evidence, as follows: The Purbeck rocks "have been divided into three distinct groups by Forbes, each characterised by the same genera of pulmoniferous mollusca and cyprides, but these genera being represented in each group by different species; they have yielded insects of many orders, and the fruits of several plants; and lastly, they contain several 'dirt beds,' or old terrestrial surfaces and soils, at different levels, in some of which erect trunks and stumps of Cycads and Coniferæ, with their roots still attached to them, are preserved. Yet when the geologist inquires if any land animals of a higher grade than reptiles lived during any one of these three periods, the rocks are all silent, save one thin layer of a few inches in thickness; and this single page of the earth's history suddenly reveals to us, in a few weeks, the memorials of so many species of fossil mammalia, that they already outnumber those of many a sub-division of the tertiary series, and far surpass those of all the other secondary rocks put together!"

Such a thin seam, one of those small exceptions in the great series of aqueous rocks, which contains the remains of land animals, might lie hidden for centuries even in the formations which are most searched by the quarryman, miner, and geologist, or might be frequently passed through by the two former, without having been sufficiently examined by the latter.† Great as have been the labours and researches of geologists hitherto, we can only look upon

* I am indebted to Sir C. Lyell for information of this interesting fact by letter and word of mouth, as soon as it was known, and also for a copy of his Supplement to the Fifth Edition of his admirable Manual, in which they are described.

† I recollect, a good many years ago, on the borders of Nottinghamshire and Lincolnshire, coming on some large quarries opened in the Lias limestone, an extension of the beds so well known at Barrow-upon-Soar. I inquired of the quarrymen whether they had ever seen anything like bones in the stone. "Bones," said they, "oh, yes! we often find horses' heads and horses' backs." "And what do you do with them?" said I. "Oh! we just admires them like, and then breaks 'em up, and puts them into the kiln." Many a fine head and body of an ichthyosaurus had doubtless thus been immolated before then; and not a day passes probably, but still more rare and valuable specimens are thus sacrificed,—a loss which nothing but the zeal of local geologists will prevent for the future.

them as but having made a commencement, and laid the foundation for more complete discoveries being made in the future.

With such a belief, I need hardly say that, without pretending to any authority on such a point, that which is called the Development hypothesis has always appeared to me too premature to be worthy of serious belief, even if it had been based on a far wider expanse of negative evidence, and had not been so damaged by positive evidence against it, as it has been.

Relative Duration of Orders and Classes.

As a general rule, it may be stated that the higher orders, as fish, reptiles, and mammalia, are more narrowly limited in duration, and therefore are specifically characteristic of a far less thickness of rock than are the lower orders and classes, the Mollusca, and those below them. This is true, whether we look at the duration of particular species, or at that of genera and orders. The student will find in the lists of the third part of this work scarcely a single species of fish or reptile common to two formations; while some of the Foraminifera that lived during the period of the Lower Greensand are still living on the globe.

Practical Importance of Fossils.

High as is the value of palæontological evidence in assisting us to unravel the complex history of the formation of our present lands, it scarcely exceeds the value of that evidence in the practical operations of the miner or the quarryman. Certain valuable mineral substances, of which we may instance coal in especial, occur in regular beds as stratified rocks. It is found that these beds of coal occur only, or chiefly, in a workable and valuable form, in a certain portion of the great series of stratified rocks. The beds of coal are associated with beds of dark shale or clay, and with others of sandstone; and the practical collier, whether working-man or overseer, naturally looks upon coal as a necessary concomitant of black shale, and wherever he finds this, or any other rock of a similar kind to that which he has been accustomed to see in his coal workings, he feels confident that coal is there also to be found. He reasons quite rightly from what he knows, only unfortunately he does not know quite enough. It often happens that in the neighbourhood of the coal-bearing districts there are other large districts occupied perhaps entirely by limestone or by sandstone, often red sandstone, or by other rocks obviously different in character from those containing the coal-beds. The practical coal-miner knows these differences, and he knows, quite rightly perhaps, that within his own district the occurrence of black shale, etc., is a strong indication, and generally a correct one, of the occurrence of coal. But then he does not know that in addition to these other masses of limestone, red sandstone, etc., with which he is acquainted, there are also many other beds of black shale, etc., belonging to sets of strata which do not contain coal. These other sets of strata are usually at a distance from his coal districts, though sometimes parts of them may be brought into their immediate neighbourhood, or even apparently intermingled with them. In such cases, fossils are an unerring test, and a single fragment even of a shell may enable us to distinguish between groups of beds that would otherwise be nearly or quite undistinguishable.

Within my own experience, I have known vast sums of money absolutely thrown away, which the slightest acquaintance with palæontology would have saved. I have known, even in the rich coal district of South Staffordshire, shafts continued down below the Coal Measures deep into the Silurian shales, with crowds of fossils brought up in every bucket, and the sinker still expecting to find coal where no coal had ever yet been found. I have known deep and expensive shafts sunk in beds too far above the Coal Measures for their ever hoping to reach them, and similar expensive shafts sunk in black shales and slates in the lower rocks far below the Coal Measures, where a pit might be sunk to the centre of the earth without ever meeting with coal. Nor are these fruitless enterprises a thing of the past. They are still going on in spite of the silent warnings of the fossils in the rocks around, and in spite of the loudly-expressed warnings of the geologists, who understand them, but who are supposed still to be vain theorists, and not to know so much as "the practical man." *

* I have elsewhere stated my belief that the amount of money fruitlessly expended in a ridiculous search after coal, even within my own experience, would have paid the entire cost of the Government Geological Survey of the United Kingdom.

Changes of Climate.

There is one subject which depends more on palæontological than petrological evidence, and that is, the change of climate which has taken place not only in different localities, but apparently over the whole earth simultaneously. When we find in the British Islands the remains of crocodiles, turtles, large nautili, and monkeys, together with palm fruits and other tropical-like plants, we cannot resist the conclusion that the climate of the British Islands must have formerly been more like that now found within the tropics than that which they at present possess. It is true that the plants and animals are all of different species from those which now exist, and we are taught by the fact of the mammoth, or fossil elephant, having been provided with a woolly coat covered with long hair, and therefore fitted to live in much cooler climates than either of the existing species of elephant, not to rely too implicitly on mere analogies of form; still the fact of the whole assemblage of the fossils of certain great groups of rock being stamped with a tropical "facies," is very strong evidence in favour of their having enjoyed a tropical climate.

But we may extend this argument to still higher latitudes. By the zealous and enlightened labours of our arctic navigators, especially those of Captain M'Clintock (now fearlessly and nobly returning on his track in search of the remains of poor Franklin's expedition), of Sir E. Belcher, and others of late, and of Parry formerly, we have been put in possession of the very remarkable fact that in latitudes where now sea and land are buried in ice and snow throughout the year, there formerly flourished animals and plants very similar to those living in our own province at that time; and it would appear that similar animals and plants were then widely spread over the whole world. There are large tracts of country lying between 73° and 76° of N. lat., and 84° and 96° of W. long., in which the rocks contain Upper Silurian fossils. In the same latitudes, but extending farther west, beds of coal, with Carboniferous plants, like those of Europe, were found; and still farther north and west, extending up to 77° 20′, or thereabouts, are limestones full of Carboniferous corals and shells (Orthoceras, etc., as well as Brachiopodæ), while in Prince Patrick's Island, at Wilkie Point, in lat. 76° 20′ N., and long. 117° 20′ W., Oolitic rocks containing an ammonite (*Ammonites M'Clintocki, Haughton*) like A. concavus, and other shells, were found by M'Clintock; and, moreover, from Exmouth and Table Islands, lat. 77° 10′, long. 95°, part of an ichthyosaurus was brought by Sir E. Belcher.—(See *Reminiscences of Arctic Ice-Travel*, by Captain M'Clintock, R.N., and *Geological Notes*, by Professor Haughton, *Journal R. D. Society*, Feb. 1857, and *Report British Association*, 1855.)

These facts, all pointing in the same direction, compel us to believe that during at least a part of the primary, secondary, and tertiary epochs, the general climate of the globe was higher and more equable than at the present day.

Facts of an opposite kind are not wanting, partly palæontological and partly petrological, such as the occurrence of boulders, and the existence of the moraines of glaciers far below their present limits, which prove the spread of a more arctic climate than we have now, not only over Europe and North America, but also in India, at a period comparatively recent, but still long antecedent to the existence of man.

Sir C. Lyell is of opinion that these changes of climate may be produced by a re-distribution of land and water, in consequence of the action of the causes now operating in the elevation and depression of land. Others doubt this, and seek for some other source of increase or decrease of temperature common to the whole earth.

PART III.

HISTORY OF THE FORMATION OF THE SERIES OF STRATIFIED ROCKS.

CHAPTER XII.

PRELIMINARY OBSERVATIONS.

WE have hitherto been dealing with general principles, examining structures which are common to all rocks, and referring the production of those structures to their several causes, and considering fossil animals and plants in connection with the species, genera, or orders of those now living on the globe. We have had occasion to remark frequently on the vast lapse of time required for the formation of these rocks, and we have just noted some of the chief generalisations as to the succession of races of animals and plants that have lived and died whilst they have been passing.

It remains now to classify and arrange the results of the operations that have been taking place during this vast lapse of time, and to give, as far as possible, a connected history of the events which have been concerned in the production of that external portion or crust of the earth which alone is open to our examination, to describe the order of succession in which different portions of it have been formed, and to give specific details as to the beings that are to be found fossil in those portions.

The way in which this order is to be discovered will, I think, be sufficiently obvious from what has been said before. At page 208, *et seq.*, we saw, that after having acquired a knowledge of the number and nature of a series of beds, by examining a cliff on a sea-shore, or other "section" where they were well exhibited, any little natural or artificial excavation in the interior of the country which enabled us to identify one of these beds assured us of the presence of all the rest above and below it. By searching out places where such "sections" were to be seen, and then following them by different indications across countries, and joining them on one to another, verifying them now and again by the discovery of other sections where they were again to be seen in more or less detail, and performing the same process for the sets of beds that successively cover them, we eventually survey great tracts of country, and arrive at a knowledge of the order and succession of subterranean groups of rock, to a much greater depth under certain localities than it would be possible to reach to by any process of mining or direct excavation.

The history of the formation of the whole crust of the globe, then, is to be learned by piecing together our knowledge of different parts of it, as they rise to the surface one from under the other, over different tracts of ground.

We might give this history in either of two ways, namely, by investigating or *tracing* it backwards from the present to the past, or by *narrating* it as nearly as possible in the order in which it occurred. I prefer the last method as the shorter and more intelligible, since it is hoped that the previous parts of this work will have sufficiently prepared the student to understand it.

As, however, to narrate this history in full, even so far as it is already known, would require a library rather than a book, what will be here given must be taken as a mere abstract, a chronological table rather than a history, by means of which the student will be able to refer to its proper period any more detailed account, which he may either read or observe for himself, of its different portions.

Even this abstract is a very imperfect, broken, and fragmentary one. Comparatively few parts of the earth's surface have as yet had their structure even sketched out; still fewer have been accurately surveyed, and had their details thoroughly unravelled, and placed in their proper and regular order. Many of the events, therefore, which are now supposed to have occurred contemporaneously in different places, may in reality have occurred in succession; many which are supposed to have directly succeeded each other may have been separated in reality by great spaces of time, of which there are no records as yet discovered, or of which none may ever be found. It is obvious that all future discoveries may add to the time we know to have elapsed, but cannot diminish it.

As the structure of the British Islands is better known than that of any other part of the globe of equal dimensions, and contains a more complete series of rocks in a small space than any other district, we shall take that as our principal authority, as it were, for our history, pointing out the several groups of rock which were produced in this part of the globe during the several periods, mentioning the principal fossils they enclose, and then give some of those other well-known typical groups of rock which are believed, or are known, to have been deposited contemporaneously with them in other parts of the earth. Where a group of rocks is known of which we have no contemporary representative in the British Islands, it will of course be best to describe it from its best known locality. Our history, therefore, will be chiefly that of the formation of the Celtic or British province, as we may call it, with occasional reference to the history of other provinces.

Chronological Nomenclature.—One difficulty meets us at the outset as to our nomenclature, that is, as to the names we are to give to the different periods of past time. This difficulty must at present be evaded, since the time is not yet come, that is to say, our knowledge is not yet complete enough to enable us to overcome it.

The early geological observers described certain kinds of rock, to which particular names were given. These names were, in the first instance, lithological, or descriptive of the kind of stone, of which Chalk, Oolite, Granite are instances.

In other cases they were petrological, such as Trap, Mountain Limestone, Coal Measures, etc. Others again were geographical, of which Wealden, Neocomian, Silurian, Oxford Clay, are examples; while others were local terms adopted by geologists, such as Lias, Cornbrash, Gault, etc. Such terms as Old and New Red Sandstone were combined lithological and geological terms, referring at once to the kind of rock of which they were composed, and their relative place in the series.

Gradually, as extended observation showed that all the aqueous rocks occurred in a certain order, and formed a series or succession of beds regularly and invariably superimposed one upon the other, a chronological sense began to be extended to these terms, having reference to this order of occurrence or corresponding relative date of formation. Thus the Oolite and the Chalk came to mean not only the rocks to which those names were first and truly applied as descriptive of their lithological character, but also all other kinds of rocks which, having been formed about the same period as these, occupied the same relative place in the general series, and contained the same fossils. Used in this sense cretaceous or chalk rocks might be made either of white chalk, of black marble, of brown sandstone, or blue slate; "cretaceous rocks" meaning in reality only rocks of *the same age* as the chalk. Silurian rocks, in like manner, mean those *of the same age* as the rocks of Siluria, and so of the rest. This double signification of words is almost unavoidable, and the student will find himself naturally and inevitably falling into it in the course of his geological pursuits. It may, however, conduce to the more ready understanding of the classification of the great series of stratified rocks, and the history of their formation, if we confine our attention to the chronological signification only of the principal terms, speaking of them as periods of time during which such and such beds were deposited, and such and such plants or animals lived. I shall not attempt to invent new terms for these periods, but shall take those most ordinarily used and accepted. When, then, we speak of Silurian, or Carboniferous, or Oolitic, or Cretaceous *periods* of time, the reader must pardon the apparent contradiction in the terms, and look on the names as *names only*, and not as descriptive designations.*

We may, again, group the great periods of geological time into still larger epochs, to which it is usual to apply the simple terms Primary, Secondary, and Tertiary. As synonyms of these, the words Palæozoic, Mesozoic, and Kainozoic, proposed by Professor Phillips, have been pretty generally adopted, signifying the periods of ancient, middle, and modern life. Geological time, then, may be thus arranged:—

3. TERTIARY OR KAINOZOIC EPOCH.
    - *n.* Human, Historical, or Recent period.
    - *m.* Pleistocene period.
    - *l.* Pliocene period.
    - *k.* Miocene period.
    - *j.* Eocene period.

2. SECONDARY OR MESOZOIC EPOCH.
    - *i.* Cretaceous period.
    - *h.* Oolitic period.
    - *g.* Triassic period.

1. PRIMARY OR PALÆOZOIC EPOCH.
    - *f.* Permian period.
    - *e.* Carboniferous period.
    - *d.* Devonian period.
    - *c.* Upper (or True) Silurian period.
    - *b.* Lower (or Cambro-) Silurian period.
    - *a.* Cambrian period.

It will be advisable perhaps to say a few preliminary words as to the commencements of each of these great epochs.

The commencement of the Primary epoch has been already spoken of; and it was shown that by the very nature of the case this must be lost in the dark uncertainty of the remote past, with no clear and definite starting-point to be determined. The earliest formations of all must necessarily have been all long ago destroyed by the erosive action of

* We may dismiss all reference to the derivation of the terms just as readily here as in many other cases. When using the term "sycophant," we rarely think of a "false fig merchant;" nor do the words "bishop" and "overseer" convey to us the same ideas, although really identical in meaning.

water, or reabsorbed by the melting agency of internal heat, and even of those later but still very early rocks, some of which do yet remain in a recognisable state, most of the contemporaries must have been destroyed or so metamorphosed as to be no longer recognisable. The commencement, then, of the Primary epoch must necessarily be uncertain, doubtful, and irregular.*

The commencement of the Secondary epoch is a marked one, depending on a great change having taken place in the character of animal and vegetable life in the interval between the formation of the last of the Primary or Palæozoic rocks and the first of the Secondary ones. This change was coincident with the occurrence of great disturbances and great denudations in the parts of the world now occupied by Europe, and perhaps some other parts. It is probable, however, that the greater break, both in the position of the rocks and the character of the fossils here than elsewhere in the series, is more apparent than real, and is owing to a great chasm in our documents, and the absence of a vast number of beds which may yet be discovered in other parts of the earth.† However that may be, there is a decided line to be drawn between Primary and Secondary rocks and fossils.

The commencement of the Tertiary epoch is more arbitrary, though it is marked also by a decided change in the rocks and fossils, and a probable absence of a number of beds. The most marked character of the Tertiary rocks is derived from the fact that a few of the animals which came into

* The term "primary" was formerly attached to granitic and highly metamorphosed rocks only; and another term, namely "transition," was used to designate many of those which are now called "primary." In consequence of this uncertainty as to the meaning of "primary," it is more usual now to speak of this epoch as Palæozoic. It is undoubtedly true that much of the granite we know is of primary or palæozoic age, and that many metamorphic rocks were formed during the same epoch. As, however, some granites are secondary or tertiary, and some secondary and tertiary rocks are just as much metamorphosed as any primary ones, the old use of those terms is now properly abandoned.

† This was written while I had but a very faint knowledge of the nature of the St. Cassian beds. The publication of Sir C. Lyell's Supplement makes English readers acquainted with the existence, in the Austrian Alps, of a large mass of beds of the very character here anticipated, namely, the St. Cassian or Hallstatt beds, and others associated with them, having fossils of an intermediate character between those found in palæozoic and those in mezozoic rocks.

existence at the commencement of the Tertiary epoch are still living on the globe. It would follow, then, that if these few species were now to die out and become extinct, the boundary between Secondary and Tertiary rocks would have to be shifted, or else it would be left with a still more arbitrary character than now. There is no essential difference between Secondary and Tertiary fossils. The genera are mostly the same, though the species are different, and often not very widely different. It was for this reason that the late Professor Edward Forbes proposed to do away with the distinction between them, and to group the whole of the great series of stratified rocks, or, in other words, to divide the whole lapse of past geologic time into two great epochs only, namely, Palæozoic and Neozoic.

In drawing up the following summary, it will be best to give, under each period, a general account of the kinds of animals and plants that are known to have lived in it, with the names of the principal generic types which then first came into existence, distinguishing those which did not survive it.

There will then be given a brief description of the groups of rocks that may be taken as typical of those formed during the period in different parts of the earth, with their maximum thickness,* as the measure of the time elapsed and the possible importance of the group, and a list of the fossils more or less complete, derived chiefly, but not entirely, from Morris's catalogue.

The history of each period will be closed by pointing out the generic types, which having come into existence earlier, then became extinct.

Reference will be made chiefly to the Celtic province, or British area, in these statements.

* It is evident that the maximum thickness must be taken as the true measure of time, or rather as the nearest approximation to it. Any less thickness at other localities merely shows that a greater portion of the period elapsed without any deposition taking place there. Much time may pass without leaving any record of its passage, but proof that time elapsed in any one locality, proves that it elapsed everywhere.

PRIMARY OR PALÆOZOIC EPOCH.

CAMBRIAN PERIOD.

(Lower Cambrian of Professor Sedgwick.)

Life of the Period.—If we adopt the limits assigned to the Cambrian period by the Government Geological Survey, we know but of very few animals, and scarcely any plants, that lived during its passage. A small branched zoophyte * (either sertularian or polyzoan), called Oldhamia, some decided traces of annelids, and a fucoid plant or two, are the only fossils known, except a doubtful impression that may possibly be that of a trilobite.

Typical Rocks.—*Wales.*—A great series of gritstones, or sandstones, and slates, generally of purple and green colours, the sandstones sometimes becoming conglomeritic, and containing fragments of still older slates and grits. In the Longmynd (Salop), there is an apparent thickness of 26,000 feet of these rocks; but this enormous thickness may perhaps be due to concealed folds or reduplication of the beds. In Anglesea, these rocks are largely metamorphosed into chloritic and micaceous schists and gneiss, the metamorphism having apparently taken place at a very early period.

Characteristic fossils in the Longmynd.—Annelid tracks, called Arenicolites didyma, and a supposed trilobite called Palæopyge Ramsayi.

Ireland.—A great series of grits and slates, generally of purple and green, or brown and liver-coloured hues, often interstratified with large beds of yellowish quartz rock, which are most abundant in what appears to be the upper portion of the group. In this upper portion the fossils also are found.

Characteristic fossils in Wicklow.—Oldhamia antiqua and radiata and numerous tracks and burrows of sea-worms, Arenicolites and Histioderma Hibernicum, *Kinahan*, sometimes beautifully distinct,

* The term zoophyte may be lawfully given to all animals having the form of plants, whether their anatomical structure be simple or complex, entitling them to be considered as a low form of Mollusc or merely Cælenterata.

showing the depression on the surface of the bed, with the tube below still retaining the marks of the tentacles. (*Journal of Geol. Soc. Dub.*, 1857.)

Cumberland.—The Skiddaw slate of Professor Sedgwick is probably of nearly the same age as the rocks above mentioned.

Characteristic fossils.—Fucoid plants.

None of the Cambrian rocks of Wicklow and Wexford are known to be metamorphosed, though it is possible that much of the mica schist and gneiss, with altered limestone of the north of Ireland and of Scotland and other parts of the world, are the metamorphosed clays, sands, and limestones of this period.

Bohemia.—Probably Stage A (crystalline schist) and Stage B (slate and conglomerate) of M. Barrande. No fossils known.

Scandinavia.—Regio 1. Fucoidarum of M. Angelin almost certainly is of this period.

America.—Sir W. Logan describes rocks, apparently of this period, below the Potsdam sandstone in Canada. No fossils.

Much of the metamorphic series of America as of Europe, the great masses of gneiss and mica schist, are doubtless altered Cambrian, or else still more ancient rocks, the unaltered members of which may never be known to us.

NOTE.—Although few traces of life have hitherto been found in the Cambrian rocks, and no unaltered rocks below them are at present known, yet the conclusion that life now first began upon the globe is one that is anything but satisfactory to my mind. Even on the supposition that no more fossils should ever be found in Cambrian, or still earlier rocks, the possibility of the existence of full assemblages of earlier life remains the same. Had general metamorphic action spread a few stages higher than it has, and the Silurian and Devonian rocks of Europe and America, and other parts of the globe, been affected by it, so as to have their organic remains obliterated and become generally converted into crystalline schists, it would have been argued that the Carboniferous period was that in which life commenced upon the globe; and had large parts of the south-west of Ireland and South Wales been left unaffected by metamorphism, great formations of sandstones and slates of Devonian age, and many thousand feet in thickness, might have been appealed to as utterly destitute of a single trace of organic existence, and therefore a proof that, during their deposition, life did not exist upon the globe. In Ireland, as in Wales, calcareous bands (cornstones, etc.) might be shown without a trace of a fossil for miles and miles, and ranging through a thickness of 10 or 12,000 feet of rock at the least.

The present known districts where unaltered Cambrian rocks are visible, may be just the parallels of such a case; and their metamorphosed contemporaries and still earlier formations may once have been crowded with organic forms, none of which we shall ever see. I do not assert that it was so, but merely that we have not yet arrived at *any proof* that it was not, nor has the accumulation of negative evidence been yet of anything like sufficient extent to preclude even its probability.

LOWER (OR CAMBRO) SILURIAN PERIOD.

(*Upper Cambrian of Professor Sedgwick.*)

Life of the Period.—The plants that lived during this period are unknown to us except by a few sea-weeds. The animals of which remains have been found in the British province consist of Zoophyta, of Polyzoa (in which class Professor Huxley would place the Graptolites), Brachiopoda, Conchifera, Gasteropoda, Cephalopoda, Echinodermata (chiefly Cystidea without arms), Annelida, and Crustacea (chiefly Trilobites). No unquestionable remains of any higher order of animals have as yet been discovered.

The following generic forms first came into existence, so far as is yet known, during this period, and those marked with an asterisk did not survive it.

Plants, Chondrites, Palæochorda.

Corals, Chætetes, Favosites, Halysites, Heliolites, Nebulipora, Petraia, Retiolites, Sarcinula, Stenopora, Strephodes.

Polyzoa, *Didymograpsus, *Diplograpsus, Graptolithus, Diastopora, Ptilodictya, Retepora.

Brachiopoda, Atrypa, Crania, Discina (Orbicula), Leptæna, Lingula, Orthis, Orthisina, Pentamerus, Porambonites, Rhynconella, Strophomena, *Trematis.

Conchifera, Ambonychia, Arca, Conocardium, Cypricardia, Lyrodesma, Modiola, Modiolopsis, Mytilus? Nucula.

Gasteropoda, Capulus, Euomphalus, *Holopæa, ~~*Helminthochites,~~ *Maclurea, Macrocheilus, Murchisonia, Phasianella, Trochus, Turbo, Raphistoma, Turritella.

Pteropoda, Conularia, Bellerophon, Ecculiomphalus, *Pterotheca, Theca.

Cephalopoda, Actinoceras, Cyrtoceras, Lituites, Orthoceras, Phragmoceras.

Echinodermata, *Agelacrinites, *Caryocystites, Echinospherites, *Hemicosmites, Glyptocrinus, Uraster, Rhodocrinus.

Annelida, *Aphrodita, Arenicola, Crossopodia, *Lumbricaria, *Myrianites, *Nemertites, *Nereites, Serpulites, Tentaculites.

Crustacea, Acidaspis, *Æglina, *Amphion, Ampyx, *Asaphus, Beyrichia, Bronteus, Calymene, Cheirurus, *Cybele, Cyphaspis, *Cyphoniscus, Dithyrocaris, *Eccoptochile, Encrinurus, Harpes, Homalonotus, *Hymenocaris, Illænus, Lichas, *Ogygia, *Paradoxides, Phacops, *Remopleurides, Sphærexochus, *Staurocephalus, *Stygina, Tiresias, Trinucleus.

TYPICAL GROUPS OF ROCK.—*Wales, etc.*

		Feet.
4.	Lower Llandovery beds	1000
3.	Caradoc Sandstone and Bala beds	9000
2.	Llandeilo flags	5000?
1.	Lingula flags[1]	5000?

1. The Lingula Flags. Dark brown and blue flags and slates, interstratified in their lower beds with sandstones, and seeming to pass down by insensible gradations into the gritstones and slates of the Cambrian rocks below, to which they are quite conformable. Thickness several thousand feet.

Characteristic Fossils.

Polyzoa: Didymograpsus Murchisonii.

Brachiopoda: Lingula Davisii.

Crustacea: Olenus micrurus, humilis, and bisurcatus; Agnostus pisiformis; Hymenocaris vermicauda.—(*Salter and Morris*).

2. Llandeilo Flags. Brown, fine grained, rather sandy flags, and black earthy rotten slates. Thick beds of contemporaneous traps and ashes in some places.

Thickness, several thousand feet independent of the traps.

[1] Sir C. Lyell, in his Manual, draws the boundary between Cambrian and Silurian at the top of the Lingula flags, and palæontologically such a boundary seems well founded. It is, however, impossible to draw any physical boundary in North Wales between 1 and 2, since they are both similar dark-coloured slates and flags, and there is conformity of position throughout.

Characteristic Fossils.

Polyzoa: Diplograpsus pristis; Graptolites Sedgwickii, incisus; Rastrites peregrinus.
Brachiopoda: Orthis alata.
Crustacea: Agnostus M'Coyii; Trinucleus fimbriatus, Lloydii; Asaphus Selwynii, Tyrannus; Ogygia Buchii, Murchisonii, Scutator; Calymene parvifrons.—(*Salter*).

3. Caradoc Sandstone and Bala Beds. In Shropshire these are chiefly thick brown and yellow sandstones, often calcareous. In Merioneth, etc., they are grey grits and sandy slates, sometimes black slates with beds of sandstone. Near Bala they have a band of concretionary limestone twenty or thirty feet thick about their middle portion, called the Bala Limestone, and another smaller occasional band near the top called the Hirnant Limestone. Great masses of contemporaneous traps and ashes are interstratified with the slates and grits in some places.

Thickness, without trap, about 9000 feet.

Characteristic Fossils.

Zoophyta: Petraia subduplicata; Stenopora fibrosa.
Polyzoa: Retepora Hisingeri.
Brachiopoda: Crania divaricata; Orthis Actoniæ, insularis, flabellulum, vespertilio, caligramma; Leptæna tenuicincta; Strophomena orthisoides.
Conchifera: Nucula varicosa.
Gasteropoda: Holopæa concinna, striatella; Murchisonia scalaris.
Cephalopoda: Lituites cornu-arietis.
Echinodermata: Caryocystites granatus, pyriformis, etc.; Glyptocrinus basalis; Hemicosmites oblongus, pyriformis; Sphæronites (Echino-sphærites) arachnoideus, aurantium, balticus, punctatus.
Crustacea: Trinucleus seticornis, concentricus; Illænus Bowmani, Davisii; Cheirurus clavifrons; Agnostus trinodus; Asaphus Powisii; Phacops apiculatus, conophthalmus; Calymene brevicapitata; Beyrichia complicata.

4. Lower Llandovery Beds. Grey and brown grits and conglomerates, with dark shales.

Thickness, several thousand feet, occupying all Cardiganshire, great part of Glamorgan and Radnor. The Plynlumon rocks.

Characteristic Fossils.

Zoophyta: Nidulites favus.

Brachiopoda: Atrypa hemisphærica, crassa; Rhynconella angustifrons; Orthis virgata.—(*Salter*).

There are also in these beds many fossils common to them and the Bala beds below, and others common to them and the Upper Silurian rocks above.—(*Ramsay, M.S.*)

Ireland.—The Lingula flags are not yet known in Ireland. Their discovery would be of interest, as it would be of importance to know whether they would be conformable to the Cambrian or to the Lower Silurian rocks, or would, as in Wales, introduce conformity throughout the series.

The Lower or Cambro-Silurian rocks of Wicklow, Wexford, and Waterford, are of the Bala and Caradoc sandstone age, as shown by their fossils, with unfossiliferous beds below them that may or may not belong to the Llandeilo flags. They consist of dark blue or black, and grey flags, slates, and grits, sometimes, as in Wales, becoming purple, green, olive, etc. They contain many contemporaneous beds of trap and ash (felstone, etc.), like those of Wales, and one or two calcareous bands (very like the Bala limestone), near Courtown, and at Tramore.

Their thickness must be many thousand feet, but there are no good continuous sections sufficient to determine it exactly.

They repose on the Cambrian rocks below, quite unconformably, stretching directly across the ends of the beds, and coming into contact with different portions of the lower rocks.

The fossils are found only in the upper part of the series in the neighbourhood of the traps* and calcareous bands, and the exact relations of the lower beds are accordingly unknown.

Another great tract of apparently similar beds stretches from the centre of Ireland (Cavan, etc.), to the coast of Down.

* The eruption of igneous rocks at the bottom of the sea, though doubtless occasionally destructive of animal life at the moment, seems generally favourable to its development during the period. Contemporaneous trap rocks have often highly fossiliferous beds intimately associated with them.

It contains a bed of anthracite which is worked and locally used for coal, and this is said to reappear in one or two spots in Tipperary, etc.

On the flanks of the Dublin and Wicklow granites, the Lower Silurian slates and grits are greatly metamorphosed into mica and other schists, and occasionally into gneiss, full of crystals of andalusite, staurolite, schorl, feldspar, and other minerals.

Other metamorphic tracts in the north-west of Ireland may be also composed of metamorphosed Lower Silurian rocks.

Cumberland.—The Coniston group of Professor Sedgwick is doubtless the equivalent of the Caradoc sandstone and Bala group. Whether the group below (his chloritic slate and porphyry) ought to be placed with the Llandeilo flag or the Lingula flag, is difficult to decide in the absence of fossil evidence. The latter is perhaps the more likely of the two, and seems to be the belief of Professor Sedgwick himself.

Scotland.—The rocks of the Border highlands from Dumfries to the Lammermuir hills belong to this period, probably both to the Llandeilo flags and the Caradoc sandstone.

Characteristic Fossils.

Diplograpsus **pristis, sextans, and teretriusculus**; Graptolites **Sedgwickii, Wilsoni, Flemingii, and priodon**; Rastrites **peregrinus**; Orthoceras, **politum, etc.**

The mica schists, etc., of the N.W. Highlands are also metamorphosed Lower Silurian rocks, containing fossils said by Mr. Salter to be like some in North America.

The following are the Lower Silurian fossils given in Morris' Catalogue besides those previously mentioned :—

Plants: Chondrites **acutangulus, informis**; Cruziana **semiplicata**; Fucoides **gracilis.**

Zoophyta: Chætetes **Petropolitanus**; Heliolites **favosa, subtilis**; Nebulipora **favulosa, etc.**; Petraia **equisulcata, elongata, rugosa, etc.**; Pyritonema **fasciculus**; Strephodes **Craigensis.**

Polyzoa: Diastopora **heterogyra**; Didymograpsus **caduceus, sextans**; Diplograpsus **bullatus, foliaceus, folium, mucronatus, nodosus, pennatus, ramosus, rectangularis**; Intricaria **obscura**; Ptilodictya **acuta, fucoides, etc.**

Brachiopoda: Orbicula (Discina) crassa, lævigata, oblongata, punctata, subrotunda; Leptæna calcarata, quinquecostata, tenuissime-striata; Strophomena alternata, anomala, corrugata, deltoidea, expansa, grandis, pecten; Lingula attenuata, brevis, curta, granulata, longissima, obtusa, ovata, tenuigranulata; Orthis alternata, basalis, confinis, costata, crispa, fallax, intercostata, lata, porcata, reversa, testudinaria; Orthisina ascendens, scotica; Pentamerus globosus, lævis, undatus; Porambonites crassa, intercedens; Retzia Salteri, etc; Rhynconella hemisphærica, pusilla, subundata, etc.; Siphonotreta micula; Trematis punctata.

Conchifera: Mon—Ambonychia gryphus, trigona, etc; Avicula vetusta, Pterinea megaloba; *Dim*—Arca Apjohni, dissimilis, transversa, etc.; Cardiola semirugata; Conocardium dipterum; Lyrodesma plana; Modiola Brycei, expansa, etc; Modiolopsis modiolaris, etc; Mytilus cinctus; Nucula lævis.

Gasteropoda: Euomphalus perturbatus, prænuntius, etc.; Holopella gracilior, etc.; Maclurea Logani, macromphala; Macrocheilus fusiformis; Murchisonia augustata, pulchra, etc.; Pleurotomaria latifasciata, etc.; Raphistoma qualteriatum; Trochus? constrictus, ellipticus; Turbo? concinnus, sulcifer, etc. Turritella cancellata.

Pteropoda: Bellerophon acutus, alatus, bilobatus, nodosus, subdecussatus, sulcatinus; Conularia elongata; Ecculiomphalus scoticus; Pterotheca corrugata, transversa; Theca triangularis.

Cephalopoda: Actinoceras Brongniartii; Cyrtoceras inæquiseptum, multicameratum; Lituites anguiformis, Hibernicus, planorbiformis, Sowerbianus, undosus; Orthoceras arcuoliratum, Barrandei, bilineatum, breviconicum, Brongniarti, calamiteum, perannulatum, politum, Pomeroense, primævum, subarcuatum, tenuistriatum, vagans, etc.; Phragmoceras approximatum, Brateri, subfusiforme, etc.

Echinodermata: Agelacrinites Buchianus; Caryocystites Davisii, Litchi, munitus; Uraster obtusus.

Annelida: Crossopodia lata, Scotica; Lumbricaria antiqua, gregaria; Myrianites Macleayii; Nemeritites Ollivantii; Nereites Cambrensis, Sedgwickii, tenuis; Serpulites dispar; Tentaculites annulatus; Trachyderma læve.

Crustacea: Acidaspis bispinosus, Caractaci; Æglina major, mirabilis; Agnostus limbatus; Amphion pseudo-articulatus; Ampyx mammillatus, nudus, rostratus, tumidus; Asaphus gigas, læviceps, laticostatus, rectifrons; Beyrichia strangulata; Bronteus Hibernicus; Calymene duplicata, obtusa; Cheirurus gelasinosus, octolobatus; Cybele rugosa, verrucosa; Cyphoniscus socialis; Dithyrocaris? aptychoides; Eccoptochile Sedgwickii; Encrinurus multisegmentatus, sexcostatus; Harpes Doranii, Flanaganni; Homalonotus bisulcatus, ophiocephalis, rudis; Illænus Murchisoni, ocularis, perovalis, Portlockii,

see Errata

quadrato-caudatus; Lichas laciniatus, laxatus; Ogygia Portlockii; Olenus scarabæoides? Phacops alifrons, Brongniartii, Dalmanni, Jamesii, mucronatus, obtusicaudatus, sublævis, truncato-caudatus, Weaveri; Remopleurides Colbii, dorso-spinifer, lateri-spinifer, longicostatus, obtusus, platyceps, radians; Staurocephalus globiceps, Murchisoni; Stygina latifrons, Murchisoni; Tiresias insculptus; Trinucleus radiatus.

In addition to the species previously mentioned, the following also occur in Lower Silurian rocks, but survived into the next period:—

Zoophyta: Favosites alveolaris, Gothlandica, Hisingeri; Halysites catenulatus; Heliolites inordinata, interstincta, megastoma, petalliformis; Petraia bina; Sarcinula organum.

Polyzoa: Ptilodictya lanceolata.

Brachiopoda: Atrypa marginalis; Orbicula (Discina) implicata; Leptæna lævigata, sericea, transversalis; Orthis biforatus, biloba, elegantula, rustica; Strophomena antiquata, applanata.

Conchifera: *Dim*—Orthonota semisulcata.

Gasteropoda: Capulus (Acroculia) Haliotis.

Pteropoda: Bellerophon dilatatus; Conularia Sowerbii.

Cephalopoda: Orthoceras centrale, subundulatum.

Annelida: Tentaculites ornatus.

Crustacea: Acidaspis Brightii; Calymene Blumenbachii; Cheirurus bimucronatus; Cyphaspis megalops; Encrinurus punctatus; Phacops caudatus, Downingiæ, Stokesii; Sphærexochus mirus.

According to Morris, the Strophomena depressa ranges from Lower into Upper Silurian, and thence through the Devonian into rocks of the Carboniferous period; and the three species of Coral, Favosites Gothlandica, Heliolites interstincta, and Petraia bina, are common to Lower and Upper Silurian and Devonian rocks.

Bohemia.—Stage C, Argillaceous schist, and stage D, Quartzites, etc., of Barrande, are of this period. Stage C probably corresponds to the Lingula flags, but is more fossiliferous, containing twenty-seven species of Trilobites alone. Stage D will then answer either to the Llandeilo flags or the Caradoc sandstones, or both.

Scandinavia.—M. Angelin's Regio A. Olenorum and Regio B. Conocorypharum, consisting of aluminous schists and limestone, approximately equal to stage C of Barrande, and therefore approximately equal to Lingula flags.

The Scandinavian beds contain seventy-one species of Trilobite of the same peculiar genera as the Bohemian beds, but without one identical species.

Angelin's regions—B C, Ceratopygarum (aluminous schist and black limestone); C, Asaphorum (grey and reddish impure limestones); and D, Trinucleorum (marly schists with calcareous concretions)—are together approximately equal to stage D of Barrande.

There are 81 species of Trilobites in the Bohemian beds D, and 176 in those of Scandinavia, B C, C, and D. The genera are the same in both countries, and the species nearly allied; but there is said to be not one species common to the two districts.

It is yet doubtful whether these specific differences, existing together with generic identities, be due to a want of exact synchronism in the age of the beds, or to the geographical distribution and limitation of the life of the period; whether, in fact, they are the result of time or space. It is perhaps most probable that they are contemporaneous, or nearly contemporaneous groups, deposited in seas separated either by intermediate lands, or by impassable depths, or traversed by currents from different sources.

North America.—According to Prof. H. D. Rogers, the following is the series of the Lower Silurian rocks of North America:—

		Feet.
HUDSON GROUP.	11. Lorraine shale and sandstones	2000
	10. Utica slate	
	9. Trenton limestone	500
BLACK RIVER GROUP.	8. Black River limestone	2500
	7. Birdseye limestone	
	6. Chazy limestone	
	5. Calciferous sandstone	100
POTSDAM GROUP.	4. Upper Primal slate	700
	3. Potsdam sandstone	700
	2. Lower Primal slate	1200
	1. Conglomerate with quartzose, feldspathic, and slaty pebbles	150

Characteristic Fossils.—Rogers says that 1 and 2 are unfossiliferous. No. 3, the Potsdam sandstone, contains a Lingula, from which it is supposed to be equal to Lingula flags. No. 4 contains Fucoids only.

Nos. 5 to 8, or the Black River group, have about 100 species of fossils, and are apparently nearly equivalent to the Llandeilo flags.

The Hudson group has a very large assemblage of fossils, of which not more than 2 or 3 per cent are found in any higher bed. They contain Trinucleus **concentricus**, Orthis **striatula** and **biforata**, etc., and are therefore supposed to be very nearly the equivalents of the Caradoc sandstone and Bala beds.

The beds described by Mr. Dale Owen are an extension and development of the Potsdam sandstone, in the country west of Lake Michigan.

They contain an abundance of fossils down to the very base, consisting of Lingula, Orbicula, Obolus, Trilobites of several peculiar forms called Dikelocephalus, etc., and of compressed subconical bodies, resembling Cephalopoda, but probably not belonging to them. The fossils are locally in immense abundance, although not numerous in species.

They are probably of the age of the Lingula flags, or may be still older.

Extinction of Life at the Close of this Period.

The genera that now became extinct have already been pointed out by the asterisks attached to those that came into existence at its commencement.

At the close of this period, or immediately after it, very considerable movements of elevation and disturbance took place over the area now occupied by the British Islands, and some parts of Western Europe. Denudation consequently occurred, removing large portions of the upper rocks and exposing the surfaces of those below. The rocks of the next period, therefore, are very frequently unconformable to those of this and the preceding period, resting now on one and now on another portion of them. This unconformity always involves the supposition of a vast lapse of time to allow of the slow action of elevating and denuding forces to produce the effect, and this supposition is almost invariably strengthened by finding that an equal change has taken place in the life of the area in consequence of the gradual action of those causes alluded to in Chapter VIII. Wherever unconformity is noted in future, the student will be careful to apply these remarks.

UPPER SILURIAN PERIOD.

LIFE OF THE PERIOD.—The plants are as little known to us as those of the preceding period.

The animals include fish, in addition to those classes mentioned in the preceding period. Of the species some range throughout all, others through two or three groups of the series, while others, again, are confined to one particular group of beds, of which they are accordingly characteristic. A few species extend from Lower into Upper Silurian Rocks, and still fewer coming into existence during this period extend into the next or Devonian. These long-surviving species mostly ranged through great depths of water, and spread over large areas. They therefore occur in the typical rocks of other countries, as well as those of the British Islands.

The following generic forms first (so far as is yet known) came into existence within the British area during this period, those with an * not surviving it.

Zoophyta: Acervularia, Alveolites, Arachnophyllum, * Aulacophyllum, Aulopora, * Cænites, * Cladocora, Cyathophyllum, Cystiphyllum, Fistulipora, * Goniophyllum, * Omphyma, * Palæocyclus, Stromatopora, Syringopora, * Thecia, Zaphrentis.

Bryozoa: Cellepora, Ceriopora, Discopora, Fenestella, Glauconome.

Brachiopoda: Athyris, Chonetes, Cyrtia, * Obolus, Retzia, Spirifer.

Conchifera: Avicula, Pterinea, Anodontopsis, * Cardiola, * Clidophorus, Dolabra, * Grammysia, Leptodomus, * Orthonota?, Psammobia, Sanguinolites.

Gasteropoda: * Holopella, Loxonema, ~~Macrocheilus~~, Natica, Nerita, Pleurotomaria. * Helminthochiton.

Echinodermata: Actinocrinus, * Apiocystites, * Crotalocrinus, Cyathocrinus, * Echinoencrinus, * Eucalyptocrinus, * Ichthyocrinus, * Lepidaster, * Marsupiocrinus, Palæchinus, * Periechocrinus, * Protaster, * Prunocystites, * Pseudocrinites, * Sagenocrinus, Taxocrinus, * Tetragonis, * Tetramerocrinus.

Annelida: * Cornulites, Serpulites.

Crustacea: * Deiphon, Eurypterus, * Leptocheles, * Proetus, Pterygotus.

Fish: Onchus, * Plectrodus.

TYPICAL GROUPS OF ROCKS.—*England—Siluria, the Border counties of England and Wales.*

		Feet.
LUDLOW GROUP.	10. Tilestone	800
	9. Upper Ludlow rock	650
	8. Aymestrey limestone	100
	7. Lower Ludlow rock	1000
WENLOCK GROUP.	6. Wenlock limestone	300
	5. Wenlock shale	1500
	4. Woolhope limestone	50
MAY HILL GROUP.	3. Denbighshire sandstone	2000
	2. Tarannon shales	1000
	1. Upper Pentamerus beds, or May Hill sandstone, or Upper Llandovery beds,	1000

The sandstones of the May Hill group were at one time confounded by the Geological Survey with the true Caradoc sandstone, which they often greatly resemble in lithological character. Professor Sedgwick first pointed out their difference; and the officers of the Geological Survey afterwards traced the boundary between the two, and showed that the sandstones of the Upper Silurian period rested unconformably on those of the Lower. The first mistake unfortunately had a bad influence on the survey of North Wales, where a thick sandstone formation, lithologically resembling the true Caradoc formation of Shropshire, was taken for it, and therefore the Bala beds were presumed to be below the Caradoc, while in reality they were themselves its true representative.—(*Ramsay, MS.*) This thick sandstone formation of North Wales, then, described first by Mr. Bowman (British Association), and then by Professor Sedgwick, under the name of *Denbighshire grits*, together with the other beds associated with it, requires to be admitted as a new, and locally a very important member of the Upper Silurian series. It has other beds underneath, more or less intimately associated with it; and the group forms the true base of the Upper Silurian series, reposing almost invariably in an unconformable position,* on the per-

* So long as the Denbighshire grits were supposed to be the same as the Caradoc sandstone, the unconformity of the Upper on the Lower Silurian, which in Derbyshire and Merionethshire is not very striking, was entirely overlooked.

fectly distinct Lower or Cambro-Silurian rocks below.—(See Professor Ramsay's forthcoming *Memoir on North Wales.*)

1. Upper Llandovery Sandstone, or Pentamerus Beds, or May Hill Sandstone. Grey and brown sandstones and conglomerates, with (in Shropshire) very calcareous bands, almost limestones. Thickness, 800 to 1000 feet.

Characteristic Fossils.

Zoophyta: Petraia bina.

Brachiopoda: Pentamerus oblongus (especially) and undatus, liratus and lens; Leptæna transversalis and Grayii; Strophomena pecten; Orthis reversa and calligramma; Atrypa hemisphærica and reticularis.

Annelida: Tentaculites anglicus.

Crustacea: Encrinurus punctatus; Phacops Stokesii; Illænus (trilobed species); Beyrichia tuberculata.

2. Tarannon Shales. Generally pale grey, nearly white shales or slates, very fine grained (spoken of by Professor Sedgwick as "paste rock"), sometimes becoming of a bright red colour. Thickness, 500 or 800 feet.

Characteristic Fossils.—Not yet thoroughly made out.

3. Denbighshire Sandstones and Flags. Generally thick bedded yellowish or brownish sandstone, largely made up of angular grains of white feldspar, with grains of quartz occasionally as large as peas, and passing into conglomerate. These are interstratified with beds of brown slaty shale, and occasionally dark, nearly black slate, overlaid by hard brown and blue flags. Thickness at least 2000 feet.

Characteristic Fossils.—The few species known seem to be the same as those in the Wenlock shale, with the addition of Theca (Creseis) Forbesii and anceps, and others, of large size and great abundance in Denbighshire.

4. Woolhope Limestone. A locally occurring group of beds of grey, argillaceous, nodular, concretionary limestone, interstratified with grey shales occasionally attaining a thickness of 100 feet.

Characteristic Fossils.

Brachiopoda: Atrypa Barrandei, Grayi; Leptæna transversalis; Pentamerus linguiferus; Rhynconella borealis; Spirifer trapezoidalis; Strophomena imbrex.

Crustacea: Illænus Barrensis; Homalonotus Delphinocephalus. (*Morris*).

5. Wenlock Shale. Generally dark grey, sometimes black shale, with occasional calcareous concretions, capped by

6. Wenlock Limestone, an irregularly occurring set of concretionary limestones, sometimes thin and flaggy, sometimes massive, highly crystalline bosses of carbonate of lime; sometimes in one, sometimes in two or three sets of beds with interstratified shales, forming a thickness of one to three hundred feet.

Characteristic fossils of the Wenlock rocks generally, but principally found in the limestone, are

Corals: Acervularia ananas, etc.; Stenopora fibrosa.

Brachiopoda: Athyris tumida; Atrypa reticularis; Pentamerus galeatus; Leptæna rugosa; Strophomena depressa and euglypha; Spirifer radiatus and interlinearis.

Gasteropoda: Euomphalus discors, funatus, and rugosus.

Pteropoda: Bellerophon Wenlockensis.

Cephalopoda: Orthoceras annulatum and primævum; Lituites Biddulphii.

Echinodermata: Crotalocrinus rugosus; Periechocrinus moniliformis; Eucalyptocrinus decorus; Marsupiocrinus cælatus; Pseudocrinus magnificus and quadrifasciatus; Echinocrinus baccatus.

Crustacea: Lichas anglicus.

The trilobites Calymene Blumenbachii, Phacops caudatus, Sphærexochus mirus, are more abundant in the Wenlock than in any other, either Lower or Upper Silurian groups.

7. Lower Ludlow rock of Shropshire is generally a brown or grey sandy flag, or argillaceous sandstone, locally called mudstone.

Characteristic Fossils.

Conchifera: Nucula sulcata and coarctata.

Pteropoda: Bellerophon expansus.

Cephalopoda: Orthoceras **Ludense, filosum, perelegans, dimidiatum**; Phragmoceras **ventricosum and pyriforme.**

Echinodermata: Protaster **Miltoni**; Palæocoma **Marstoni.**

Crustacea: Phacops **granulatus**; Pterygotus **punctatus.**

8. Aymestrey Limestone. A nodular concretionary limestone, sometimes pure and crystalline, at others argillaceous and impure; like the Wenlock, but more local in its occurrence.

Characteristic Fossils.

Brachiopoda: Pentamerus **Knightii**; Rhynconella **Wilsoni, navicula**; Lingula **lata, Lewisii.**

Conchifera: Pterinæa **Sowerbyi**; Avicula **reticulata**; Orthonota **amygdalina**; Cardiola **interrupta, fibrosa.**

9. Upper Ludlow of Shropshire, etc. A grey argillaceous sandstone, often calcareous, and containing calcareous nodules passing up into shales with sandstones, which gradually acquire a red colour.

Characteristic Fossils.

Brachiopoda: Chonetes **lata**; Rhynconella **navicula (Athyris), nucula**; Orthis **orbicularis, lunata**; Orbicula **rugata.**

Conchifera: Pterinæa **retroflexa**; Avicula **Danbyi, etc.**; Orthonota **cymbæformis.**

Gasteropoda: Turbo **coralii**; Murchisonia **coralii.**

Pteropoda: Bellerophon **expansus.**

Cephalopoda: Orthoceras **ibex, imbricatum.**

Annelida: Serpulites **longissimus.**

Crustacea: Homalonotus **Knightii**; Pterygotus **problematicus.**

Fish: Onchus **tenuistriatus, Murchisonii**; Plectrodus **mirabilis, pustriliferus, pleiopristis.**

10. Tilestone. Red, shaly, and flaggy sandstones. At the base, near the junction of the Ludlow and Tilestone beds in Herefordshire, are one or two little thin, but very widely extended bands, called "bone beds," full of the teeth and bones of small fish. These bone beds, wherever they occur, are indications of great lapse of time, during which little

mineral deposition took place. Near Llangaddock, Caermarthen, there are 1000 feet of red beds capped by grey highly micaceous flagstones containing Ludlow fossils.

Characteristic Fossils.

Brachiopoda: Lingula cornea.
Gasteropoda: Turbo Williamsi, corallii, octavius; Trochus helicites; Turritella gregaria.
Cephalopoda: Orthoceras tracheale, bullatum.
Crustacea: Pterygotus Banksii; Himantopterus bilobus, acuminatus, maximus.

Cumberland, etc.—According to Professor Sedgwick the following are the typical groups of rocks deposited during the Upper Silurian period in the north of England:—

3. Kendal group = Ludlow rocks.
2. Ireleth slates = Wenlock rocks.
1. Coniston grits = May Hill sandstone.

1. The Coniston grits have few fossils, and their identity with the May Hill sandstone is therefore doubtful, although very probable.

2. The Ireleth slate group is divided into four stages: *a*, Lower Ireleth slate; *b*, Ireleth limestone; *c*, Upper Ireleth slate; *d*, Coarse slate and grit. Fossils are rare, but generally of the Wenlock type.

3. The Kendal group is divided into three stages: (*a*) A great group of flags and grits; fossils abundant and of the Lower Ludlow type. (*b*) Thick grit and flagstone, with bands of coarse slate; fossils locally abundant, and of Upper Ludlow type. (*c*) Tilestones, resembling those of Shropshire, etc.—(Sedgwick, *Synopsis of Classification, etc.*)

Four species of star-fish have been found by Professor Sedgwick in the Kendal group (stage *b*), of which Uraster primævus is the most abundant, and Protaster Sedgwickii the most interesting.

Scotland.—Not much has hitherto been known as to the existence of Upper Silurian rocks in Scotland. The representatives of the Tilestones, however, and probably the lower groups, have lately been discovered by Mr. Slimon of Lesmahagow, and described by Sir R. Murchison.—(*Geological Journal*). These are dark grey schistose rocks, with lighter and more siliceous stony bands, and other schists containing calcareous concretions.

The fossils discovered by Mr. Slimon and described by Mr. Salter are Crustacea of the genus Pterygotus and allied genera. These Crustaceans more nearly resemble lobsters or prawns in external form than trilobites, and were apparently six feet long or more.

Ireland.—No detailed descriptions of the Upper Silurian rocks of Ireland have yet been published. The labours of Mr. Griffith, however, and more recently of the Geological Survey, have shown the existence of rocks of this age on the western side of the island. The Dingle promontory contains the representatives of both the Ludlow and Wenlock rocks, and possibly of part of the May Hill sandstone group also. Abundance of most of the characteristic fossils, and some not found in England, though occurring in the Upper Silurian rocks, either of Scandinavia or of North America, have been found.—(*Salter*.)

In Galway, as shown by Mr. Griffith, and confirmed by Sir R. I. Murchison and others, there is a vast series of grey grits and slates reposing unconformably on mica schist, etc., and having frequently red sandstones at its base, and sometimes great beds of conglomerate in its upper part, containing perfectly rounded pebbles and boulders of quartz rock and syenite up to eighteen inches in diameter.* Abundance of fossils have been found near the base of this series, comprising all the characteristic species of the May Hill sandstone or Pentamerus beds, and in other parts an assemblage of corals like those found in the Wenlock rocks. This great group of rocks in Galway must have a thickness of several thousand feet at least, but its details have yet to be worked out.

* In an excursion last summer with Mr. John Kelly I measured some of the smooth round boulders of syenite embedded in these Silurian rocks, and found them frequently a foot, and sometimes, though rarely, eighteen inches in diameter. Other almost equally massive conglomerates occur in the Silurian rocks of Lisbellaw, south of Enniskillen. In Galway, on the northern side of the beautiful promontory of Kilbride, on the shores of Lough Mask, a magnificent assemblage of fossils is to be seen in the rocks of the beach.

Somewhat similar rocks form a small range of high land at Ughool near Ballaghadereen in Mayo, from which a great series of Wenlock corals and other Upper Silurian fossils had been collected by Mr. Griffith, and also last year by Mr. Kelly and myself.

One feels inclined to speculate from these facts on the former existence of a range of mountains rising where the Irish Sea now flows, and composed of an axis of Cambrian and Lower Silurian rocks, with Upper Silurian on their flanks sloping down into the border country of England and Wales on the one side, and to the west coast of Ireland on the other.

Besides the Upper Silurian fossils already mentioned, the following are given in Morris' Catalogue as to be found only in that series, most of them being, I believe, Wenlock species:—

Plants: Chondrites **antiquus.**

Amorphozoa: Acanthospongia **Siluriensis**; Cliona **prisca**; Cnemidium **tenue**; Verticillites? **abnormis.**

Zoophyta: Alveolites **Bechei, fibrosa, Grayi, oculata**; Arachnophyllum **typus**; Aulacophyllum **mitratum**; Aulopora **consimilis, irregularis, serpens**; Chætetes **Bowerbankii, Fletcheri, pulchellus**; Cladocora **sulcata, vortex**; Cænites **intertextus, juniperinus,** etc.; Cyathoxonia **Siluriensis**; Cyathophyllum **angustum, articulatum, Loveni, recurvum, truncatum**; Cystiphyllum **cylindricum, Siluriense,** etc.; Favosites **aspera, cristata, multipora**; Fistulipora **decipiens**; Goniophyllum **Fletcheri, pyramidale**; Heliolites **Grayi, Murchisoni, scita, tubulata**; Nebulipora **papillata**; Omphyma **turbinatum**; Palæocyclus **porpita, præacutus, etc.**; Strephodes **plicatus, etc.**; Stromatopora **nummulitisimilis, striatella**; Strombodes **Bechei, Wenlockensis**; Syringopora **bifurcata, filiformis, etc.**; Thecia **expatiata, Grayana**; Zaphrentis **lata, turbinata.**

Polyzoa: Ceriopora **abnormis, affinis, etc.**, Diastopora **irregularis**; Discopora **antiqua, favosa, squamata**; Escharina **angularis**; Fenestella **Lonsdalei, Milleri, reticulata, subantiqua, etc.**; Glauconome **disticha**; Heteropora? **crassa**; Ptilodictya **scalpellum.**

Brachiopoda: Athyris **Circe, compressa, didyma, navicula, obovata**; Atrypa **cuneata, Lewisii, orbicularis**; Chonetes **striatella**; Crania **cranioIaris, Sedgwickii**; Cyrtia **exporrecta**; Orbicula (Discina) **Forbesii, Morrisi, perrugata, rugata, striata, Verneuillii**; Leptæna **Duvalii, Fletcheri, minima, etc.**; Lingula **crumena, parallela, quadrata**; Obolus **Davidsoni, transversus**; Orthis **æquivalvis, Bouchardii, Davidsoni, Lewisii**; Porambonites? **Capewelli**; Rhynconella **Davidsoni,** pentagona, rotunda, etc.; Siphonotreta anglica; Spirifer crispus, elevatus, Pisum, plicatellus; Strophomena compressa, filosa.

Conchifera: Mon—Ambonychia acuticosta; Avicula ampliata, antiqua, retroflexa, etc.; Pterinea lineata, orbicularis, planulata, rectangularis, etc.; Anodontopsis angustifrons, lævis, etc. *Dim*—Arca primitiva, subæqualis, etc.; Clidophorus antiquus, coarctatus, planulatus, etc.; Conocardium æquicostatum, pristis; Dolabra? elliptica, obtusa; Grammysia cingulata, etc.; Leptodomus globulosus; Lyrodesma cuneata; Modiola antiqua; Modiolopsis Wilsoni, solenoides, etc.; Mytilus Chemungensis, mytilimeris, etc.; Nucula anglica, levata, etc.; Sanguinolites amygdalinus, compressus, inornatus, etc.; Tellina? affinis. Cypricardia solenoides, Psammobia? rigida.

Gasteropoda: Capulus euomphaloides; Euomphalus alatus, carinatus, sculptus; Helminthochiton Griffithii; Holopella cancellata, gregaria, etc.; Loxonema elegans, sinuosa; Murchisonia articulata, torquata, etc.; Pleurotomaria balteata, etc.; Trochus? multitorquatus; Turbo? cirrhosus.

Pteropoda: Bellerophon carinatus, Murchisoni, obtectus; Conularia subtilis; Ecculiomphalus lævis.

Cephalopoda: Actinoceras Brightei, nummularium; Cyrtoceras approximatum; Lituites articulatus, giganteus, Ibex, tortuosus; Orthoceras articulatum, baculiforme, circulare, fimbriatum, vertebrale, etc.; Phragmoceras arcuatum, compressum, ventricosum, etc.

Echinodermata: Actinocrinus arthriticus, retiarius, simplex; Apiocystites pentrematoides; Cyathocrinus capillaris, goniodactylus, pyriformis; Eucalyptocrinus granulatus, polydactylus; Ichthyocrinus pyriformis; Lepidaster Grayi; Periechocrinus articulosus; Protaster Sedgwickii; Prunocystites Fletcheri; Pseudocrinites bifasciatus, oblongus; Sagenocrinus expansus, giganteus; Taxocrinus, tuberculatus; Tetramerocrinus formosus; Uraster hirudo, primævus, Ruthveni.

Annelida: Cornulites serpularius; Serpulites curtus, pervertus; Spirorbis Lewisii; Tentaculites tenuis; Trachyderma coriaceum, squamosum.

Crustacea: Acidaspis Barrandii, coronatus, crenatus, Dama, dumetosus, quinquespinosus; Ampyx parvulus; Bronteus laticauda; Calymene tuberculosa; Ceratiocaris ellipticus, inornatus, solenoides; Deiphon Forbesii; Encrinurus variolaris; Eurypterus cephalaspis; Leptocheles leptodactylus, Murchisoni; Lichas Barrandi, Grayii, hirsutus, nodulosus, Salteri, verrucosus; Proctus latifrons, Ryckholti, Stokesii.

Fish: Sphagodus?

Besides the above, the following species also are found in Upper Silurian rocks, which survived into the next, or Devonian period:

Polyzoa: Ceriopora granulosa.

Brachiopoda: Atrypa aspera, reticularis.

Conchifera: Clidophorus ovatus.

Cephalopoda: Orthoceras dimidiatum, imbricatum.

While one species found in Upper Silurian survived into the Carboniferous period, viz., the

Cephalopod: Bellerophon trilobatus.

Bohemia.—The rocks deposited during the Upper Silurian period in what is now Bohemia, are divided by M. Barrande into—Stage E, Calcaire inferieur. Stage F, Calcaire moyen. Stage G, Calcaire superieur. Stage H, Schists culminans.

Scandinavia.—M. Angelin similarly divides the Upper Silurian rocks of this district into his Regio D. E. Harparum, shales and white limestones, and Regio E Cryptonomorum, limestones resting on sandstones and shales.

Of these, Stage E of Barrande and Regio E of M. Angelin certainly equal very nearly the Wenlock rocks of Sir R. Murchison, there being 18 species of Brachiopods, besides corals and other fossils common to this group of rocks in the three countries. Sir R. I. Murchison gave, in 1847, a list of 74 species found in the rock of Gothland (Regio E), 47 of which occur in Britain, 13 in Ludlow rocks, and 14 in the Wenlock, the 20 others being found in both. The Regio D, E, of M. Angelin is not represented in Bohemia. It may possibly be equal to May Hill sandstone. The stages F, G, H, of Barrande are not recognisable in Scandinavia. There are 167 species of trilobites in the Upper Silurians of Bohemia, and 99 in those of Scandinavia, with only *one* species, the Calymene Blumenbachii, common to the two countries. The total thickness of the Upper and Lower Silurian and Cambrian rocks of Bohemia is between 30,000 and 40,000 feet; that of the same rocks in Scandinavia is not more than 1000 or 1200 feet; of the total number of fossil species found in the two countries (which is from 2000 to 2500), not more than one per cent are common to the two countries, except in the Brachiopods, in which the number may perhaps rise to five per cent.—(See M. Barrande's very interesting *Parallèle entre les depôts Siluriens de Boheme et de Scandinavie*, Prague, 1856). M. Angelin says that in Scandinavia there is not one species common to any two of his seven Regiones; but this may perhaps arise from his over minute distinctions in the species of Mollusca, etc. M. Barrande has, however, only a few species common to any two of his six stages. While in

Britain there are said to be more than 90 according to Sir R. Murchison in Siluria, but only 5 according to Professor Sedgwick in the north of England, common to Upper and Lower Silurian rocks, several of these ranging through nearly all the groups. If, on the other hand, we look at the number of *genera* of trilobites in Scandinavia and Bohemia, we find 39 in Bohemia and 45 in Scandinavia, of which 30 are common to the two countries, those 30 being the most important and well-established genera, containing the greatest number of species and individuals.*

North America.—The rocks of this region of the age of the Upper Silurian period, are

Group	Beds	Feet.
HELDERBERG GROUP.	10. Upper Pentamerus limestone 9. Encrinal limestone 8. Delthyris shaly limestone 7. Pentamerus limestone 6. Tentaculite limestone	300
ONONDAGA AND NIAGARA GROUP.	5. Onondaga salt group, a grey ash-coloured shale, with gypsum and rock-salt 4. Niagara limestone, compact grey limestone, resting on blue calcareous shale	1000
CLINTON GROUP.	3. Clinton group. *c.* Variegated red marls and calcareous shales *b.* Shales and argillaceous limestone and calcareous sandstone *a.* Greenish and yellowish slates with ferruginous sandstone	2400
MEDINA GROUP.	2. Medina sandstone. *b.* White fine-grained sandstone, alternating with red and greenish shale at top	450
	a. Soft brown argillaceous sandstone, and red shale	600
	1. Grey sandstone with thick beds of siliceous conglomerate, containing fragments of the lower rocks	400

According to Professor Rogers (Johnston's Physical Atlas, 2d Edition), not only does the Medina group contain a conglomerate made of pebbles of the lower rocks, but it and the

* I have perhaps dwelt at a little greater length on these facts relating to the Silurian period than the relative importance of the rocks of that period might warrant, because they bring before the reader's notice principles which are equally applicable to the rocks of all other periods.

whole Upper Silurian rocks are distinctly unconformable to the Lower, as they are in Wales and other parts of the world.

Characteristic Fossils.—The Clinton group contains Pentamerus oblongus and lævis; and together with the Medina group is probably = May Hill sandstone. The Niagara limestone contains Calymene Blumenbachii; Homalonotus delphinocephalus; Rhynconella Wilsoni and cuneata; Orthis elegantula; Pentamerus galeatus; Orthoceras annulatum; Favosites gothlandica, etc; and is therefore = Wenlock series.—(*Lyell's Manual.*)

It does not appear that there is any exact equivalent of the Ludlow rocks.

Extinction of Life at the Close of this Period.—The following generic forms now became extinct, in addition to those marked with an asterisk at its commencement. It is obvious that these are the genera common to Upper and Lower Silurian rocks:—

Corals: Halysites, Nebulipora.
Polyzoa: Graptolites, Ptilodictya.
Brachiopoda: Porambonites.
Conchifera: Ambonychia, Lyrodesma, Modiolopsis.
Pteropoda: Theca, Ecculiomphalus.
Cephalopoda: Lituites, Phragmoceras.
Annelida: Tentaculites, Trachyderma.
Crustacea: Acidaspis, Ampyx, Beyrichia, Calymena, Cyphaspis, Encrinurus, Homalonotus, Illænus, Lichas, Phacops.

DEVONIAN PERIOD.

Life of the Period.—Plants are known in some of the rocks deposited during this period; but they have not yet been fully described, though several of them are figured in Miller's Testimony of the Rocks.

Among the animals, fish become locally very abundant in the rocks of this period.

The following generic forms first made their appearance, so far as is known, during this period; those marked with an asterisk did not survive it:—

Plants:[1] Calamites, Lepidodendron, Stigmaria, Knorria.
Corals: Amplexus, *Chonophyllum, *Emmonsia, *Endophyllum, * Hallia, * Metriophyllum, * Pachyphyllum, * Pleurodictyum, * Smithia, * Spongiophyllum.

[1] If we take what is commonly called the Upper Old Red Sandstone (or Upper Devonian) out of the Devonian period, and place it in the Carboniferous, the Devonian date of these plants would become very problematical.

Polyzoa: Hemitrypa, Ptylopora.

Brachiopoda: * Calceola, * Davidsonia, * Stringocephalus, ? Strophalosia, Terebratula, * Uncites, Producta.

Conchifera: Aviculopecten, Anodonta, ? Axinus, Corbula, Cucullæa, Megalodon, ? Pullastra, ? Sanguinolaria, Posidonomya.

Gasteropoda: Vermetus.

Pteropoda: Porcellia.

Cephalopoda: * Clymenia,[1] Goniatites, Nautilus.

Echinodermata: * Adelocrinus, Cupressocrinus, * Hexacrinus, Pentremites.

Crustacea: Phillipsia, Trimerocephalus.

Fish: Acanthodes, * Actinolepis, Asterolepis, * Bothriolepis, * Byssacanthus, * Cephalaspis, * Cheiracanthus, * Cheirolepis, * Climatius, * Coccosteus, * Conchodus, Ctenacanthus, Ctenoptychius, * Dendrodus, * Diplocanthus, Diplopterus, * Dipterus, * Glyptolepis, * Glyptopomus, Gyroptychius, Holoptychius,[1] * Homothorax, * Lamnodus, * Osteolepis, * Pamphractus, * Parexus, * Phyllolepis, * Placothorax, * Platygnathus, * Pterichthys, * Ptychacanthus, * Stagonolepis, * Tripterus.

Reptiles: * Telerpeton.[1]

TYPICAL GROUPS OF ROCK.—There has long hung much obscurity over the classification of the rocks which belong to this period. This has chiefly been owing to the fact that we have in the British Islands two distinct types of rock which never come into close contiguity with each other, and do not contain any fossils in common, but are yet undoubtedly intermediate in age between the Silurian and Carboniferous periods. One of these types has long been known to British geologists as the Old Red Sandstone; the other, confined to Devon and Cornwall, was not classed with the former till Mr. Lonsdale, and Professor Sedgwick, and Sir R. I. Murchison worked it out. The Old Red Sandstone type is not known on the Continent; but the rocks and fossils of Devon reappear in the Eifel and other parts of the Continent.[2] The Old Red Sandstone was

[1] If we put the Upper Old Red Sandstone into the Carboniferous rocks, these and some other genera no longer date from the Devonian, but from the next period.

[2] Mr. Godwin Austen believes that the Devonian rocks of Devon, and the Eifel, etc., are in reality contemporaneous with the Upper Silurian rocks, the two having been deposited simultaneously in two distinct sea basins, one open to the north (Upper Silurian), the other (Devonian) open to the south. He thinks the Old Red Sandstone was the freshwater deposit of a subsequent part of the same great period.

formerly placed as the lowest rock of the Carboniferous series by some authors (Professor Phillips and others), while a part of what was formerly called Old Red Sandstone by others (Tilestone) is now placed as the upper part of the Silurian series. Recent researches by the Geological Survey in Kerry and Cork induce me to believe that what has hitherto been called Old Red Sandstone, and treated as one great group, must in reality be separated into two—the upper part, or Old Red Sandstone proper, being really the base of the Carboniferous; while the larger portion must be separated from the rest under another designation, and looked upon as more closely allied to the Silurian system. In the Dingle promontory, there are good representatives of Wenlock and Ludlow rocks, the latter containing abundance of Pentamerus *Knightii* and other Ludlow fossils, surmounted quite conformably by two great groups of purple and green gritstones and conglomerates, while over all these, widely and utterly unconformably to them and to the Silurian rocks, there sweep red sandstones and conglomerates three or four thousand feet thick, which pass up conformably into the base of the Carboniferous series. This upper group of red sandstones and conglomerates also contains fossils (plants in Ireland, plants and fish in Scotland) that place it in more close connection with the Carboniferous than with any other formation. This separation of the Old Red Sandstone into two widely separated portions is analogous to that of the New Red Sandstone introduced by Sir R. I. Murchison, who showed that what was once looked on as one group was in reality two, so distinct as to belong to different epochs, one Primary, the other Secondary.

I shall also separate from the rocks of this period those which are called Upper Devonian in Devonshire (the Marwood, Pilton, and Petherwin beds), and treat them as belonging to the Carboniferous period.

There remains some little doubt, perhaps, whether the middle and lower Devonian groups of Devonshire be strictly contemporaneous with the so-called Middle and Lower Old Red Sandstone. The latter contain fish and a few plants only, while the former have neither fish nor plants in them, in the British islands at all events. I shall therefore describe them separately as belonging to this period, but without attempting to draw them more closely together. In Russia, indeed, the fish of the one are found with the fossils of the other, as shown by Sir R. I. Murchison; but questions of geographical distribution arise to complicate any deductions as to exact synchronism in two such distant localities as Russia and Britain.

Devon and Cornwall.—A great series of slates, sandstones and conglomerates, and limestones, of various textures and colours, brown, blue, and red. According to Professor Sedgwick, they may be classed as follows:—

3. DARTMOUTH SLATE GROUP: Coarse roofing slates and quartzites, ending upwards with beds of red, green, and variegated sandstone.

2. PLYMOUTH GROUP:
   - *c.* Coarse red sandstone and flagstone.
   - *b.* Calcareous slates.
   - *a.* Great Devon limestone.

1. LISKEARD OR ASHBURTON GROUP.

Characteristic Fossils.—The following list contains nearly all the species mentioned in Morris' Catalogue as Devonian, omitting those called "Upper Devonian," from Marwood, Pilton, Petherwin, etc.:

Zoophyta: Acervularia **Goldfussi, pentagona, Roemeri, etc.**; Alveolites **suborbicularis, etc.**; Arachnophyllum **Hennahi**; Campophyllum **flexuosum**; Chonophyllum **perfoliatum**; Cyathophyllum **Boloniense, cæspitosum, Marmini, etc**; Cystiphyllum **Damnoniense, vesiculosum**; Endophyllum **abditum, etc.**; Favosites **polymorpha, reticulata**; Gorgonia **ripistria**; Hallia **Pengellyi**; Heliolites **porosa**; Pachyphyllum **Devoniense**; Petraia **celtica**; Pleurodictyum **problematicum**; Sarcinula **Cantabrica**; Smithia **Bowerbanki**; Spongiophyllum **Sedgwicki**; Strephodes **helianthoides, vermicularis**; Stromatopora **concentrica, polymorpha, placenta.**

Polyzoa: Fenestella **antiqua, arithritica**; Hemitrypa **oculata**; Retepora **repisteria.**

Brachiopoda: Athyris **hirundo, juvenis, lacryma, phalæna, plebeia**; Atrypa **desquamata**; Calceola **sandalina**; Chonetes **sarcinulata**; Cyrtia **heteroclita**; Leptæna **interstrialis**; Strophomena **gigas? nobilis? nodulosa, umbraculum**; Orthis **arcuata, calcar, granulosa, hians, lens, longisulcata**; Pentamerus **brevirostris, globus, optatus**; Producta **convoluta, interrupta**; Retzia **ferita**; Rhynconella **amblygona, angularis, anisodonta, bifera, compta, crenulata, cuboides, laticosta, proboscidalis, protracta, sphærica, subdentata**; Spirifer **aper-**

turatus, concentricus, costatus, grandævus, heteroclitus, lævicostus, megalobus, mesomalus, microgemma, nudus, obliteratus, pulchellus, rudis, simplex, speciosus; Stringocephalus brevirostrum, Burtini, giganteus; Strophalosia fragaria; Terebratula virgo; Uncites porrectus.

Conchifera: Mon—Avicula anisota, cancellata, reticulata, rudis, texturata; Aviculopecten rugosus; Pterinea radiata; *Dim;* Corbula Hennahi; Cypricardia Phillipsii; Megalodon carinatus, cucullatus; Nucula Krachtæ, lineata, plicata; Pullastra? antiqua.

Gasteropoda: Euomphalus annulatus, circularis, radiatus; Loxonema lincta, præterita, reticulata; Macrocheilus brevis, elongatus, harpula, ventricosus; Murchisonia bigranulosa, geminata, tricincta; Murex harpula; Natica meridionalis; Pleurotomaria cirriformis, gracilis, impendens; Trochus Boueii; Turbo cirriformis, subangulatus; Vermetus antitorquatus, texatus.

Pteropoda: Bellerophon bisulcatus, striatus.

Cephalopoda: Cyrtoceras armatum fimbriatum, nodosum, ornatum, rusticum, and eight others; Goniatites globosus, inconstans, spiralis, transitorius; Nautilus germanus; Orthoceras cylindraceum, cylindricum, ellipsoideum, tubicinella.

Echinodermata: Cyathocrinus megastylus, nodulosus; Echinosphærites (Sphæronites) tessellatus; Hexacrinus depressus, interscapularis, macrotatus.

Crustacea: Bronteus flabellifer; Cheirurus articulatus; Harpes macrocephalus; Phacops laciniatus, latifrons, punctatus; Trimerocephalus lævis.

The following are the few fossils which are said in Morris' Catalogue to be common to the true Devonian and the so-called Upper Devonian (which are in reality Lower Carboniferous) rocks:—

Brachiopoda: Athyris concentrica; Chonetes plicata; Spirifer disjunctus.

Conchifera: Cucullæa Hardingii.

Gasteropoda: Loxonema nexilis.

In addition to these, the following fossils are said to be found in the Devonian beds of Devonshire, and the Carboniferous limestone of other parts of the British Islands. This list may be compared with that previously given at pp. 412 and 424, of fossils common to Silurian and Devonian rocks:—

Polyzoa: Fenestella prisca; Ptylopora flustriformis.

Brachiopoda: Strophomena arachnoidea, crenistria; Orthis resupinata; Rhynconella acuminata, Mantiæ, mesogona, pugnus, rhomboidea; Spirifer distans, glaber, pinguis; Terebratula hastata, sacculus.

Conchifera: Mon—Aviculopecten plicatus; ? Posidonomya Becheri. *Dim*—Conocardium aliforme, minax.

Gasteropoda: Loxonema **rugifera, tumida**; Macrocheilus **imbricatus**; Murchisonia **angulata, spinosa, tæniata**; Pleurotomaria **monilifera.**
Pteropoda: Porcellia **Woodwardii.**
Cephalopoda: Goniatites **crenistria, excavatus, mixolobus, serpentinus, spirorbis.**
Echinodermata: Actinocrinus **triacontadactylus**; Cyathocrinus **geometricus, pinnatus.**
Crustacea: Phillipsia **Brongniartii.**

Belgium and the Rhine.—A series of rocks of a similar type, and with similar fossils to those just mentioned, are found in this district. They are divided by M. Dumont into

3. EIFEL GROUP.	*c.* Eifel limestone. *b.* Grey shales, occasionally calcareous. *a.* Red sandstone and conglomerate.
2. AHRIAN GROUP.	Bluish grey grits, sandstones, and shales.
1. COBLENTZ GROUP.	Green and grey grits, sandstones, and shales.

Sir R. I. Murchison, in his Siluria, gives a slightly different classification into Lower, Middle, and Upper Devonian; the Upper containing some beds above the Eifel limestone, as follows:—

3. UPPER.	*b.* Clymenia and Cypridina schists. *a.* Goniatites retrorsus schists.
2. MIDDLE.	*b.* Eifel or Stringocephalus limestone. *a.* Calceola schists = Ahrian group.
1. LOWER.	*b.* Wissenbach slates. *a.* Coblentz or Spirifer sandstone.

The upper division, however, is clearly the same as that which I have thought it best to transfer to the Carboniferous period.

Characteristic Fossils of the two lower groups according to Murchison:—

Lower Group.

Zoophyta: Pleurodictyum **problematicum.**
Brachiopoda: Spirifer **macropterus and speciosus**; Terebratula **Archaici,** Orthis **circularis**; Leptæna **plicata**; Chonetes **semiradiatus.**
Trilobites: Phacops **laciniatus and latifrons**; Homalonotus **Ahrendi and armatus.**

Middle Group.

Zoophyta: Cyathophyllum **cespitosum**; Favosites **polymorpha**; Heliolitis **pyriformis.**
Brachiopoda: Calceola **sandalina**; Stringocephalus **Burtini**; Uncites

gryphus; Davidsonia Verneuillii; Spirifer cultrijugatus, speciosus, heteroclytus, undiferus, lævicostus.

Conchifera: Megalodon cucullatus; Lucina proavia.

Gasteropoda: Murchisonia bilineata.

Trilobites: Phacops latifrons; Pleuracanthus punctatus.

Fish: Fragments of Coccosteus.

Rocks and fossils like those of Devon and Cornwall not being known in any other part of the British Islands, we must speak of those now to be described as Devonian with a certain reserve as to the exact propriety of the name. They have hitherto all been described as Old Red Sandstone, which has been taken as synonymous with Devonian.

Scotland.—The labours of the late lamented Hugh Miller on the so-called Old Red Sandstone of Scotland have made that district classic ground.

According to his classification, as given by Professor Sedgwick in his Synopsis, the series of rocks are the following:—

UPPER.	7. Yellow siliceous sandstone.
	6. Impure concretionary limestone.
	5. Red sandstone and conglomerate.
MIDDLE.	4. Grey sandstone and earthy slate.
LOWER.	3. Red and variegated sandstone.
	2. Bituminous schists.
	1. Great conglomerate and red sandstone.

The upper division I should now relegate to the base of the Carboniferous series; and Miller, in his Testimony of the Rocks, throws some doubt on the superposition of No. 4 above 3 and 2. It appears that they nowhere come actually into contact, and that it is possible that No. 4 may be a fresh-water deposit, more or less contemporaneous with the marine beds 3 and 2. The balance of evidence, however, both in Miller's opinion and that of Professor Sedgwick, recently confirmed to myself, is in favour of the order given above.

Characteristic Fossils.—There are in No. 2 a great abundance of plants, mostly Fucoids, or sea-weeds, and in beds in the Orkneys, believed to be nearly contemporaneous with these, many land plants, Ferns, and Lycopodiaceæ, together with Calamites and true Coniferous wood.—(*T. of R.* p. 433.) The following fish also have been found in these beds, or beds believed to belong to the Lower group of the above classification:—

Fish: Asterolepis Asmusii, minor; Cheiracanthus grandispinus, microlepidotus, minor, Murchisoni, pulverulentus; Cheirolepis Cummingæ, curtus, macrocephalus, Trailli, magus, velox; Coccosteus cuspidatus, decipiens, maximus, microspondylus, oblongus, pusillus, trigonopsis; Dendrodus incurvus, latus, sigmoideus, strigatus; Diplacanthus crassispinus, gibbus, longispinus, perarmatus, striatulus, striatus; Diplopterus affinis, Agassizii, macrocephalus; Dipterus macrolepidotus; Glyptolepis elegans, leptopterus, microlepidotus; Glyptopomus minor; Gyroptychius angustus, diplopteroides; Holoptychius Andersoni, Sedgwickii; Homothorax Flemingii; Osteolepis arenatus, brevis, macrolepidotus, major, microlepidotus; Pamphractus Andersoni; Platygnathus Jamesoni, paucidens; Pterichthys cancriformis, cornutus, hydrophilus, latus, major, Milleri, oblongus, productus, quadratus, testudinarus; Tripterus Pollexfeni.

The fossils of No. 4 of the preceding table are—

Plants: Parka decipiens; and some others.
Fish: Cephalaspis Lyelli, etc.; Climatius reticulatus; Parexus incurvus.

Herefordshire and South Wales.—The so-called Old Red Sandstone of this large district is composed of the following groups:—

		Feet.
2.	Red and yellow sandstone marls and conglomerate	3000 or 4000
1.	Cornstone group	5000 or 6000

Of these, I believe that No. 1 only properly belongs to the Devonian period, and shall describe No. 2 in the Lower Carboniferous period.

1. The Cornstone group consists of a great series of blood-red shales and marls at bottom, graduating down into the dull red and blue shales and micaceous flags of the Tilestone group, and alternating upwards with red, green, and grey sandstones and flagstones, and with frequent partial bands of impure concretionary limestone, locally known as "cornstone."

Characteristic Fossils.

Crustacea: Eurypterus species.
Fish: Cephalaspis Lewisi, Lloydi, rostratus; Byssacanthus arcuatus; Ctenacanthus ornatus; Ptycacanthus dubius.

Ireland: Kerry and Cork.—In the Dingle promontory we have the following groups lying conformably on the Ludlow rocks:—

		Feet.
3.	Dingle beds	4000
2.	Glengariff grits	6000
1.	Red slates and sandstones . .	1000

1. The red slates and sandstones lying conformably over the rocks containing Pentamerus Knightii and other Ludlow fossils, may possibly be the representatives of the Tilestone group, but as it contains no fossils in Kerry, we cannot determine this satisfactorily.

2. The Glengariff grits consist of very thick bedded massive green or purple sandstones or gritstones, of a very peculiar lithological aspect, interstratified with beds of red or green slate. Sometimes the sandstones, sometimes the slates, are calcareous, forming concretionary beds very like the South Welsh cornstones. Steady sections of 5000 or 6000 feet may not unfrequently be seen in these rocks in the promontories of Dingle, Iveragh (between Killarney and Valentia), and those lying between the bays of Kenmare, Bantry, Dunmanus, and Roaring Water.

Not a trace of a fossil has yet rewarded the researches of the collectors of the Geological Survey.

3. Dingle beds. These consist of red sandstones and slates, with beds of conglomerate, which in the Dingle promontory are thick and prominent, containing angular and subangular fragments of red jasper, hornstone, felstone, and other rocks, together with pebbles of Silurian limestone or calcareous sandstone containing Pentamerus oblongus, and other fossils of the May Hill sandstone group.

No fossils proper to the group itself have yet been discovered in it.

Over the upturned and denuded edges of all these beds, as well as those of the Silurian beds below, sweep the thick beds of red sandstone and conglomerate which form the Old Red Sandstone. This is the case throughout the Dingle promontory; but in that of Iveragh, on the south side of Dingle Bay, and over all the rest of the country, this unconformity is no longer perceptible, and the conglomerates also rapidly die out to the south, so that we get only the Glengariff grits covered by red and purple slates and sandstones, with no very obvious boundary between them and the Dingle beds, nor between the latter and the Old Red Sandstone.

North America, (from Prof. H. D. Rogers [illegible])

		Feet.
9.	Catskill group, red shales and red and grey sandstones, with a few white quartz pebbles	5000
8.	Chemung group, grey, blue, and olive-coloured shales, and grey and brown sandstones	3200
7.	Portage group, fine-grained grey flagstone, with blue shale partings	1700
6.	Genessee slate, brownish black and bluish grey slate	300
5.	Hamilton group, bluish grey, brownish and olive shale, with thin dark grey sandstones	600
4.	Marcellus shales, black and bituminous, with thin argillaceous limestone at base	300
3.	Upper Helderburg or Corniferous limestone, straw-coloured, light grey or bluish, with chert nodules	350
2.	Caudagalli grit, argillaceous calcareous thin bedded sandstone	300
1.	Oriskāny sandstone, coarse yellowish calcareous sandstone	200

The Oriskāny sandstone is considered by its fossils to be undoubtedly contemporaneous with the Lower Devonian group of the Rhine. The others represent the superior parts of that formation, and it is possible that some of them are rather Lower Carboniferous than Devonian.

Formations possibly belonging to the Devonian period are largely developed in Australia; and characteristic fossils have been brought from China, where they are used as medicines.

The Cape of Good Hope, too, has large formations, believed to belong to the Devonian period, of which we may shortly hope to hear more from the labours of my former colleague Mr. Andrew Wyley.

Genera becoming Extinct at the Close of this Period.

Besides those marked with an asterisk at the commencement of this period, the following generic forms, derived from earlier periods, appear to have become extinct at its close:—

Corals: Acervularia, Arachnophyllum, Cystiphyllum, Heliolites,[1] ~~Petraia~~, Stromatopora.

Brachiopoda: Atrypa.

[1] With the exception of one so called in the Middle Eocene.

Conchifera: Clidophorus.

Echinodermata: Echinosphærites.

Crustacea: Bronteus, Cheirurus, Harpes, Homalonotus, Phacops, Pterygotus.

CARBONIFEROUS PERIOD.

Preliminary Observations.—In the account of the deposits of the preceding period it will be seen that I have ventured to detach from it the rocks called Upper Old Red in Scotland, and Upper Devonian in Devonshire, and by parity of reasoning, the Upper or Old Red Sandstone proper of the south of Ireland and of South Wales, and to consider the rocks so detached as forming the base of the Carboniferous system of rocks. This conclusion has been forced upon me rather unwillingly, and against my previous belief, by the examination of the structure of the south of Ireland. It has always been the opinion of the Irish geologists, especially of Mr. Griffith and Mr. John Kelly, of whom the latter has published this opinion in a paper in the "Journal of the Geological Society of Dublin." The correctness of their view on this point, however, was obscured by the endeavour to identify all below the Old Red Sandstone proper with Silurian rocks, and altogether to obliterate the Devonian period. Admitting the existence of a Devonian period as intermediate between the Silurian and Carboniferous, and placing in it the rocks and fossils just described as belonging to it, we may retain the Old Red Sandstone proper (that which stretches round the Carboniferous rocks of the south-east of Ireland and those of South Wales, and the Border counties, and the thin skirts and patches of Old Red in North Wales and North England, and the upper part of that of Scotland), as forming the true commencement of the Carboniferous period. There is in many places a perfect blending of the Old Red into the Lower Carboniferous rocks, or into beds which contain fossils having always a generic and often a specific identity with undoubted Carboniferous forms. Still there are a sufficient number of peculiar species, both of plants and shells in these lower rocks, to warrant the separation of the Carboniferous system of the British islands into an upper and a lower series, the general terms of which may be stated as follows :—

UPPER.	4. Coal Measures. 3. Carboniferous limestone.
LOWER.	2. Carboniferous slate, or Lower Limestone shale, with Coombola grits and Yellow sandstones. 1. Old Red Sandstone, passing up into Yellow sandstone.

LIFE OF THE PERIOD.—The plants that lived during this period have been very abundantly preserved, no less than 294 species having been found in the British Islands alone, according to Morris' Catalogue. There are also abundance of corals, shells, and fish, and some Crustacea, though the great group of the Trilobites was now becoming very scarce in species, and the individuals of those species seem to have had but a local distribution. Reptiles occur on the Continent, though no remains of them have been found in the British Islands in the Upper Carboniferous rocks.

The following generic forms date their origin from this period, so far as is at present known, those confined to it being marked as before with an asterisk :—

Plants: * Adiantites, Alethopteris, * Anabathra, * Annularia, * Antholites, * Aphlebia, * Aspidaria, * Asterophyllites, Calamites, * Cardiocarpon, Carpolithes, * Caulopteris, * Crepidopteris, * Cyclocladia, Cyclopteris, * Cyperites, * Dadoxylon, Endogenites, Flabellaria, * Halonia, * Hippurites, * Hydatica, Hymenophyllites, *Knorria,[1] Lepidodendron, *Lepidophyllum, * Lepidostrobus,[2] * Lomatophloyos, Lycopodites, * Lyginodendron, * Megaphytum, * Musocarpum, * Myriophyllites, Neuropteris, * Næggerathia, * Odontopteris, Otoptaris, * Palmacites, Pecopteris, * Picea, Pinites, * Pinnularia, * Pitus, * Poacites, * Polyporites, * Pothocites, * Protopteris, * Rhabdocarpus, * Sagenaria, * Selaginites, * Sigillaria, Sphenophyllum, Sphenopteris, * Sternbergia, * Stigmaria, * Trigonocarpum, * Ulodendron, Walchia.

[1] It is probable that the beds containing Calamites and Knorria and Lepidodendron, on the Continent, as well as those of the British Islands, would not be Devonian according to the classification here adopted.

[2] If Lepidodendron really be found in true Devonian rocks (according to the classification here adopted), then these two other genera, founded only on parts of Lepidodendron, date also from the Devonian period. Dr. Hooker refers certain seeds or spores found in the Upper Silurian to Lepidostrobus, in which case it will date still farther back.

Corals: * Astræopora, * Cladochonus, * Columnaria, * Cyathopsis, * Dendropora, * Heterophyllia, * Lithodendron, * Lithostrotion, * Lonsdaleia, * Michelinia, * Mortieria, * Nematophyllum, * Petalaxis.

Polyzoa: * Sulcoretepora, Vincularia.

Brachiopoda: Camarophoria, * Hypodema.

Conchifera: Inoceramus (or a shell having a similar external form), ? Lima, Pecten, Pinna, * Pteronites, ? Anatina, ? Axinus, Cardinia, Cardiomorpha, Edmondia, Leda, Lithodomus, Lucina, ? Lutraria, Mactra, Myacites, Myalina, ? Pandora, Pleurophorus, * Sedgwickia, Solemya, ? Unio, ? Venus.

Gasteropoda: Buccinum, Cylindrites, Dentalium, Eulima, Lacuna, Littorina, ? Melania, * Metoptoma, Pattella, * Phanerotinus, * Platyschisma, ? Pupa, * Trochella.

Cephalopoda: * Poterioceras, * Trigonoceras.

Echinodermata: Archæocidaris, * Astrocrinus, * Atocrinus, * Codonaster, * Dichocrinus, * Euryocrinus, * Mespilocrinus, * Pentremites, * Perischodomus, * Platycrinus, * Sycocrinus, * Synbathocrinus.

Annelida: Sabella, Serpula, * Spiroglyphus, Spirorbis.

Crustacea: Bairdia, * Brachymetopus, * Cyclus, Cythere, Cypris, * Entomoconchus, * Griffithides, * Limulus, Macrura, * Phillipsia.

Insecta: Curculioides, Corydalis.

Fish: * Amblypterus, * Asteroptychius, * Carcharopsis, *Cheirodus, * Chomatodus, * Cladodus, * Cochliodus, Cœlacanthus, * Colonodus, * Cricacanthus, * Ctenodus, * Diplodus, * Dipriacanthus, * Erismacanthus, * Eurynotus, * Glossodes, Gyracanthus, Gyrolepis, * Helodus, * Homacanthus, * Lepracanthus, Leptacanthus, * Megalichthys, * Oracanthus, * Orodus, * Orthacanthus, Palæoniscus, * Petalodus, * Petrodus, * Physonemus, * Platycanthus, Platysomus, * Plectrolepis, * Pleuracanthus, * Pœcilodus, * Polyrhizodus, * Psammodus, * Psammosteus, Pygopterus, * Rhizodus, * Sphenacanthus, * Tristychius, * Uronemus.

Reptiles: * Archægosaurus.

LOWER CARBONIFEROUS PERIOD.

Typical Groups of Rock.—*Ireland.*—I have already said, that in the Dingle promontory there is a mass of 3000 or 4000 feet of red sandstone, and conglomerates, the true Old Red sandstone, utterly unconformable to the Devonian and Upper Silurian rocks below, but conformable to the Carboniferous rocks above. The junction, however, of the Old Red and Carboniferous is not very well seen there, but is admirably shown when the rocks are traced round to the neighbourhood of Glengariff at the head of Bantry Bay. In that district the Glengariff grits are the lowest rocks seen, having the characters before described, and being surmounted by a great series of purple, and red, and green sandstones and slates which must represent both the Dingle beds and the Old Red Sandstone, all lying apparently conformably, and without any marked boundary between them.

The upper part of this red series alternates with many green and grey coloured beds, and some liver-coloured slates, and in these, fragments of plants are found; a little higher the red colour disappears, and we have grits and slates of various shades of green, yellow, or grey, eventually interstratified with black shales or slates. These black beds rapidly increase in thickness as we ascend, still interstratified at first with numerous sets of beds of thick massive gritstone, but above these black shales or slates alone occur, eventually becoming calcareous, and containing thin beds of impure concretionary limestone.

The fossils of these calcareous bands, which are the highest beds seen in Bantry Bay, are all Carboniferous fossils such as are found in the Lower Limestone shale of South Wales and elsewhere. Carboniferous species (shells and encrinites) likewise occur below, in the shales interstratified with the grits, and also in the grits themselves, but there are here other fossils also, which are not found in the higher part of the series. Together with these fossils are some plants similar to, but not exactly identical with, the plants usually found in the Carboniferous series, and these plants extend down into the green and grey shales interstratified with the red beds, where, however, they are not accompanied by marine species. I would group these beds, then, as follows:—

		Feet.
CARBONIFEROUS SLATE.	5. Lower Limestone shale with calcareous bands, .	150
	4. Dark grey and black slates and shales, . .	2000
	3. Coomhola grit series, . .	2500
OLD RED SANDSTONE.	2. Yellow Sandstone series . .	1000
	1. Red sandstone and slate, . .	2000

1. The red or purple sandstone and slate contains a few

green or grey beds, but no fossils. It stretches continuously from the extreme west of Cork and Kerry into Waterford and Tipperary, where it reposes unconformably on the Lower Silurian rocks, having a conglomerate at its base, partly made of the fragments of the rocks it rests on, partly of well-rounded quartz pebbles. It still retains a thickness of 2000 or 3000 feet, till it dies away rapidly towards Wexford in one direction, and towards Carlow in the other, reappearing afterwards merely as little local patches here and there in the hollows of the lower rocks.

2. The Yellow Sandstone series can only be separated from No. 1 by the greater abundance of greenish, greyish, and yellowish beds among the red ones, and by the occurrence of remains of plants in the former. It is continuous with No. 1 over all the south of Ireland, and probably extends a little further than it, since the thinning out of the Old Red Sandstone seems to take place from below upwards, higher and higher beds extending further and further, showing gradual depression to have been taking place during the period.

3. The Coomhola grit series can, in Bantry Bay, only be separated from the Yellow Sandstone by the shales between the grits being dark grey or black, and the occurrence of some marine fossils in some few of the beds together with the plants.

4. The dark grey shales and slates of the Carboniferous slates are perfectly well marked by the absence of grit beds, but they contain few or no fossils in Bantry Bay.

5. The Lower Limestone shale cannot be separated from the shales and slates below, except by the occasional appearance of calcareous bands together with an abundance of some marine Carboniferous fossils.

The latter rocks, Nos. 3, 4, and 5, preserve the characters and the thickness here assigned to them over all the country from Bantry Bay to the Old Head of Kinsale and the mouth of Cork Harbour, the only variation being a diminution in the number and thickness of the grit-stones in the Coomhola grit series, and a corresponding increase in the dark grey slates above. They likewise preserve their character and thickness northwards as far as Sneem on the north side of Kenmare Bay. But when we proceed to the head of this bay about Kenmare itself, we find a remarkable change to have occurred. The Carboniferous limestone there makes its appearance in its ordinary form, having under it a thickness of about 50 feet of the beds just described as Lower Limestone shale, precisely similar to the shales with calcareous courses in Bantry Bay, and containing the same fossils. But at Kenmare these beds rest directly on red slates and sandstones, forming the upper part of the Old Red Sandstone, —the great mass of the Carboniferous slate series, with all the Coomhola grit group, that is so strongly developed 10 or 15 miles to the westward and southward, being entirely absent at Kenmare. Neither does this absence of a group of beds nearly 5000 feet thick produce any apparent unconformity, though as all the beds are at very high angles, and a good deal contorted, it is impossible to decide whether they were originally quite conformable or not. North and east of Kenmare over all the rest of the south of Ireland to Tralee, Ballybunnion, and Limerick on the north, and to Cork, Youghal, and Wexford on the east, this latter type prevails, the whole of the Carboniferous slate group being absent except the small portion of it called here the Lower Limestone shale.

"I believe, then, that all the beds mentioned above as lying below the Lower Limestone shale form in reality a Lower Carboniferous series, which is only locally developed in its true proportions, introducing when it is so developed a perfect apparent continuity and blending from the base of the true Old Red Sandstone, or perhaps in some places even from the Devonian rocks themselves up into the highest of the Carboniferous series:—

Characteristic Fossils.

No. 1 has no fossils.

No. 2. The Yellow Sandstone series contains, in different parts of the south of Ireland—

Plants: Knorria sp.; Lepidodendron sp.; Calamites sp.; Stigmaria sp.; Cyclopteris (or Sphenopteris) Hibernica; and some others of which the affinity is not exactly known.

Conchifera: Anodon Jukesii (near Cork, and at Knocktopher, County Kilkenny).

Crustacea: Fragments of Pterygotus?

Fish: Fragment of scale.

No. 3. The Coomhola grit series contains—

Brachiopoda: Lingula large new sp.

Conchifera: Avicula Damnoniensis; Cucullæa Hardingii, trapezium, etc.; Avicula new sp.; Aviculopecten new sp.; Axinus sp.; Nucula sp.; Curtonotus (*Salter, MS.*) several sp.

Gasteropoda: Several undescribed.

Pteropoda: Bellerophon one or two trilobed species.

Cephalopoda: Orthoceras one or two species.

Echinodermata: Actinocrinus sp.; Platycrinus sp.; Rhodocrinus sp.

Mingled with these occur the ordinary and characteristic Carboniferous species—Rhynconella pleurodon; Spirifer cuspidatus and disjunctus (Verneuillii); and others.

No. 4. The few fossils found in the great mass of the Carboniferous slates are mostly, if not all, Carboniferous species. Scales of a fish of the genus Cælacanthus occur.

No. 5. The fossils characteristic of this small group are—

Zoophyta: Michelinia, etc.

Polyzoa: Fenestella plebeia, etc.

Brachiopoda: Orthis filiaria; Strophomena crenistria; Athyris squamosa; Rhynconella pleurodon; Spirifer cuspidatus and disjunctus (Verneuillii).

Conchifera: Modiola Macadami.

Echinodermata: Stems of Actinocrinus, Platycrinus, Poteriocrinus, and Rhodocrinus.

All the above being common in the Carboniferous limestone.

Devon and Cornwall.—The Petherwin slates, the Pilton beds, the Marwood sandstones, and others belonging, as is believed, to the same period as the Carboniferous slate and Coomhola grits of Ireland.

Characteristic Fossils.

Polyzoa: Ceriopora gracilis.

Brachiopoda: Athyris hispida; Chonetes convoluta; Orthis interlineata, semicircularis; Spirifer protensus; Strophalosia caperata.

Conchifera: Mon—Avicula Damnoniensis, exarata, subradiata; Aviculopecten granulosus, nexilis, pectinoides; Pterinea spinosa. *Dim*—Cucullæa amygdalina, angusta, depressa, Hardingii, trapezium; Mytilus Damnoniensis; Nucula latissima; Pullastra? elliptica; Sanguinolaria? sulcata; Sanguinolites complanatus, liratus.

Gasteropoda: Euomphalus serpens; Loxonema sinuosa; Natica nexicosta.

Pteropoda: Bellerophon subglobatus.

Cephalopoda: Clymenia bisulcata, fasciata, lævigata, plurisepta, undulata, and six others; Goniatites biferus, linearis, vinctus; Nautilus megasipho; Orthoceras Phillipsii, striatulum, tentaculare.

Echinodermata: Adelocrinus hystrix; Cyathocrinus distans; Taxocrinus macrodactylus.

Crustacea: Phacops granulatus.

Besides these which seem to be peculiar to the Lower Carboniferous rocks, the following occur, which are found also in the higher parts of the Carboniferous system :—

Polyzoa: Fenestella plebeia; Glauconome bipinnata.

Brachiopoda: Athyris oblonga; Chonetes sordida; Strophomena analoga; Producta laxispina, prælonga, scabricula; Rhynconella pleurodon; Spirifer Bouchardi, calcaratus, lineatus, macronotus, Urii.

Conchifera: Aviculopecten granosus.

Pteropoda: Bellerophon Urii.

Cephalopoda: Orthoceras cinctum, undulatum.

Echinodermata: Cyathocrinus ellipticus; Pentremites ovalis.

South Wales.—The Old Red Sandstone surrounding the South Welsh coal-field has in some places, but not always, a base of conglomerate reposing on the Devonian cornstone group, over which are red sandstones and marls, which in their upper parts have yellow sandstones interstratified with them, containing fragments of plants, and appearing to graduate upwards into the black shales and sandstones of the Lower Limestone shale, which in its upper part is interstratified with beds of limestone, passing thus into the base of the Carboniferous limestone.

Characteristic Fossils.—The only fossils I know recorded from the Old Red Sandstone of this district are—

Plants: The fragments mentioned above.

Those of the Lower Limestone shale are exactly the same as those in the Lower Limestone shale of south Ireland.

Scotland.—In accordance with the classification here adopted, we must place in the Lower Carboniferous series the beds called Upper Old Red Sandstone of Scotland, which, if our present views be correct, should alone be called Old Red Sandstone; the so-called Middle and Lower Old Red Sandstone being provisionally termed Devonian.

They consist of red sandstones and conglomerates, having in their upper part yellow sandstones, in which plants and fish remains are found, and these are believed to be connected more or less with the base of the Upper Carboniferous rocks, through the group called Calciferous Sandstone by Mr. Maclaren, which is possibly of about the same age as the Coomhola grits of the south-west of Ireland.

Characteristic Fossils of the Yellow Sandstone of Scotland:—

Plants: Cyclopteris (Sphenopteris) Hibernica; Calamites; and others.

Mollusca and Annulosa not yet known.

Fish: * Acanthodes pusillus; * Actinolepis tuberculatus; Asterolepis Malcolmsoni; Bothriolepis favosus, ornatus; Conchodus Ostræformis; Cosmacanthus Malcolmsoni; Holoptychius giganteus, Murchisoni, nobilissimus, princeps; * Lamnodus biporcatus, Panderi, sulcatus; * Phyllolepis concentricus; * Placothorax paradoxus; * Stagonolepis Robertsoni.

Reptiles: * Telerpeton Elginense.

The Rhine.—If the views here given as to classification be correct, we must place as Lower Carboniferous the rocks called Upper Devonian in the Rhenish Provinces, which are subdivided by F. Roemer into

4. Schists with Rhynconella cuboides and Producta subaculeata.
3. Schists with many Clymeniæ, Goniatites and Cypridina.
2. Limestone with Goniatites auris, etc.
1. Schists with Receptaculites Neptuni.

No. 1 may possibly be a Devonian rock, as the undetermined fossil called Receptaculites Neptuni occurs in Ludlow rocks at Ludlow; but the other three groups are identified with the so-called Upper Devonian of Devon, especially by the presence of the little Cypridina serratostriata in great abundance.—(*Murchison*, *Siluria*, p. 372.)

Taking the Old Red Sandstone proper as the true base of the great Carboniferous system of Britain, and understanding that the great mass of the Carboniferous slate group above it is found only in the south-western corners of Ireland and England, dying out everywhere rapidly to the north and east, except a few of the upper beds, known as the Lower

* Not knowing the ground, I feel some doubt as to the position of the beds in which the fossils marked * are found.

Limestone shale, which seems also to die out towards the north and east in England, though they spread over all Ireland; and taking into account that the Old Red Sandstone proper appears to be entirely wanting in Devon and Cornwall, where the Carboniferous slate rests on true Devonian rocks, we have now to trace the range of the upper part of the Carboniferous system through the British Islands. In doing this we will again commence with the south-west portions of

Ireland: Kerry, Cork, and Waterford.

	Feet.
2. Coal Measures	+ 2000
1. Carboniferous limestone	1500
Old Red Sandstone	

No. 1. Over this district the Carboniferous limestone forms a nearly unbroken series of beds of grey limestone, sometimes compact, sometimes crystalline, generally in very highly inclined positions, and often so traversed by slaty cleavage as to have its stratification entirely obscured. It occurs only in the plains and bottoms of the valleys.

No. 2. Directly on the upper beds of the limestone occur black indurated shales, likewise traversed by slaty cleavage, but never making good roofing slate; higher up, these alternate with greenish or olive-coloured fine-grained grits and flags; and among these, or above them, occur two or three thin bands of coal, together with abundance of coal plants. The shales have often curiously concretionary globular forms, of one or two feet in diameter, appearing in them, piled one over the other, a single spheroid sometimes embracing parts of two or more beds. Except in weathering into these singular spheroidal forms, the shales do not appear different from those which are not concretionary. These Coal Measures are commonly highly inclined and contorted, and often inverted, and the coals are not only changed into anthracite, but squeezed and crushed so as to be only got in small dice-like fragments. The regularity of the beds is also interfered with, so that beds of which the original thickness was probably a couple of feet or so, have now for many yards only one or two inches, and then suddenly expand into large pockets of coal twenty or thirty feet in thickness. Coal-mining here is conducted like vein-mining.

Clare, Limerick, Tipperary, Kilkenny, etc.

	Feet.	Feet.
5. Coal Measures	+	2000
4. Upper Limestone	250 to	1000
3. Calp or Middle Limestone . . .	400 to	1000
2. Lower Limestone		1000
1. Lower Limestone shale . . .	50 to	150
Old Red Sandstone.		

No. 1 is everywhere the same as before described.

No. 2 is a series of thick grey limestones generally light coloured, sometimes crystalline, sometimes compact; large parts of it are magnesian, sometimes becoming a true dolomite. In some parts of the district, some of the beds become as oolitic as the Bath stone, still, however, retaining their grey colour. In some places, especially in Limerick, contemporaneous traps and trappean breccias are interstratified with these beds and with the upper or yellow part of the Old Red Sandstone below them.

No. 3. The Calp consists of black limestones, sometimes very earthy, interstratified with black shales, that become in some places more important than the limestones. The limestones of this group are usually unfit for burning into lime. Chert bands and nodules are very abundant in the Calp.

No. 4. Thick and thin bedded crystalline and compact limestones of various colours, but usually light coloured. Chert bands and nodules are also abundant occasionally.

No. 5. The Coal Measures are exactly the same as those previously described in Kerry and Cork, except that they are little contorted, lying generally horizontal or nearly so, and the coal beds retain their thickness apparently unaltered—this thickness, however, being rather inconstant between 6 inches and 2 or 3 feet. The fossils found in the lower part of these coal shales are marine (Goniatites, Bellerophon, and Pecten papyraceus). Coal plants, however, are abundant in the higher part near the beds of coal. It is possible that these Coal Measures may be of the same age as the Millstone grit of central and northern England.

North of Ireland.—As we trace the Carboniferous series from the central to the northern districts of Ireland, a still further change takes place always in the same direction, that is, always becoming more complicated and subdivided as we proceed from south to north. The typical rocks then become

7. Coal measures.
6. Millstone grit.
5. Upper Limestone.
4. Calp, { Upper Calp shale. / Calp sandstone. / Lower Calp shale. }
3. Lower Limestone.
2. Lower Limestone shale.
1. Yellow Sandstone and Old Red Sandstone.

1. The Yellow Sandstone of Dr. Griffith, as shown in the north of Ireland, is interstratified with dark shales and grey limestones, containing common Carboniferous fossils in great abundance. It has also red beds of shale interstratified with it, but may perhaps be a rather different group from the Yellow sandstones forming the top of the true Old Red Sandstone in the south of Ireland.

2. This group does not appear to differ in any respect from the Lower Limestone shale of the south of Ireland.

3. The Lower Limestone is also apparently just like that of the south.

4. The Calp becomes more purely an earthy deposit, and in its middle portion the shales are split up by a considerable group of sandstone beds, sometimes containing traces and thin seams of coal.

5. The Upper Limestone is probably the same as the Great Scaur Limestone of the North of England.

6 and 7. These also are similar to the corresponding beds in Derbyshire and Yorkshire, shortly to be described.

Let us now turn to England, and trace in like measure the Carboniferous series from south to north.

South Wales and the Border Counties.—The rocks of the Carboniferous period may here be grouped as follows :—

	Feet.
4. Coal Measures . .	7000 to 12,000
3. Millstone grit, or Farewell rock .	1,000
2. Carboniferous Limestone .	500 to 1,500
1. Lower Limestone shale . . .	500
Old Red Sandstone.	

1. The Lower Limestone shale consists of dark earthy shales, occasionally interstratified with yellowish sandstones below, and always with thin flaggy limestones in its upper part. It seems, therefore, to graduate downwards into the top of the Old Red Sandstone, as well as upwards into the Carboniferous limestone.

Characteristic Fossils.—Species of the genera Actinocrinus, Platycrinus, and Rhodocrinus; Spirifer disjunctus and cuspidatus; Rhynconella pleurodon; Strophomena crenistria; Chonetes Hardrensis. Teeth and scales of Psammodus and Palæoniscus.—(*Salter.*)

2. Carboniferous limestone. A great series of compact limestones, thick and thin bedded, of various shades of grey and red, sometimes, as near Bristol, interstratified with brown, grey, and red shales below, and with shales and sandstones (often red), in the upper portion.[1] Thickness 500 to 1500 feet.

3. Millstone grit or Farewell rock. A series of sandstones, hard, quartzose, white, or grey, and near Bristol red. Maximum thickness about 1000 feet.

4. Coal Measures. An enormous series of alternations of many hundred beds of shales, sandstones, and coals, the latter varying from one inch to seven or eight feet in thickness. The total thickness of the whole group is not less than 7000 feet, and is believed in some places to be even as much as 12,000 feet.[2]

[1] The section near Bristol is very peculiar. It is given in great detail, from the measurements of Mr. D. Williams, in the first volume of "Memoirs of the Geological Survey." If we take the first ten divisions of that section for millstone grit, and put the others into groups with Irish designations, it would be as follows:—

Nos.		Ft.	In.
1 to 10.	Millstone grit (partly red sandstone)	975	9
11 to 169.	Upper Limestone (the first 370 feet containing many red sandstones interstratified with the limestones)	576	0
170 to 296.	Calp (black and brown argillaceous limestones and shales)	477	0
297 to 374.	Lower Limestone	766	4
375 to 489.	Lower Limestone shale (Carboniferous slate)	411	0
490 to 540.	Yellow sandstone series	293	10
540 to 587.	Old Red Sandstone	474	7
		3974	6

[2] It was in the examination of the South Welsh coal-field, while on the geological survey of the United Kingdom, that Sir W. Logan was first

Near Bristol it is thinner, and is divisible into three sub-groups, having a central band of hard sandstones called Pennant.

		Feet.
c.	Upper Coal Measures . . .	1800
b.	Pennant series	1725
a.	Lower Coal Measures . . .	1565

This central band of sandstones is traceable also in South Wales, by means of a hard quartzose sandstone called Cock-shoot rock.

In the Forest of Dean coal-field, the thicknesses given above are diminished to about one-third, or

Coal Measures.	
Millstone grit . . .	270
Carboniferous limestone .	480
Lower Limestone shale .	165

—(*Mems. Geol. Survey*, vol. i. p. 129.)

Derbyshire, etc.—The base of the formation is not here seen, but we have the following groups :—

		Feet.
4.	Coal Measures, more than . .	2700
3.	Millstone grit	1600
2.	Upper Limestone shale . . .	400
1.	Carboniferous limestone, more than	600

1. The Carboniferous limestone is a series of pure pale-grey, thick-bedded limestones, with scarcely a trace of clay or shale interstratified with them, over large areas, and through a thickness of several hundred feet. On the south-west, however, towards Staffordshire, shales alternate with its upper portion. Over the centre and north of Derbyshire, two contemporaneous beds of greenstone, called toadstone, are interstratified with the limestones. The thickness of these toadstones is sometimes as much as 100 feet, but generally 20 or 30.

2. Upper Limestone shale. This is a series of beds of black shale, without either limestone or sandstone in all the central part of the district, and about 500 feet thick.

struck with the invariable position of the beds of coal upon an "under-clay," crowded with Stigmaria (roots of Sigillaria, etc.), which he inferred was the old soil on which the plants grew that formed the coal.

It is not recognised as an independent group in the South Welsh district.

It is generally devoid of fossils.

3. Millstone grit. Thick yellow white or brown sandstones, sometimes fine-grained, sometimes very coarse, containing quartz grains as large as pease. Separated into four groups of sandstones by three little intervening coal-seams and their associated shales.

4. Coal Measures. Alternations of sandstones and shales, with interstratified beds of coal generally resting upon fire-clay. The Lower Coal Measures in Derbyshire and Yorkshire contain many beds of hard sandstone called "ganister," and it is difficult to draw any decided boundary line between them and the Millstone grit.

Proceeding northwards from Derbyshire we find a gradual change taking place in the arrangement and grouping of the beds mentioned above. The Coal Measures retain their characters, but the Millstone grit first becomes more separated by beds of shale and coal, while the Upper Limestone shale becomes split up by beds of sandstone above and of limestone below, and eventually likewise contains beds of coal; and lastly, the limestone itself has its beds separated by shales and sandstones, which finally, as we go farther north, include beds of coal, so that the whole series becomes a great series of Coal Measures containing interstratified limestones in its lower part only. This change is perceptible by examining the rocks of the two following localities :—

North Yorkshire and Durham. (*Phillips.*)

	Feet.
4. Coal Measures . . .	more than 2000
3. Millstone grit	414
2. Yoredale series	540
1. Great or Scaur Limestone group,	more than 1119

1. The Great or Scaur Limestone, as described by Foster in Teesdale (Phillip's Manual, p. 163), consists of ten sets of beds of limestone from 7 feet to 130 feet in thickness, separated by as many sets of shale and sandstone varying from 12 to 240 feet thick, the total thickness of the whole being 1119 feet, with the bottom not seen.

2. The Yoredale series contains nine sets of limestone from 2 to 30 feet thick, with as many alternations of shales and sandstone from 17 to 70 feet thick, with occasional beds of coal, the whole being 544 feet thick.

3. The Millstone grit here contains one central band of limestone called Feltop lime between alternations of sandstone, shale with ironstone, and coal, having a total of 414 feet.

4. The Coal Measures of the Tyne district (Newcastle, etc.) are about 2000 feet in thickness, containing about 600 separate beds (or measures), and a total of about 60 feet of coal. The coal lies in many beds, two of which are 6 feet in thickness, and three others 3 feet and more. The Lancashire coal-field, containing higher beds than are to be seen on the Tyne, is more than double this thickness, or about 5000 feet, including 75 beds of coal over a foot thick (some being 6 feet), and a total thickness of 150 feet of coal.

Scotland.—The Carboniferous rocks of the country between Edinburgh and Glasgow may be judged of from the following section, of which the upper 600 feet is taken from the Monkland district, and the rest from that of Carluke :—

	Ft.	In.
Red Sandstone (Carboniferous) . .		
Alternations of sandstones and shales, with coal and ironstone	130	0
Limestone	1	0
Alternations, etc., five beds of coal 4 feet thick, many others less	1635	0
"Gare" limestone	4	9
Intermediate strata	150	0
"Ochrey" limestone	3	0
Sandstone with shale, etc., one coal .	51	0
Limestone	4	0
Alternations, etc., four coals of 2 or 3 feet, many ironstones	405	0
1st Cawmey limestone	1	6
Shale	8	6
1st Kinshaw limestone	2	0
Alternations, etc., one little coal . . .	16	4
2d Kinshaw limestone	2	10
Shale, with ironstone balls	29	5
Carry forward	2444	4

	Ft.	In.
Brought forward	2444	4
2d Cawmey limestone	4	6
Shale, with ironstone bands . . .	42	0
Foulband limestone	3	6
Alternations, etc., one coal of 1 foot eight inches	86	0
3d Cawmey limestone	2	6
Shale, with ironstone band . . .	20	0
Main limestone	4	6
Shale and fire-clay, with one coal . .	29	0
Coarse limestone, with intermediate band of fire-clay.	5	6
Sandstone, with shale and little coal .	54	0
Limestone	2	0
Fire-clay, sandstone, and shale, with one small coal	34	0
Oyster-shell limestone (Producta, etc.) .	4	0
Alternations of shale, whitish sandstone and fire-clay	104	0
	2839	10

Old Red Sandstone to an unknown depth.

Devon and Cornwall.—This district contains beds belonging to the Upper as well as the Lower Carboniferous series, but they are very anomalous and scarcely comparable with any degree of certainty with those of the rest of Britain. They consist of—

2. Culm Measures.
1. Shales and limestones, probably the Lower Limestone shale.

1. The shales, etc., over the Marwood sandstone group resemble more or less the Lower Limestone shales of South Wales, except that they are traversed by slaty cleavage, and have in their upper parts a dark-coloured limestone that may be a debased representative of the Carboniferous limestone.

2. The Culm Measures are a great series of alternations of shales (sometimes cleaved into slates), sandstones, and fine conglomerates, with a few beds of earthy anthracite or culm. Whether they are of the same age as the true Coal Measures is doubtful. They may perhaps have been deposited contemporaneously with part of the Carboniferous limestone, but under different conditions, and probably in water (fresh or salt) altogether separated from the seas of the north. Or if we suppose with Sir R. Murchison that the black lime-

stone of group 1 represents the whole of the Carboniferous limestone, then the Culm Measures may be of the age of the Millstone grit, and possibly that of the coal-bearing rocks of the Kilkenny and the Kerry coal-field.

Midland Counties.—The Carboniferous rocks of the midland counties of England are by no means typical groups. They consist generally of the uppermost portion, or Coal Measures only, resting unconformably on Silurian or still older formations. It is probable that during the time of the deposition of the Carboniferous limestone there was land existing where the midland counties of England now are, which land only became covered with water in consequence of a gradual depression taking place in the latter part of the Carboniferous period.

Characteristic Fossils.—Palæontologically the Upper Carboniferous rocks can only be separated into two groups, the Carboniferous limestone and the Coal Measures. Even with respect to these, it seems rather doubtful how far their palæontological distinctions are due to differences of condition, and how far to lapse of time. I am not aware that the plants of the Lower Coal Measures of Scotland, which appear to be of the same age as the Lower Limestone of Ireland, or perhaps the Lower Limestone shale of South Wales and Ireland, differ specifically from those of the true Upper Coal Measures of Central England. Neither does it appear that there is any but a quite local restriction of particular species of marine remains to particular parts of the limestones, since fossils that are found in the Lower Limestones of one district appear to occur in the Upper Limestones of another district, and *vice versâ*. I shall therefore confine myself to giving an abstract of most of the species mentioned by Morris in his Catalogue, referring them to two lists as he does to two groups.

Characteristic Fossils of the Carboniferous Limestone.

Foraminifera: Endothyra **Bowmanni**; Nodosaria **fusiliniformis**; Textularia **species.**

Zoophyta: Amplexus **coralloides, cornubovis, Henslowi, nodulosus, spinosus**; Astræopora **cyclostoma**; Aulopora **campanulata, gigas**; Campophyllum **Murchisoni**; Chætetes **depressus, radians, septosus**; Cladochonus **bacillaris, crassus, etc.**; Clisiophyllum **coniseptum, multiplex, turbinatum, etc.**; Columnaria **Egertoni**; Cyathoxonia **cornu, etc.**; Cyathophyllum **expansum, plicatum, regium, etc.**; Cyathopsis **fungites**; Dendropora **megastoma**; Diphyphyllum **concinnum, etc.**; Favosites **dentifera, incrustans, parasitica**; Fistulipora major, minor; Gorgonia, Lonsdaliana, ziczac; Heterophyllia grandis, ornata; Lithodendron affine, fasciculatum, junceum, etc.; Lithostrotion Portlocki, striatum, etc.; Lonsdaleia rugosa, etc.; Michelinia favosa, megastoma, tenuisepta, etc.; Mortieria vertebralis; Nematophyllum arachnoideum, etc.; Petalaxis Portlockii; Sarcinula radiata; Stenopora tumida, inflata, etc.; Strephodes multilamellatus; Strombodes emarciatum, floriforme; Syringopora geniculata, ramulosa, reticulata; Zaphrentis cornucopiæ, cylindrica, patula, etc.

Polyzoa: Cellepora Urii; Ceriopora distans, rhombifera, etc.; Diastopora megastoma; Fenestella flabellata, irregularis, plebeia, etc.; Glauconome gracilis, pluma, etc.; Hemitrypa Hibernica; Ichthyorachis Newenhami; Orbiculites antiquus; Polypora fastuosa, laxa, polyporata, etc.; Ptylopora pluma; Pustulopora oculata, spicularis; Retepora undata; Sulcoretepora parallela, raricosta; Vincularia dichotoma, etc.

Brachiopoda: Athyris ambigua, depressa, expansa, fimbriata, Royssii, etc.; Camarophoria crumena, laticliva; Chonetes comoides, Dalmaniana, papilionacea, papyracea, etc.; Discina (Orbicula) nitida, Ryckholtiana, etc.; Hypodema Dumontiana; Leptæna (Strophomena) distorta, senilis, Sharpei; Lingula elliptica, mytiloides, parallela, etc.; Orthis[1] circularis? Michelini, etc.? Pentamerus carbonarius? Producta aculeata, concinna, Cora, costata, fimbriata, flexistria, gigantea, granulosa, lobata, longispina, Martini, mesoloba, plicatilis, punctata, scabricula, scotica, semireticulata, etc.; Retzia radialis; Rhynconella acuminata, angulata, pleurodon, reniformis, etc.; Spirifer acutus, attenuatus, bisulcatus, calcaratus, cuspidatus, glaber, lineatus, macronotus, pinguis, striatus, triangularis, Urii, etc.; Strophalosia striata; Terebratula hastata, sacculus.

Conchifera: Mon—Avicula lunulata, squamosa, etc.; Aviculopecten anisotus, arenosus, dissimilis, ellipticus, interstitialis, tesselatus, etc. (and fifty-five other Irish species according to M'Coy); Inoceramus? auriculatus, pernoides, etc.; Lima? obliqua; Pecten deornatus, stellaris, etc.; Pinna flabelliformis, etc.; Posidonomya lateralis, tuberculata, vetusta, etc.; Pterinea? Thomsoni; Pteronites angustatus, etc. *Dim*—Anatina? attenuata; Anodontopsis subtruncatus; Arca cancellata, Lacordaireana, etc.; Axinus axiniformis, etc.; Cardiomorpha lamellosa, oblonga, etc.; Conocardium[2] Hibernicum, minax, rostratum, etc.; Corbula senilis, etc.; Cucullæa arguta, obtusa; Cypricardia cylindrica, rhombea, etc.; Dolabra orbicularis, etc.; Edmondia sulcata, unioniformis, etc.; Leda attenuata, etc.; Leptodomus costellatus, etc.; Lithodomus? dactyloides, etc.; Lucina? Dunoyeri, etc.; Lutraria? elongata; Mactra

[1] The species of Orthis described by M'Coy are very doubtful.
[2] See *ante*, p. 363, some doubts as to the class which these shells belong to.

ovata, etc.; Modiola granulosa, lingualis, Macadami, etc.; Myacites constricta, sulcata, etc.; Myalina gryphus, etc.; Mytilus Flemingii, comptus; Nucula brevirostrum, gibbosa, undulata, etc.; Pullastra (Tapes?) bistriata, etc.; Sanguinolites angustatus, oblongus, etc.; Sedgwickia attenuata, gigantea, etc.; Solemya primæva; Solen? pelagicus; Venus? elliptica, parallela.

Gasteropoda: Capulus angustus, neritoides, etc.; Dentalium? inornatum; Euomphalus acutus, æqualis, calyx, catillus, Dionysii, pentangulatus, pileopsideus, tabulatus, etc.; Lacuna antiqua; Littorina pusilla; Loxonema brevis, impendens, rugifera, sulculosa, tumida, etc.; Macrocheilus acutus, curvilineus, parallelus, etc.; Meptoptoma elliptica, sulcata, etc.; Murchisonia elongata, Larcomi, Vittata, etc.; Natica ampliata, elliptica, plicistria, etc.; Nerita spirata, striata; Patella curvata, lævigata, etc.; Phanerotinus cristatus, etc.; Platyschisma helicoides, ovoidea, etc.; Pleurotomaria abdita, carinata, conica, naticoides, vittata, etc.; Trochella prisca; Trochus lepidus, Yvanii; Turbo biserialis, semisulcatus, etc.

Pteropoda: Bellerophon bicarenus, cornuarietis, decussatus, hiulcus, spiralis, Urii, etc.; Conularia n. s. (Mus. I. I.); Porcellia lævigata, Puzo.

Cephalopoda: Actinoceras giganteum; Crytoceras Verneuillianum; Goniatites atratus, crenistria, diadema, funatus, Listeri, sphæricus, striatus, vesica, etc.; Nautilus biangulatus, cariniferus, globatus, ingens, Koninckii, multicarinatus, tuberculatus, etc.; Discites (section of Nautilus) complanatus, discus, Levellianus, sulcatus, etc.; Orthoceras angulare, dactyliophorum, Gesneri, Goldfussianum, ovale, reticulatum, unguis, etc.; Poterioceras fusiforme, etc.; Trigonoceras paradoxicum, serratum.

Echinodermata: Actinocrinus amphora, Gilbertsoni, lævis, polydactylus, Parkinsoni, etc.; Archæocidaris glabrispina, Munsteriana, triserialis, Urii, vetusta; Astrocrinus tetragonus; Atocrinus Milleri; Codonaster acutus, trilobatus; Cupressocrinus? calyx, impressus; Cyathocrinus bursa, conicus, planus, etc.; Dichocrinus elongatus, etc.; Mespilocrinus Forbesianus; Palæchinus elegans, ellipticus, sphæricus, etc.; Pentremites acutus, Derbiensis, ellipticus, inflatus, ovalis, etc.; Perischodomus biserialis; Platycrinus coronatus, gigas, granulatus, laciniatus, lævis, pileatus, rugosus, striatus, etc.; Poteriocrinus conicus, crassus, granulosus, quinquangularis, radiatus, etc.; Rhodocrinus costatus, granulatus, etc.; Sycocrinus clausus, etc.; Synbathocrinus conicus; Taxocrinus Egertoni, etc.

Annelida: Sabella antiqua; Serpula omphalodes, etc.; Serpulites carbonarius, etc.; Spiroglyphus marginatus; Spirorbis caperatus, globosus, minutus; Vermilia minuta.

Crustacea: Brachymetopus (Phillipsia) discors, Maccoyyi, Ouralicus; Cyclus radialis; Cypridina primæva; Dithyrocaris orbicularis, etc.;

Entomoconchus **Scouleri**; Griffithides **Eichwaldi, globiceps, longiceps, etc.**; Limulus **trilobitoides**; Phillipsia **Derbiensis, pustulata, seminifera.**

Fish: Asteroptychius **Portlocki, etc.**; Carcharopsis **prototypus**; Cheirodus **pes-ranæ**; Chomatodus **cinctus, etc.**; Cladacanthus **paradoxus**; Cladodus **acutus, basalis, Hibberti, mirabilis, parvus, etc.**; Climaxodus **imbricatus**; Cochliodus **contortus, magnus, etc.**; Colonodus **longidens**; Cricacanthus **Jonesi**; Ctenacanthus **arcuatus, brevis, major, etc.**; Ctenoptychius **macrodus, serratus**; Dipriacanthus? **falcatus, Stokesii**; Erismacanthus? **Jonesi**; Glossodes? **marginatus**; Helodus **didymus, planus, turgidus, etc.**; Holoptychius **Hibberti, Hopkinsii, etc.**; Homacanthus **macrodus, microdus**; Leptacanthus **junceus, priscus**; Onchus **falcatus, plicatus, sulcatus, etc.**; Oracanthus, **confluens, Milleri, etc.**; Orodus **angustus, cinctus, ramosus, etc.**; Petalodus **acuminatus, Hastingsiæ, rectus, etc.**; Petrodus? **petalliformis**; Physonemus **arcuatus, subteres**; Platycanthus **isosceles**; Pœcilodus ~~Petalodus~~ **obliquus, parallelus, transversus, etc.**; Polyrhizodus? **pusillus, radicans**; Psammodus **canaliculatus, rugosus, etc.**; Rhizodus **ferox.**

Characteristic Fossils of the Coal Measures.

Plants: Adiantites **concinnus, obovatus**; Alethopteris **heterophylla, lonchitica, Serlii, etc.**; Anabathra **pulcherrima**; Annularia **fertilis, longifolia**; Antholites **anomalus,**[1] **Pitcairnia**; Aphlebia **adnascens**; Aspidaria **confluens, cristata, quadrangularis, etc.**; Asterophyllites **equisetiformis, longifolia, tuberculata, etc.**; Calamites **approximatus, cannæformis, nodosus, ramosus, Suckowii, undulatus, etc.**; Cardiocarpon **acutum, apiculatum**; Carpolithes **alatus, sulcatus, Zamoides, etc.**; Caulopteris **primæva, etc.**; Chondrites **Prestvici**; Crepidopteris **marginata**; Cyclocladia **major**; Cyclopteris **obliqua, orbicularis, reniformis, etc.**; Cyperites **bicarinata**; Dadoxylon **approximatum, Brandlingi**; Diploxylon **elegans**; Endogenites **striata**; Equisetites **dubius**; Flabellaria **Borassifolia**; Halonia **disticha, gracilis, etc.**; Hippurites **giganteus, longifolius**; Hydatica **columnaris, prostrata**; Hymenophyllites **dissecta, furcata**; Knorria **imbricata, Sellonii, taxina**; Lepidodendron **dichotomum, elegans, Harcourtii, longifolium, obovatum, selaginoides, Sternbergii, etc.**; Lepidophyllum **intermedium, etc.**; Lepidostrobus **comosus, ornatus, etc.**; Lomatophloyos **crassicaule**; Lychnoporites **superus**; Lycopodites **cordatus, etc.**; Lyginodendron **Landsburgii**; Megaphytum **Allani, etc.**; Musocarpum **contractum**; Myriophyllites **dubius, gracilis**;

[1] Dr. Hooker, from the examination of recent specimens, is of opinion that this is the spike of a very highly organised flowering plant in full flower, possibly one of the Bromeliaceæ; another argument against the value of mere negative evidence.—(*Lyell's Supplement*).

Neuropteris acuminata, acutifolia, cordata, flexuosa, gigantea, Loshii, tenuifolia, etc.; Nœggerathia flabellata, foliosa; Odontopteris Britannica, Lindleyana, etc.; Palmacites astrocariiformis; Pecopteris abbreviata, arborescens, Miltoni, muricata, oreopteridis, plumosa, etc.; Picea Withami; Pinites ambiguus, etc.; Pinnularia capillacea; Pitus antiqua, primæva; Poacites cocoinus, Zeæformis; Polyporites Bowmanni; Pothocites Grantoni; Protopteris punctata; Rhabdocarpus amygdalæformis; Sagenaria aculeata, Rhodiana, uniosa, etc.; Selaginites patens; Sigillaria elegans, organum, reniformis, tessellata, etc.; Sphenophyllum emarginatum, Schlotheimi, etc.; Sphenopteris Brongniartii, elegans, linearis, macilenta, trifoliata, etc.; Sternbergia species; Stigmaria (roots of Sigillaria, and perhaps of other allied plants) ficoides, melocactoides, minima; Trigonocarpum Dawesii, Nœggerathii, etc.; Ulodendron Allani, majus, minus, etc.; Walchia piniformis.

Conchifera: Mon—Avicula decepta, modiolaris, obliqua, etc.; Aviculopecten papyraceus; Inoceramus? costatus, lævis, obliquatus. *Dim*—Artemis? parva; Axinus sulcatus; Cardinia acuta, ovalis, Phaseola, robusta, subconstricta; Modiola caudata, producta, etc.; Myacites Ansticei; Myalina carinata, quadrata; Mytilus triangularis; Nucula acuta, æqualis; Unio? aquilinus, centralis, etc.

Gasteropoda: Euomphalus carbonarius, Gloveri; Littorina obscura, solida; Loxonema Oweni, reticulata; Macrocheilus Flemingii, fusiformis, Manni; Natica vetusta; Patella Greenwoodi; Pleurotomaria usocona; Turbo appropinquans; Turritella elevata.

Pteropoda: Bellerophon decussatus, interlineatus, navicula, etc.; Conularia quadrisulcata.

Cephalopoda: Goniatites dorsalis, intermedius, splendidus, etc.; Nautilus armatus, concavus, falcatus, etc.; Orthoceras annulare, scalpratum.

Echinodermata: Archæocidaris? species?

Crustacea: Cypris arcuata, influta, Scoto-Burdigalensis, subrecta, etc.; Eurypterus Scouleri; Limulus anthrax, rotundus; Macrura species.

Insecta: Curculionides Prestvicii, Austicei; Corydalis Brongniartii.

Fish: Acanthodes sulcatus; Amblypterus nemopterus, Portlocki, etc.; Ctenacanthus nodosus, etc.; Ctenodus alatus, cristatus, etc.; Ctenoptychius apicalis, denticulatus, etc.; Diplodus gibbosus, minutus; Diplopterus carbonarius; Eurynotus fimbriatus; Gyracanthus formosus, tuberculatus, etc.; Gyrolepis Rankinii; Helodus mitratus, simplex; Holoptychius falcatus, Garneri, granulatus, minor, Portlocki, sauroides, striatus; Megalichthys falcatus, Hibberti; Onchus subulatus; Orthacanthus cylindricus; Palæoniscus carinatus, Egertoni, monensis, etc.; Platysomus declivus, parvulus; Plectrolepis rugosus; Pleuracanthus lævissimus, planus; Pleurodus affinis, Rankinii; Pœcilodus angustus; Psammosteus granulatus, vermicularis; Ptychacanthus sublævis; Pygopteris Bucklandi, etc.;

Sphenacanthus serrulatus; Tristychius arcuatus; Uronemus lobatus.

Reptiles: None yet found in Britain; Archæosaurus and Apateon on the Continent; footprints of Labyrinthodon in America.

Belgium.—According to M. Dumont—

SYSTEME HOUILLIER.	4. Alternations of "ampelite" (sandstone), shale, and coal.
SYSTEME CONDRUSIEN.	3. Crinoidal limestone, dolomite, productus limestone, with chert and anthracite. 2. Grey sandstone, soft sandstone, and anthracite. 1. Grey shales, calcareous shales, dark limestone and pisolitic iron ore (oligiste).

Characteristic Fossils.—The plants of No. 4 correspond to those of our Coal Measures. The large Productæ and other fossils of No. 3 correspond in the main with those of the Carboniferous or mountain limestone of the British Islands. The lowest division, No. 1, contains Spirifers, Cyathophyllum mitratum, Pleurotomariæ, and other fossils, found also in the lower divisions of Northumberland and Scotland. They may possibly be nearly of the same age as the Pilton and Marwood beds of Devon and the Carboniferous slate of Ireland.

Carboniferous rocks occur in small detached localities in many other parts of Europe, but do not admit of description as *typical* rocks of the period. The fossils contained in them agree with those already mentioned, with just that amount of difference that might be expected to arise from the laws of geographical distribution.

Reptiles such as Archæosaurus and Apateon occur occasionally.

North America: Nova Scotia.—According to Mr. Dawson—

UPPER GROUP.	3. Greyish and reddish sandstones and shales, with beds of conglomerate, and a few thin beds of limestone and coal. 3000 feet and more.
MIDDLE OR GOOD COAL GROUP.	2. Grey and dark-coloured sandstones and shales, with red and brown beds, coal, ironstone, and bituminous limestone. 4000 feet and more.
LOWER OR GYPSIFEROUS GROUP.	1. Red and grey sandstones and conglomerates, and red and green marls and shales, with thick beds of gypsum and limestone. 6000 feet and more.

Characteristic Fossils.—Those of No. 1 consist of Productæ, Terebratulæ, Encrinites and Corals, etc., in the limestones, many analogous to, and some even identical with, those of the Carboniferous limestone of Britain. Scales of Holoptychius and Palæoniscus have also been discovered. Lepidodendron and other plants occur in the sandstones.

In No. 2, Stigmaria, Sigillaria, and other genera of plants, occur in abundance, generically identical with those of our Coal Measures; Cypris, Modiola, a land shell (Pupa?), Ganoid fish, and three species of Reptiles also are known.

In No. 3, Calamites, Ferns, and Coniferous wood are found.

Altogether there is a thickness of more than 14,000 feet, without reaching any exact base, or arriving apparently at the very highest beds of the series. There are seventy-six beds of coal, of which, however, most are only 1 or 2 inches thick, and the thickest not more than 4 feet.—(*Dawson's Acadian Geology*).

Some of the beds of group 1, consisting of sandstones with variegated marls and gypsum, and a few beds of coal, were seen formerly by myself in Newfoundland, on the south shore of St. George's Bay, and at the northern extremity of the Grand Pond.—(*Report on Geology of Newfoundland*).

United States.—According to Professor Rogers—

3. UPPER CARBONIFEROUS or COAL MEASURE GROUP.	Coal Measures, alternations of sandstones, shales, and coals, like groups 2 and 3 of the Nova Scotia district, but thinning out westward, so as to be only 3000 feet in Pennsylvania, 1500 in the Illinois Basin, and not more than 1000 in Iowa and Missouri.
2. MIDDLE CARBONIFEROUS GROUP.	Soft red shales and argillaceous red sandstones, in Pennsylvania, 3000 feet. In Virginia— *c.* Blue, olive, and red calcareous shales, with thick red and brown sandstone. *b.* Light-blue limestone, sometimes Oolitic. *a.* Buff, greenish, and red shales, with sandstone. Total thickness, 3000 feet. In the Western States— *b.* Grey and yellow sandstone. *a.* Light blue and yellow limestone,* 1000 feet.

* The light-blue limestone mentioned above thickens towards the south-west and dies away to the north-east, in Pennsylvania.

1. Lower Carboniferous Group.	White, grey, and yellow sandstones, alternating with coarse siliceous conglomerates, and dark-blue and olive-coloured slates. In some places contains black carbonaceous slate, and a bed or two of coal. 2000 feet thick in Pennsylvania, thinning out to nothing in the north-west.

Characteristic Fossils.—Those of No. 1 are said to be coal plants in some parts, and marine remains, Crinoids, and Molluscs, in others. It may possibly be the equivalent of the Carboniferous slate of Ireland and Marwood beds of Devon.

Those of No. 2 are like those of No. 1 of the Nova Scotia district, generically identical with the fossils of the Carboniferous limestone of Britain.

Those of No. 3 are in like manner coal plants, belonging to the same generic forms as the British, but with many local and peculiar species. The marine beds contain corals, shells, and fishes, and the littoral beds show the tracks of reptiles.

Australia: New South Wales.

5. Dark brown shales, with impressions of plants . . .	300 feet and more
4. Sydney sandstone, thick white or light-yellow sandstone, with quartz pebbles occasionally, and partings of shale .	700 feet.
3. Alternations of shales and sandstones	400 feet.
2. Shales containing two or three good beds of workable coal, 6 feet thick	200 to 300 feet.
1. Wollongong sandstones, thick dark-grey reddish-brown, often calcareous, with large calcareous concretions . .	400 feet and more

This is only a part of the series, as there may be beds below No. 1, and others above No. 5.

Characteristic Fossils.—Those of No. 1 are, Stenopora crinita; Producta rugata; Spirifer subradiatus, Stokesii, and avicula; Pachydomus, Orthonota, Pleurotomaria, Bellerophon, etc.

Those of No. 2 are, Glossopteris Browniana; Vertebraria indica; Pecopteris australis; Phyllotheca australis.

There are fish said to have been found by Mr. Clarke in No. 3 or 5, together with fragments of plants. No fossils have yet been found in No. 4.

Victoria.—The same formations as New South Wales. We may expect shortly to receive more definite information respecting them from my former colleague, Mr. Selwyn, and the geological survey under his direction.

In Tasmania similar rocks occur, similarly associated with a thin group of shales, containing one or two good beds of coal.

In addition to the fossils mentioned above, plants of the genera Sphenopteris and Zeugophyllites occur, and also other shells, among which are Producta **brachythæra,** Spirifer **vespertilio,** etc., together with Fenestella and other corals, and with large Pectens and other bivalve shells.

India.—We may shortly expect more definite information than we yet possess, from the labours of my former colleagues, Professor Oldham and his staff, on the geological survey of that country.

Extinction of Generic Forms at the Close of the Period.

In addition to those marked with an asterisk at the commencement of this period, the following generic or ordinal forms of an earlier date now became extinct :—

Plants :[1] Lepidodendron, Sigillaria, and Stigmaria.

Corals : Amplexus, Campophyllum, Clisiophyllum, Cyathaxonia, Cyathophyllum, Diphyphyllum, Favosites, Fistulipora, Heliolites,[2] Sarcinula, Strephodes, Strombodes, Syringopora, Zaphrentis.[3]

Polyzoa : Polypora, Ptylopora.

Brachiopoda : Athyris, Chonetes, Orthis, Pentamerus, Retzia.

Conchifera : ? Pterinæa,[4] Conocardium, Dolabra, Leptodomus, Sanguinolites.

Gasteropoda : Raphistoma.

Pteropoda : Conularia.

Cephalopoda : Actinoceras.

Echinodermata : Actinocrinus, Cupressocrinus, Palæchinus, Poteriocrinus, Rhodocrinus, Taxocrinus.

Annelida : Serpulites.

[1] This is on the supposition that these plants really lived during part of the Devonian period, which is now very doubtful.

[2] With the exception of one Tertiary species, called Heliolites.

[3] Except one doubtful species in the Inferior Oolite.

[4] A species, referred to this genus with doubt, occurs in Carboniferous rocks. If not rightly so referred, the genus became extinct at the close of the Devonian period.

Crustacea: Cypridina, Dithyrocaris, Phillipsia, and with that the whole order of Trilobites.

Fish: Acanthodes, Asterolepis, Coccosteus,[1] Ctenacanthus, Ctenoptychius, Diplopterus, Holoptychius, Onchus, Ptychacanthus.

PERMIAN PERIOD.

Life of the Period.—The plants do not seem to have differed greatly from those of the preceding period. The animals were also more or less closely allied to the preceding, with the addition of some reptile forms previously unknown.

The generic forms now first appearing are the following, those marked * being limited to the period.

Plants: * Caulerpites, Confervites, Voltzia.
Protozoa: * Bothroconis, * Mammillopora.
Foraminifera: Dentalina, Spirillina, Textularia.
Corals: * Polycœlia.
Polyzoa: * Synocladia, * Thamniscus.
Brachiopoda: None.
Conchifera: * Bakewellia, ? Lima, * Schizodus (part of Axinus).
Gasteropoda: ? Rissoa.
Annelida: Vermilia.
Fish: * Acrolepis, * Gyropristis.
Reptiles: Labyrinthodon, * Palæosaurus, Thecodontosaurus, ? Ichnites of Corncockle Moor, etc.

Typical Groups of Rocks.—*Durham, etc.*—According to Professor Sedgwick—

	Feet.
6. Red gypseous marls	100
5. Thin-bedded grey limestone	80
4. Red gypseous marls, slightly saliferous	100
3. Magnesian limestone	500
2. Marl slate	60
1. Lower Red Sandstone	200

1. Is a coarse pale-red sandstone, resting unconformably on the Coal Measures, often containing large fragments of

[1] Provided the C. carbonarius of M'Coy be rightly named; otherwise the genus was extinct at the close of the Devonian period.

coal plants, that *may* have been drifted out of the Coal Measures, and sometimes fragments of coal.

2. Marl slate, a brown indurated fossil shale, with occasional beds of thin compact limestone.

Characteristic Fossils.

Plants: Neuropteris Huttoniana; Caulerpa selaginoides.

Brachiopoda: Lingula Credneri; Discina speluncaria; Productæ and Spirifers.

Fish: Palæoniscus elegans, comptus, glaphyrus, etc.; Platysomus macrurus; Acrolepis Sedgwickii; Pygopterus mandibularis, etc.; Cælacanthus granulosus, etc.

3. Magnesian Limestone. A singularly diversified mass of limestones, sometimes compact, at others crystalline, brecciated, earthy, globular, oolitic, cellular, etc.; some beds like piles of cannon or musket balls, others like bunches of grapes, etc.; some very hard, some quite friable, some thin and flexible. General colour shades of yellow, sometimes red and brown.

Characteristic Fossils.

Sponges: Scyphia, Tragos, etc.

Foraminifera: Dentalina, Spirillina, etc.

Corals: Calophyllum, Calamopora, Petraia profunda, etc.

Polyzoa: Fenestella retiformis, etc.

Brachiopoda: Producta horrida, umbonillata; Strophalosia excavata, Goldfussi, Morrisiana, parva; Camarophoria Schlotheimi, etc.; Spirifer cristatus, etc.

Conchifera: Bakewellia antiqua, etc.; Schizodus Schlotheimi; Cardiomorpha modioliformis; Pleurophorus costatus, etc.

Gasteropoda: Turbo helicinus, etc.; Loxonema fasciata, etc.; Macrocheilus symmetricus; Euomphalus Permianus; Pleurotomaria antrina.

Cephalopoda: Nautilus Freieslebeni and Bowerbankianus.

Fish: Platysomus striatus.

Nos. 4, 5, and 6, are sufficiently described already; they are destitute of fossils, except a few traces of bivalves in No. 5.

Midland Counties of England.—A great series of red and variegated sandstones and conglomerates, with breccias containing angular fragments of trap and of Silurian and Carboniferous rocks, together with thick dark red marls, and in some places mottled calcareous bands, like the cornstones of the Old Red Sandstone.

The total thickness in many places exceeds 1000 feet.

Characteristic Fossils.—Pleurophorus **costatus**, near Manchester, and other shells like those of the magnesian limestone of Durham.

In a red sandstone near Bristol, belonging to this period, there have been found the remains of the reptiles Palæosaurus **cylindrodon** and **platyodon**, and Thecodontosaurus **antiquus**.

Tracks of the Batrachian reptile Labyrinthodon have been found in these beds.

Ireland and Scotland.—The red sandstones of Roan Hill, near Dungannon, containing abundance of Palæoniscus **catopterus**, are probably Permian. Yellow magnesian limestones, exactly like those of Durham, and with many of the characteristic fossils previously mentioned, occur in patches at Ardtrea,* county Tyrone, and at Cultra, near Belfast.

The red sandstones of Dumfries, with tracks of reptiles so beautifully figured by Sir W. Jardine in his "Ichnology of Annandale," may also possibly belong either wholly or in part to the Permian rather than the Triassic period.

South of Russia: Government of Perm.—According to Sir R. I. Murchison the district of Perm exhibits so great a development of the rocks of this period as to induce him to select that name for it. These beds are said to be very various, but in one locality they have the following type:—

c. Conglomerate and sandstone.
b. Red sands and copper beds.
a. Sandstones, limestones, gypsum, and grit beds.

The limestones are often numerous, and contain fossils like those of the magnesian limestone of England and the Zechstein of Germany, while other beds contain Thecodontosauria and fishes.

In Thuringia so great is the accordance with the British

* See Professor King's paper (*Dublin Nat. Hist. Review*, No. x.), or *Journal of the Geological Society, Dublin*, vol. vii.

series, both in the rock groups and their included fossils, that Professor King in his monograph places them side by side as follows:—

THURINGIA.	NORTH OF ENGLAND.
Stinkstein	Crystalline limestone.
Rauchwacke . . .	Brecciated limestone.
Dolomit	Fossiliferous limestone.
Zechstein	Compact limestone.
Mergel, or Kupfer Schiefer .	Marl slate.
Rothe todle liegende . .	Lower Red Sandstone.

Professor Sedgwick long ago pointed out the remarkable similarity of the fish in the Mergel Schiefer and his Marl slate.—(See Sedgwick's paper on *Mag. L. Trans. Geol. Soc.*)

The following additional generic forms seem to have become extinct at the close of this period:—

Plants: Neuropteris, Sigillaria, and Stigmaria.
Corals: Aulopora, Chætetes, Petraia, Stenopora.
Polyzoa: Fenestella, Glauconome.
Brachiopoda: Camarophoria, Arthisina, Producta.
Conchifera: Axinus, Myalina, Solemya.
Echinodermata: Cyathocrinus, Archæocidaris.
Crustacea: Ceratiocaris.
Fish: Cœlacanthus, Gyracanthus, Palæoniscus, Platysomus, Pygopterus.

During the Permian period, and at its close, the part of the earth now occupied by Western Europe seems to have been more than usually affected by movements of elevation and disturbance attended with consequent large denudation of the previously existing rocks. We are obliged therefore to look to other parts of the globe where tranquillity reigned during the portion of time that elapsed at the close of the Primary and the commencement of the Secondary epochs for the typical deposits during this part of the earth's history. Future research will probably be prolific of future discovery of records now unknown to us belonging to the Permian and Triassic periods. Some of these discoveries are even now being made, but many others will doubtless follow.

As a consequence of this disturbance and denudation, the Permian rocks of Britain are frequently unconformable to the Carboniferous, and the Triassic to the Permian.

CHAPTER XIII.

SECONDARY OR MESOZOIC EPOCH.

TRIASSIC PERIOD.

LIFE OF THE PERIOD.—We have known comparatively little of this till very lately, and even yet we know it much more imperfectly than we do that of other neighbouring periods. In our own islands, we have only the scantiest traces, consisting chiefly of some stems of plants and some footsteps and fragments of bones of reptiles. This scantiness of fossils is principally due to the nature of the rocks which were deposited during this period in those parts of the globe where are now the British Islands and Western Europe. These rocks are chiefly red sandstones and red marls. This red colour seems either to have been the result of matter (peroxide of iron, etc.) destructive of life in the seas in which it prevailed, or to have been ill adapted to the preservation of the remains of animals that were deposited along with it. Fossils are far more rarely found in red rocks than in those of any other colour. Where, as in some parts of the Continent, limestones and other rocks devoid of red are found, fossils are also abundant, consisting of the remains of marine animals of various kinds.

The generic forms making their first appearance in this period are—

Plants: Œthophyllum, Albertia, Anomopteris, Pterophyllum, Dictyophyllum.

Brachiopoda: Koninckia, Thecidium.

Conchifera: Ostræa, Gervilia, * Myophoria, * Isoarca, Opis, Trigonia, Myoconchus, Plicatula.

Gasteropoda: * Scoliostoma, Naticella, Nerinæa, * Platystoma.

Cephalopoda: * Ceratites, Ammonites, Belemnites.

Echinodermata: * Encrinus, Ophiura.

Fish: Acrodus, * Placodus, * Pemphix, * Ceratodus, Hybodus, * Saurichthys, * Dipteronotus.

Reptiles: * Trematosaurus, * Nothosaurus, * Simosaurus, * Mastodonsaurus (Labyrinthodon), * Capitosaurus, * Cladyodon, * Rhyncosaurus, besides Ichnites of reptiles in Scotland.

Mammal: * Microlestes.

Those marked * did not survive the period.

TYPICAL GROUPS OF ROCK.—*Germany.*—

	Feet.
3. Keuper	1000
2. Muschelkalk . . .	600
1. Bunter Sandstein . .	1500

1. The Bunter Sandstein, or "variegated sandstone," is a red and white sandstone interstratified with red marls and thin bands of limestone, sometimes oolitic, sometimes magnesian. This is the "Grès bigarré" of the French.

Characteristic Fossils.

Plants: Thirty species have been found near Strasburg; Ferns, Cycads, and Conifera. Among them are Calamites **Mougerti**; Equisetites; Æthophyllum **speciosum and stipulare**; Neuropteris **elegans**; Voltzia **heterophylla**; Albertia **elliptica**; Anomopteris.

Fish: Acrodus **Braunii**; Placodus **impressus.**

Reptiles: Trematosaurus; Nothosaurus **Schimperi**; footprints of Labyrinthodon.—(*Vogt's Lehrbuch*, vol. i. p. 383).

2. Muschelkalk. A compact reddish grey, or yellowish limestone, rarely oolitic, but in some places magnesian, especially in the lower beds, which include beds of gypsum and rock salt. It might accordingly be divided into two subgroups:—

b. Upper Muschelkalk, regularly bedded limestone, more than 300 feet thick.

a. Alternations of limestone, dolomite, marl, and gypsum or anhydrite and rock salt, 280 feet.

Characteristic Fossils.

Brachiopoda: Terebratula vulgaris.

Conchifera: Ostrea placunoides and Schubleri; Pecten discites, lævigatus; Lima striata; Gervilia socialis; Myophoria vulgaris, lineata.

Gasteropoda: Turritella reallata.

Cephalopoda: Ceratites nodosus; Nautilus bidorsalis; ? Rhyncolithus hirundo.

Echinodermata: Encrinus liliiformis; Ophiura prisca, scutellata.

Fish: Pemphix Suensi; Acrodus Gaillardoti; Ceratodus heteromorphus; Hybodus Mougeoti and major; Saurichthys apicalis and costatus.

Reptiles: Nothosaurus, Simosaurus.—(*Vogt*).

3. Keuper. Marnes irisées of the French. Principally red and green marl, but is locally divisible into three subgroups, namely:—

c. Keuper sandstone of a yellowish white, sometimes green and reddish colour, containing calamites and other plants.
b. Keuper marls, with gypsum and dolomite, containing coprolites, fish, and saurian bones, scales, and teeth.
a. Lettenkohle (clay coal) group, a dark grey shale or grey sandstone, containing small irregular beds of impure earthy coal, with remains of Mastodonsaurus (Labyrinthodon), Gervillia, Posidonomya, and Lingula.

This latter group rests directly on the Muschelkalk, and seems, from its animal remains, to belong to it, but its plants are those of the Keuper.

Characteristic Fossils of the Keuper.

Plants: Calamites arenaceus; Equisetites; Pterophyllum Jaegeri, Munsteri; Nilsonia.

Conchifera: Posidonia minuta.

Reptiles: Mastodonsaurus (Labyrinthodon); Capitosaurus.

Mammal: Microlestes antiquus.

Near Stuttgart, and in other parts of Germany, the Keuper sandstone is capped by a layer of sandstone breccia, full of the remains of Saurians and fish in fragments, exactly like that known in England as the "bone bed." It is still doubtful whether this belongs more properly to the Trias or the Lias. Like the bone bed at the top of the Ludlow, it may perhaps be taken as an indication of a great gap in the series of beds.

In the Supplement of Sir C. Lyell before mentioned, we have the latest intelligence regarding a set of beds which fill up the gap indicated by these "bone beds;" and, moreover, give us the true marine fossiliferous equivalents of the elsewhere fresh-water or unfossiliferous Keuper, and possibly also of part of the Bunter.

Near Hallstatt (south-east of Salzburg) on the north side of the Austrian Alps, and at St. Cassian on the south side, are a set of beds composed of red, pink, and white marble, from 800 to 1000 feet in thickness, and containing more than 800 species of fossils.

These species are mostly peculiar to the Hallstatt and St. Cassian beds, but they belong to genera, some of which are only to be found elsewhere in beds belonging to the Palæozoic rocks, while others are equally confined to beds of Mesozoic age, as is shown in the following table:—

PALÆOZOIC GENERA.	TRIASSIC GENERA.	MESOZOIC GENERA.
Cyrtoceras.	Ceratites.	Ammonites.
Orthoceras.	Scoliostoma.	Belemnites.
Goniatites.	Naticella.	Nerinæa.
Loxonema.	Platystoma.	Opis.
Holopella.	Isoarca.	Cardita.
Murchisonia.	Pleurophorus.	Trigonia.
Euomphalus.	Myophoria.	Myoconchus.
Porcellia.	Monotis.	Ostræa.
Megalodon.	Koninckia.	Plicatula.
Cyrtia.		Thecidium.

"The first column marks the last appearance of several genera which are characteristic of Palæozoic strata. The second shows those genera which are characteristic of the Upper Trias, either as peculiar to it or as reaching their maximum of development at this era. The third column marks the first appearance of genera destined to become more abundant in later ages."—(*Lyell's Supplement.*)

Underneath the Hallstatt and St. Cassian beds are others called the Guttenstein and Werfen beds, containing *Ceratites cassianus*, *Myacites fassaensis*, *Naticella costata*, etc. They consist of—

		Feet.
b.	Guttenstein beds, black and grey limestone, alternating with red and green shale	150
a.	Werfen beds, red and green shale and sandstone, with gypsum and rock salt.	

It is yet doubtful whether these are only a lower portion of the St. Cassian beds, or are to be considered as equivalents of the Lower Trias.

Over the St. Cassian beds again come 2000 feet of white or greyish limestone, known as the Dachstein beds, and above these 50 feet of grey and black limestone with calcareous marls, called the Kœssen beds. Each of these groups contain a peculiar set of fossils of a character which renders it uncertain whether they should be classed as Upper Triassic or as Lower Liassic groups.

The Dachstein beds are unfossiliferous below, but the upper portion contains beds entirely made up of Corals (Lithodendron) and others, containing Hemicardium **Wulferi,** Megalodon **triqueter,** and other large bivalves.

The Kœssen beds contain as characteristic fossils, Avicula **contorta** **and inæquivalvis,** Pecten **Valoniensis,** Cardium **rheticum,** Spirifer **munsteri,** together with many Brachiopodas, some peculiar, a few found in the Lias. "According to Mr. Suess, the Kœssen beds correspond to the upper bone bed of Swabia."—(*Lyell's Supplement.*)

I would press upon the reader's attention that we have in these beds one or two of the missing links that are to reward the researches of future geologists, and fill up the many gaps in our geological history.

England.—The Triassic rocks of England are anything but typical, notwithstanding that they occupy a greater surface than perhaps any other formation. The important central division, the Muschelkalk of Germany, is entirely wanting, as are the still more important Hallstatt and St. Cassian beds. The labours of the Geological Survey of the last few years have shown the following to be the groups in the Midland Counties where the formation is best developed :—

3. Red and variegated marls.
2. White sandstone.
1. Red and mottled sandstone.

1. The Red and Mottled Sandstone has a base of "brick-red" sandstone, very fine-grained and thick-bedded. Over this come reddish-brown sandstones, or red and white sandstones, with beds of marl, and thick, rather irregular bands of partially consolidated conglomerate, called "pebble-beds." Mottled calcareous concretionary sandstones, not unlike some varieties of "cornstone," occur occasionally in this "brown" division, often associated with the marls. The whole group seems to be locally represented by a dolomitic conglomerate, unless that should be referred rather to the Permian period.

2. The White Sandstone is a very persistent and well-marked group over a very wide area, forming the hill on which Beeston Castle (Cheshire) stands, and spreading through a great part of the midland counties of England. It is generally white, sometimes mottled with red, and is often used as a building stone, for which purpose it is occasionally sufficiently well adapted.

3. The Red and Variegated Marls contain irregular beds of sandstone, and almost invariably beds, and veins, and strings of gypsum, and frequently thick masses of rock salt. In Cheshire, near Northwich, the following section shows a part of the thickness of these beds :—

	Feet.
Upper strata (marl, etc.)	127
1st bed of rock salt	85
Indurated marl (locally called stone) .	30
2d bed of rock salt	106
Indurated marls, with thin beds of salt .	151
	499

Over this thickness of 500 feet are other beds of marl, etc., before we reach the base of the Lias, and, under them, others before we should attain the top of the Whitestone, so that the entire depth of this group must be 700 feet, with 500 without the salt.—(*Ormerod on Cheshire, Geological Journal*, vol. iv.)

An occasional set of beds of a pale-coloured sandstone, called by myself formerly the "Dove-coloured Sandstone," in the upper part of this group, contains fossil plants and fragments of reptiles, enabling us to identify this group, No. 3, with the Keuper of Germany. No. 1 is almost certainly the same as the German Bunter sandstone, and the French Grès bigarré.

Characteristic Fossils of the Trias in England.

A few fragments of plants.

Reptiles: Labyrinthodon Buchlandi, giganteus, leptognathus, pachygnathus, scutulatus, ventricosus; Rhyncosaurus articeps.

Ireland.—In the north, near Belfast, a considerable mass of red sandstones belong either to the Bunter sandstone or the Permian. Over them is a group of red and variegated marls, which, near Carrickfergus, contain beds of gypsum and rock-salt, of which the following is a section:—

	Feet.
Red marls, with gypsum	510
Red salt	22
Marl and salt	26
Pure rock salt	84
Mixed rock salt	14
Pure rock salt	39
Blue bands and freestone, etc.	25
	700

These have other beds of red marl above them, about 100 or 150 feet thick, over which is the base of the Lias. They, in all probability, therefore belong to group No. 3, and equal to the Keuper of Germany.

At the close of the Triassic period, the following additional generic forms appear to have become finally extinct:—

Plants: Calamites.

Brachiopoda: Cyrtia, Strophalosia.

Conchifera: Megalodon, Pleurophorus.

Gasteropoda: Euomphalus, Murchisonia.

Holopella: Loxonema.

Pteropoda: Porcellia.

Cephalopoda: Goniatites, Orthoceras, Cyrtoceras.

Reptiles: The Labyrinthodont order, Thecodontosaurus.

THE OOLITIC OR JURASSIC PERIOD.

Life of the Period.—We have here no occasion to complain of scarcity of fossils, either in general or in the British Islands. There is an abundance of fossil plants in some of the rocks of this period, while in others are found crowds of marine and fresh-water shells and fish, together with large strange marine repiles. Flying reptiles also occur, and huge terrestrial carnivorous lizards. Footprints of gigantic birds are known in some red sandstones in America, belonging to this period; and in England fragments of several small land mammalia have been discovered.

The following generic forms date their origin from this period; those limited to it being marked with an asterisk.

Plants: * Acrostichites, * Araucarites, * Baiera, * Bensonia, * Brachyphyllum, * Bucklandia, * Cryptomerites, * Ctenis, Cupressus, Cycadeoidea, * Dammarites, * Lilia, Lonchopteris, * Naiadites, * Pachypteris, * Palæozamia, Peuce, * Phlebopteris, * Podocarya, * Polypodites, * Polystichites, Pterophyllum, * Sagenopteris, * Salicites, * Schizopteris, * Solenites, * Sphœreda, * Sphœrococcites, * Stricklandia, Strobelites, * Tæniopteris, * Taxites, Thuytes, * Tympanophora, Zamiostrobus, * Zamites.

Sponges: Manon, Spongia.

Foraminifera: Bulimina, Cristellaria, Flabellina, Marginulina, Nodosaria, Rotalina, Spirolina, Vaginulina, Vulvulina, Webbina.

Zoophyta (corals): * Anabacia, * Axosmilia, * Calamophyllia, * Cladophyllia, * Clausastræa, * Comoseris, * Convexastræa, * Cyathophora, * Dentipora, * Discocyathus, * Eunomia, * Goniocora, * Isastræa, * Latomeandra, * Microsolena, Millepora, * Montlivaltia, * Prionastræa, * Protoseris, * Rhabdophyllia, * Stylina, * Thamnastræa, * Thecosmilia, Trochocyathus.

Polyzoa: Alecto, * Apseudina, * Chrysaora, Cricopora, Idmonea, Terebellaria, Theonoa.

Brachiopoda: Terebratella.

Conchifera: *Mon.*—Crenatula, Exogyra, Gryphea, Hinnites, * Limea, * Placunopsis, * Pteroperna, Trichites. *Dim.*—Astarte, * Ceromya, Corbis, Cyprina, Cyrena, Cytherea, Diceras, * Goniomya, * Gresslya, * Hippopodium, Isocardia, Limopsis, ? Mya, Myoconcha, Neæra, Pachyrisma, Pectunculus, Pholadomya, Pholas, Potamomya, Sphæra, * Tancredia, Thracia, * Unicardium.

Gasteropoda: Actæon, * Actæonina, * Alaria, * Brachytrema, Bulla, * Ceritella, Cerithium, Chemnitzia, * Cirrus, Delphinula, * Deslongchampsia, Emarginula, Fissurella, Fusus, Hydrobia, Monodonta, Nerinæa, Neritina, * Neritopsis, Paludina, Pileolus, Pteroceras, * Purpurina, * Rimula, * Rissoina, Solarium, * Spinigera, Stomatia, * Trichotoma.

Cephalopoda: * Acanthoteuthis, Ancyloceras, * Geoteuthis.

Echinodermata: * Acrosalenia, * Amphiura, * Apiocrinus, Astropecten, Cidaris, Diadema, * Dysaster, Echinus, Extracrinus, * Hemicidaris, * Holectypus, * Hyboclypus, * Millericrinus, Nucleolites, * Ophioderma, Ophiura, Pentacrinus, * Pygaster, * Pygurus, Solaster.

Annelida: Vermicularia.

Cirrhipedia: Pollicipes.

Crustacea: * Archæoniscus, ? Astacus, * Coleia, Cypridea, Eryon, Estheria, * Glyphæa, * Mecocheirus, ? Pagurus.

Insecta: Berosus, Carabus, Cerylon, Coccinella, Colymbetes, Cyphon, Elater, Gyrinus, Helophorus, Lacophilus, Limnius, Melolontha, Rhyncophora, and many genera of Carabidæ, Blapsidæ, Buprestidæ, Nemoptera, Orthoptera, Homoptera, and Diptera, etc. etc.

Fish: Æchmodus, * Amblyurus, * Arthropterus, * Aspidorhyncus, Asteracanthus, Belonostomus, Caturus, * Centrolepis, * Ceramurus, * Chondrosteus, * Conodus, * Cosmolepis, * Ctenolepis, * Cyclarthrus, * Dapedius, * Eugnathus, * Ganodus, Gyrodus, * Gyronchus, * Gyrosteus, Ischyodus, * Isodius, * Legnonotus, Lepidotus, * Leptolepis, * Macrosemius, Microdon, * Myriacanthus, * Nothosomus, * Ophiopsis, * Oxygnathus, * Pachycormus, * Pholidophorus, * Pleuropholis, * Pristacanthus, * Ptycholepis, Pycnodus, * Sauropsis, * Scaphodus, * Semionotus, * Sphærodus, Sphenonchus, * Squaloraia, Strophodus, * Tetragonolepis, * Thrissonotus, * Thyellina.

Reptiles: Cetiosaurus, Chelone, Goniopholis, Ichthyosaurus, Lacerta, * Macellodus, * Macrorhyncus, Megalosaurus, * Nothetes, Plesiosaurus, * Pleurosternon, * Pliosaurus, Pterodactylus, * Steneosaurus, Streptospondylus, * Teleosaurus, Tetrosternon, Trionyx.

Mammalia: * Amphitherium (or Thylacotherium), * Phascolotherium, * Ptereognathus, * Plagiaulax, * Spalacotherium, * Triconodon.

Typical Groups of Rock.—*South of England.*—If we arrange the whole series of the rocks of this period in their order of occurrence in slightly different but neighbouring localities, we shall have the following list:—

Group	Bed	Feet.	Subdivisions
D. PORTLAND, or UPPER OOLITE.	12. Purbeck beds	150	*c.* Upper. *b.* Middle. *a.* Lower.
	11. Portland beds	170	*b.* Stone. *a.* Sand.
	10. Kimmeridge clay	600	Dark clay.
C. OXFORD, or MIDDLE OOLITE.	9. Coral rag	180	*c.* Upper Calcar. grit. *b.* Oolitic limestone. *a.* Lower Calcar. grit.
	8. Oxford clay	600	*b.* Dark clay. *a.* Kelloway rock.
B. BATH, or LOWER OOLITE.	7. Cornbrash	80	*c.* Cornbrash. *b.* Forest marble *a.* Bradford clay.
	6. Great Oolite	130	*b.* Freestone and rag. *a.* Stonesfield slate.
	5. Fuller's earth	130	
	4. Inferior Oolite	230	*c.* Ragstone. *b.* Freestone. *a.* Pea grit.
A. LIAS.	3. Upper Lias	300	*b.* Lias sands. *a.* Upper shale.
	2. Marlstone	200	*b.* Rock beds. *a.* Sands.
	1. Lower Lias	600	*c.* Lower shale. *b.* Limestone and shale. *a.* Bone bed or beds.

A. The Lias. Essentially a great clay deposit, with occasional bands of a peculiar compact argillaceous limestone near the bottom, and an argillaceous sandstone near the middle, with a loose sandy deposit at top connecting it with the group above.

A 1. Lower Lias. At the top of the red marls of the Triassic Keuper group below is a little layer of hard sandstone full of fragments of bones and teeth of reptiles and fish. In some places bones of Keuper reptiles have been seen in it, and the layer therefore referred to the Trias; in other places it is full of undoubted Lias fossils. It is probable that there is in reality more than one bone bed, the diminutive representative of the great passage beds between the Trias and the

Lias, 2000 feet and more in thickness, which are found at Dachstatt and Kœssen.

In some places the black shales of the Lower Lias rest on the red marls without any bone bed and without any limestone, while in others a group of limestones interstratified with clays, having a thickness of 20 to 50 feet, is seen. Over these limestones occur the ordinary blue clay of which the Lower Lias is generally composed.

Characteristic Fossils.

Brachiopoda: Terebratula numismalis.

Conchifera: Gryphæa incurva; Ostræa læviuscula; Gervilia lævis; Pecten sublævis; Arca truncata and elongata; Hippopodium ponderosum; Cardinia Listeri; Pholadomya ambigua.

Gasteropoda: Trochus imbricatus.

Cephalopoda: Belemnites acutus, pistilliformis, and elongatus; Ammonites Henleyi, planicostatus, anguliferus, oxynotus, Coynarti, and many others.

Fish: Æchmodus (Tetragonolepis) angulifer; Dapedius monilifer; Eugnathus tenuidens; Pycnodus liassicus, etc.

Reptiles: Species of Ichthyosaurus, etc.

A 2. The Marlstone is a well marked division of the Lias, being more arenaceous, though still fine grained, and often bound by calcareous or ferruginous cement into a hard stone. In Gloucestershire it is divisible into the hard "rock bed" above, and the sands, often rather argillaceous, below.

Characteristic Fossils.

Brachiopoda: Rhynconella tetrahedra, variabilis; Terebratula resupinata, subpunctata, punctata, cornuta, Edwardsii; Spirifer rostratus.

Conchifera: Gryphæa cymbium; Pecten cinctus and æquivalvis; Lima gigantea; Cardinia crassissima; Pholadomya Murchisoniæ; Myacites donaciforme.

Cephalopoda: Nautilus striatus and truncatus; Ammonites margaritatus, spinatus, and others; Belemnites Brugnierianus.

Echinodermata: Uraster Gaveyi; Tropidaster pectinatus; Ophioderma Gaveyi.

A 3. Upper Lias. This consists of a great thickness of blue clay, over which are some brown and yellow sands, hitherto classed with the inferior oolite, but separated from it on good palæontological evidence by Dr. Wright of Cheltenham,[1] and called by him Upper Lias sands, capped by a particular band called the "Cephalopoda bed," from the abundance of those fossils which it contained.

Characteristic Fossils.

Brachiopoda: Rhynconella furcillata.

Conchifera: Cypricardia brevis; Astarte lurida, excavata; Gresslya abducta; Perna rugosa; Modiola plicata; Hinnites abjectus; Lima ornata, etc.

Gasteropoda: Turbo capitaneus.

Cephalopoda: Belemnites irregularis; Nautilus inornatus; Ammonites insignis, variabilis, radians, concavus, striatulus, bifrons, communis.

In addition to the preceding fossils the following may be taken as characteristic of the Lias in general, either occurring indiscriminately throughout it, or the exact part of which they are characteristic not being known:—

Plants: Araucarites peregrinus; Cupressus latifolius; Equisetetes Brodei; Naiadites acuminata; Otopteris obtusa; Palæozamia Bechei, Bucklandi; Strobilites elongata.

Foraminifera: Polymorphina liassica; Spirilina infima.

Brachiopoda: Crania Moorei; Discina (Orbicula) reflexa; Leptæna liassina, granulosa, etc; Rhynconella acuta, pygmæa, subconcinna; Spirifer rostratus, Walcotti, verrucosus, etc; Terebratula globulina, indentata, Lycettii, etc.; Thecidium Bouchardi, Moorei, rusticum.

Conchifera: Avicula cygnipes, decussata, novemcostæ; Gervillia crassa; Gryphæa depressa; Inoceramus dubius; Lima antiquata, gigantea, etc.; Plicatula spinosa; Cardinia ovalis, etc; Cardium multicostatum; Leda ovum and rostralis; Modiola minima; Myacites elegans; Pholadomya decorata, obliquata, and ventricosa; Unicardium cardioides.

Gasteropoda: Pleurotomaria compressa and expansa.

Cephalopoda: Ammonites aculeatus, annulatus, armatus, bifer, bisulcatus, complanatus, Conybeari, Engelhardtii, Duncani, falcifer, heterophyllus, nitidus, obtusus, planicostatus, serpentinus, spinatus, sulcatus, Turneri, and many others; Belemnites acuarius, penicillatus, compressus, trifidus, etc.; Geoteuthis Bollensis; Nautilus annularis, intermedius, semistriatus, etc.; Rhyncolites.

[1] Wright on "Upper Lias Sands."—*Journal of Geological Society*, vol. xii.

Echinodermata: Aspidura loricata; Astropecten arenicolus, etc.; Diadema minimum; Extracrinus briareus, subangularis; Ophioderma Egertoni, etc.; Ophiura Murravii; Pentacrinus basaltiformis. etc.; Uraster Gaveyi.

Crustacea: Astacus? glaber; Coleia antiqua; Glyphea liassina.

Insecta: Berosus species; Gyrinus natans; Melolontha; Æshna Brodei, etc.; Libellula dislocata, etc.; Gryllus Bucklandi; Cicada Murchisoniæ; Asilus ignotus, etc.

Fish: Acrodus latus, nobilis, etc.; Æchmodus speciosus, radiatus, etc.; Amblyurus macrostomus; Asteracanthus Stuchburii; Belonostomus Anningiæ; Centrolepis asper; Dapedius politus, micans, etc.; Eugnathus fasciculatus, etc.; Hybodus carinatus, etc.; Lepidotus fimbriatus, etc.; Leptolepis caudalis, etc.; Myriacanthus granulatus, etc.; Pachycormus acutirostris, etc.; Pholidophorus Bechei, etc.; Ptycholepis Bollensis, etc.

Reptiles: Ichthyosaurus acutirostris, communis, intermedius, latifrons, latimanus, lonchiodon, platyodon, tenuirostris, thyreospondylus; Plesiosaurus arcuatus, brachycephalus, dolichodeirus, Hawkinsii, macrocephalus, macromus, megacephalus, rugosus, subtrigonus; Pterodactylus macronyx; Teleosaurus Chapmanni.

The lithological type and the characteristic assemblages of fossils are applicable to the Lias throughout England from Lyme Regis to Whitby, if we allow for some variations in thickness and in the character of the minor groups of rock, and for a local distribution in the fossils.

B. The Lower or Bath Oolite, composed of the four groups called, 4. The Inferior; 5. Fuller's Earth; 6. The Great Oolite; and 7. The Cornbrash.

4. The Inferior Oolite near Cheltenham, where it attains its greatest development, consists of, *a.* The Pea Grit, a pisolitic limestone, made up of flattened oval concretions rather larger than peas, sometimes 40 feet thick; *b.* The Freestone, a fine pale-coloured oolitic or shelly limestone 164 feet thick, containing a bed of marl 7 feet thick near the top; *c.* The Ragstone, a brown sandy limestone, sometimes hard, sometimes incoherent, 38 feet thick.

Characteristic Fossils.

Corals: several species of Montlivaltia, Thamnastrea, Isastræa, etc.

Brachiopoda: Rhynconella concinna, decorata, Wrightii, etc.; Terebratula globata, fimbria, simplex, plicatata, etc.; Thecidea triangularis.

Conchifera: Lima proboscidea and gibbosa; Trigonia clavicostata, decorata, angulata, etc.; Myacites; Gervillia lævigata; Pholadomya fidicula, etc.

Gasteropoda: Pleurotomaria fasciata; Nerita costata, etc.

Cephalopoda: Ammonites corrugatus, Humphresianus, dimorphus, Parkinsoni, subradiatus, Sowerbyi, etc.; Belemnites abbreviatus, etc.; Nautilus truncatus, lineatus.

Echinodermata: Cidaris Fowleri, etc.; Acrosalenia Lycetti, etc.; Echinus germinans; Hemipedina tetragramma, etc.; Pygaster semisulcatus, etc.; Clypeus Agassizii; Nucleolites Plotii.

Annelida: Serpula grandis, convoluta, etc.

Fish: Hybodus crassus; Pholidophorus Flesheri; Strophodus magnus and subreticulatus.

In the Cheltenham district even the subdivisions of the Inferior Oolite mentioned above have their lists of peculiar and characteristic fossils.—(*Memoirs of the Geological Survey*, 1857; *Mr. Hull on the Geology of Cheltenham*).

5. Above the Inferior Oolite comes, in the Gloucestershire district, a series of blue and yellow shales, clays, and marls, some of which are of the peculiar kind of clay called Fuller's earth, the name assigned to the group. Interstratified with these are occasional bands of limestone.

The maximum thickness is about 150 feet, rather rapidly diminishing in all directions.

Characteristic Fossils.—None; those it has are a mixture of Inferior Oolite and Great Oolite species.

6. Great Oolite. This, like all the other oolitic groups, except the clays, has a very variable lithological character. Mr. Lycett says, that near Minchinhampton it is made up of Weatherstones, Sandstones, and Limestones, the Weatherstones, shelly calcareous sandstones, being always at the base of the group, but passing laterally into Sandstones, which are commonly covered by Limestones, while the Weatherstones have never any of the Limestones above them.—(*Jour. Geolog. Soc.*, vol. iv.; and *Palæontolog. Soc.*, 1850). Mr. Hull divides the Great Oolite near Cheltenham into two zones, *a*. The Under zone, a variable series of sandy flags, "slates," and blue limestones, with white oolitic free-

stones, showing much oblique lamination. The flaggy limestones, and sometimes the thick bedded ones, split in some places into very thin slabs, which are called, though erroneously, "slates."* The Stonesfield slate, so celebrated for its terrestrial reptiles and mammalian remains, belongs to these beds, and it might therefore give its name to the zone. The Collyweston slate of Northampton belongs to this group; thickness, 35 feet. *b*. The Upper zone is well marked in Gloucestershire, by the occurrence of a bed of marl at its base, and a band of hard white limestone at its summit, the intermediate beds being oolitic limestones, sandstone or sandy limestone, greatly marked by oblique lamination; thickness, 100 feet.—(*Memoirs of the Geological Survey*, 1857).

Characteristic Fossils of the Great Oolite and Stonesfield Slate:

Plants: Bucklandia squamosa; Carpolithes diospyriformis, Lindleyanus; Halymenites ramulosus; Hymenophyllites macrophylla; Lilia lanceolata; Naiadites ovata; Palæozamia pectinata; Sphenopteris cysteoides; Tæniopteris latifolia, etc.; Thuytes articulatus, etc.

Protozoa: Scyphia Brownii, pistilliformis; Spongia cymosa, etc.

Corals: Clausastræa Prattii; Convexastræa Waltoni; Cyathophora Prattii; Eunomia radiata; Isastræa Conybeari, etc.; Microsolena excelsa, etc.; Millepora pyriformis; Montlivaltia cupuliformis, etc.; Stylina conifera, etc.; Thamnastræa Lyelli, etc.

Polyzoa: Alecto dichotoma; Ceriopora dumetosa, etc.; Cricopora cæspitosa, etc.; Diastopora foliacea, etc.; Heteropora conifera, etc.; Idmonea triquetra; Theonoa clathrata.

Brachiopoda: Crania antiquior; Discina granulata; Rhynconella concinna, farcta, Hopkinsi, etc.; Terebratella? hemisphærica; Terebratula digona, equirostris, flabellum, hemisphærica.

Conchifera: Avicula Braamburiensis; Gervillia crassicosta, lanceolata, monotis, etc.; Gryphæa minuta; Inoceramus amygdaloides; Lima bellula, impressa, etc.; Ostræa costata, rugulosa; Pecten clathratus, Flemingii, personatus, retiferus, Woodwardi; Placunopsis ornatus, radians, socialis; Pinna cuneata; Plicatula tuberculosa; Pteroperna costatula, etc.; Arca Eudesii, pulchra, etc.; Astarte orbicularis, pumila, etc.; Cardium pes-bovis, semiglabrum, Stricklandi; Ceromya similis; Corbis Lajoyei; Corbula depressa; Cucullæa cancellata,

* I have formerly pointed out the advisability of confining the term "slate" to those rocks of which the thin plates are the result of "cleavage," not of deposition.

concinna, imperialis; Cypricardia Bathonica; Cyprina Jurensis; Cytherea dolabra; Isocardia nitida; Limopsis oolitica; Lithodomus parasiticus; Lutraria gibbosa; Modiola compressa, imbricata, Lycetti, tumida; Myacites Phillipsi; Myoconcha Actæon, etc.; Neæra Ibbetsoni; Pachyrisma grande; Pectunculus minimus Phlodomya acuticosta, nana; Tancredia angulata; Thracia incerta; Trigonia conjungens, cuspidata, Goldfussi, imbricata, Moretoni, subglobosa, etc.; Unicardium depressum, etc.

Gasteropoda: Actæon pullus and Sedgwickii; Actæonina bulimoides etc.; Alaria armata, etc.; Brachytrema turbiniformis, etc.; Bulla doliolum; Ceritella acuta, etc.; Cerithium Royssii, etc.; Chemnitzia variabilis, simplex, phasianoides, etc.; Cylindrites brevis, cuspidatus, etc.; Delphinula alta, etc.; Eulima communis, etc.; Fissurella acuta; Fusus coronatus; Monodonta decussata; Natica Michelini, etc.; Nerinæa Dufresnoyi, fasciata, funiculus, punctata, triplicata, etc.; Nerita hemisphærica, etc.; Neritopsis striata, etc.; Patella arachnoida, lata, rugosa, striata, etc.; Phasianella acutiuscula, cincta, parvula, nuciformis, tumidula; Pleurotomaria composita, obesa, etc.; Pteroceras Bentleyi, Wrightii; Purpurina glabra, Morrissii; Rimula clathrata; Rissoina acuta, cancellata, etc.; Solarium polygonium, varicosum; Stomatia Buvigneri; Trochotoma acuminata, extensa, obtusa, etc.; Trochus acis, Dunkeri, Leckenbyi, obsoletus, spiratus, etc.; Turbo capitaneus, gemmatus, obtusus, etc.

Cephalopoda: Ammonites Braikenridgii, gracilis, subcontractus; Belemnites Bessinus, fusiformis; Nautilus Baberi, dispansus.

Echinodermata: Acrosalenia radiata, rarispina; Apiocrinus Parkinsoni and Pratii; Astropecten Cotteswoldiæ; Cidaris glandifera, maxima; Diadema pentagonum; Hemicidaris confluens, pustulosa; Solaster Moretonis.

Annelida: Serpula obliqui-striata and triangulata, etc.

Cirrhipedia: Pollicipes ooliticus.

Crustacea: Pagurus? platycheles.

Insecta: Coccinella Wittsii; Curculiodes sp.; Prionus Bucklandi; Hemerobioides giganteus.

Fish: Acrodus leiodus; Belonostomus leptosteus; Caturus pleiodus; Ganodus Bucklandi, Colei, etc.; Gyronchus oblongus; Hybodus apicalis, dorsalis, etc.; Lepidotus tuberculatus; Leptacanthus serratus; Pycnodus Bucklandi, etc.; and several other genera.

Reptiles: Cetiosaurus longus, medius; Megalosaurus Bucklandi; Pterodactylus Bucklandi; Teleosaurus Cadomensis.

Mammalia: Amphitherium Broderipii, Prevostii; Phascolotherium Bucklandi; Stereognathus ooliticus.

7. Cornbrash Group. This is a very variously composed set of clays, sands, and limestones, containing local divisions such as the Bradford Clay, the Forest Marble, and the Cornbrash itself.

The Bradford Clay is a blue unctuous clay occurring at Bradford, and extending for a few miles around it; it is never more than forty or fifty feet in thickness; locally full of Apiocrinites Parkinsoni (rotundus). The Forest Marble (so named from Wychwood forest) is composed of coarse fissile oolite, with much oblique lamination, hard shelly limestones, blue marls and shales, yellow siliceous sand, with large spheroidal blocks of limestone, and fine oolitic freestone. It is rarely more than forty, never more than eighty, feet thick. The Cornbrash is generally a rubbly cream-coloured limestone in thin beds, always nodular and concretionary, each fragment having a deep red coating. Not more than fifteen feet thick.

Characteristic Fossils.—Locally those of the Forest Marble are different from those of the Cornbrash. Most of those of the Bradford Clay are found also in the Great Oolite. Taken together as a group, they may be stated as—

Brachiopoda: Rhynconella Morieri; Terebratula intermedia, lagenalis, obovata.

Conchifera: Anomia semistriata; Lima rigidula; Ostræa species; Perna quadrata; Cardium citrinoideum, globosum; Ceromya concentrica; Gresslya peregrina; Isocardia minima, triangularis; Modiola Lonsdalei; Myacites securiformis and uniformis; Nucula Menkii; Pholadomya deltoidea, lyrata; Sanguinolaria parvula.

Gasteropoda: Cerithium granulatum; Chemnitzia vittata; Littorina punctura.

Cephalopoda: Ammonites discus.

Echinodermata: Acrosalenia pustulata, Wiltonii; Apiocrinus elegans and exutus; Astropecten Phillipsii; Diadema vagans; Hemicidaris alpina; Pentacrinus cingulatus; Pygaster Morrissii.

Fish: Asteracanthus acutus.

Characteristic Fossils of the whole of Group B or Bath Oolite:

There are fossils not mentioned in the preceding lists which are yet very characteristic of the Bath group in general, being found in two or more members of it. These are—

Corals: Anabasia orbulites; Cladophyllia Babbeana; Comoseris vermicularis; Isastræa explanulata and limitata; Stylina solida.

Brachiopoda: Terebratula cardium, coarctata, and maxillata.

Conchifera: Avicula costata, echinata; Gryphæa gigantea; Lima Cardiiformis; Ostræa acuminata; Pecten vagans; Placunopsis Jurensis; Pinna ampla; Arca Hirsonensis; Corbis aspera; Cucullæa cucullata; Hinnites tegulatus and velatus; Leda lachryma; Lucina Bellona and despecta; Modiola aspera, furcata, gibbosa, Sowerbyana; Myacites decustata, elongata; Myoconcha crassa; Nucula variabilis; Opis lunulatus; Trigonia duplicata.

Gasteropoda: Alaria Phillipsii, trifida; Bulla undulata; Natica adducta, cincta; Nerinæa cingenda; Nerita pseudocostata; Neritopsis varicosa; Patella sulcata; Pileolus lævis and plicatus; Pleurotomaria scalaris; Rimula Blotii; Trochus ornatissimus; Turbo elaboratus.

Cephalopoda: Ammonites arbustigerus, Blagdeni; Belemnites giganteus.

Echinodermata: Acrosalenia aspera, hemicidaroides, spinosa; Cidaris elegans, propinqua; Diadema depressum, subangulare; Holectypus depressus, hemisphæricus; Hyboclypus caudatus; Nucleolites clunicularis; Pentacrinus Milleri; Pygurus Blumenbachii.

Yorkshire, etc.—The foregoing description of the Bath Oolite is applicable, with more or less accuracy, to all the country south of the Humber. Proceeding into Yorkshire, however, a very remarkable change takes place both in the rocks and the fossils.

The little insignificant-looking band of the Cornbrash continues lithologically and palæontologically the same; below this, however, instead of limestone, there is a great mass of shale and sandstone, with a band of shelly oolite in the centre, and underneath all, ferruginous sands and calcareous sandstone, that may either represent the Inferior Oolite or the Upper Lias sands.

Professor Phillips gives the following as a condensed account of this Yorkshire type:—

	Feet.
5. Shelly Cornbrash limestone of Gristhorp and Scarborough	10
4. Sandstones, shales, ironstones, and coals of Gristhorp, Scarborough, and Scalby, enclosing some calcareous shelly bands	200
3. Shelly oolite, and clays of Cloughton and West Nab .	60
2. Sandstones, shales, ironstones, and workable coal of the Peak, Stainton Dale, and Haiburn Wylie . . .	500
1. Irony sandstone and subcalcareous beds, with bands of shells and plants	60

Characteristic Fossils of the Yorkshire Lower Oolites:

Plants: Acrostichites Williamsonis; Baiera gracilis; Brachyphyllum mammillare; Carpolithes areolatus; Cryptomerites divaricatus, Ctenis falcata; Cyclopteris Beanii, digitata, Huttoni; Dictyophyllum rugosum; Equisetites columnaris, lateralis; Hymenophyllites Williamsonis; Otopteris acuminata, graphica; Pachypteris lanceolata, ovata; Palæozamia elegans, pecten, etc.; Pecopteris denticulata, exilis, Whitbiensis, etc.; Phlebopteris contigua; Polypodites crenifolius; Pterophyllum coruptum, etc.; Sagenopteris cuneata, Phillipsii; Schizopteris gracilis; Solenites furcatus, etc.; Sphenopteris arguta, crenulata, hymenophylloides, etc.; Sphærococcites arcuatus; Tæniopteris major, vittata, etc.; Thuytes expansus; Tympanophora racemosa, simplex; Zamites gigas, etc.

Conchifera: Cardinia vetusta; and other shells like Anodon.

Crustacea: Estheria (Cypris) concentrica.

Some of the Equisetites are found erect, and everything tends to show that we have in this type a true secondary coal formation of the Oolitic period, in addition to the primary coal formation formed in that which is distinctively called the Carboniferous period.

C. The Oxford or Middle Oolite consists of two principal groups—the Oxford Clay and the Coral Rag.

8. The Oxford Clay is generally a dark blue clay, sometimes dark grey, approaching to black. In its lower portion it has some beds of tough calcareous sandstone, with brown sands, called Kelloway rock, from a place in Wiltshire. This Kelloway rock appears to be wanting in the midland counties, but reappears in Yorkshire with the same characters and fossils. The maximum thickness of the Kelloway rock is 80 feet. That of the whole Oxford clay, including it, cannot be less in some places than 600 feet.

Characteristic Fossils.

Brachiopoda: Discina latissima; Lingula ovalis; Rhynconella lacunosa; Terebratula insignis.

Conchifera: Avicula expansa; Gervillia siliqua; Gryphæa bilobata, dilatata; Ostræa archetypa, inæqualis, undosa; Anatina undulata; Arca subtetragona; Artemis carinata, lurida, zonata; Cardinia hamata; Corbis ovalis; Cucullæa concinna; Leda Phillipsii; Myacites Alduini; Nucula elliptica; Pholadomya obsoleta.

Gasteropoda: Alaria composita; Pleurotomaria depressa, Munsteri; Trochus guttatus.

Cephalopoda: Acanthoteuthis antiquus; Ammonites alternans, annularis, athletus, Bakeriæ, bifrons, bipartitus, Brightii, Callovicensis, Comptoni, crenatus, Duncani, Elizabethæ, Eugenii, excavatus, flexicostatus, fluctuosus, funiferus, gemmatus, Gowerianus, Gulielmi, Jason, Kœnigi, Lalandeanus, Lamberti, lenticularis, longispinus, Lonsdalei, modiolaris, oculatus, planula, Reginaldi, Sedgwickii, varicostatus, Vernoni; Belemnites anomalus, Beaumontianus, gracilis, hastatus, Owenii, tornatilis; Nautilus hexagonus.

Echinodermata: Amphiura Prattii.

Annelida: Serpula intestinalis and vertebralis.

Cirrhipedia: Pollicipes concinnus, planulatus.

Crustacea: Astacus? leptomanus and Stricklandi; Mecocheirus Pearcei.

Fish: Lepidotus macrocheirus; Leptolepis costalis, macrophthalmus; Strophodus radiato-punctatus.

9. The Coralline Oolite or Coral Rag. Like all the other calcareous or arenaceous groups of the oolite, this is very irregular, and subject to great variations in character and thickness. There is a pretty close general resemblance in the Yorkshire and Wiltshire types, while in the intermediate district the whole group seems to disappear. It may be divided into three sub-groups—

c. Upper Calcareous grit,	maximum thickness	60	feet.
b. Coralline Oolite,	„	50	„
a. Lower Calcareous grit,	„	80	„

a. The Lower beds in Yorkshire are a series of grey marly sandstones seventy feet thick, passing up into cherty limestone, covered by sands full of great calcareous concretions capped by strong calcareous sandstones.

b. A variable group of irregular masses of nodules made of corals compacted together, often earthy, and connected by blue clay, passing into blue crystalline limestone, alternations of hard shelly oolite, and soft perishable limestone, and in Wiltshire a rubbly nodular oolite, sometimes pisolitic.

c. The Upper group, obscurely indicated in the south, is in the north like group *a*, but more ferruginous and less cherty, passing up by intercalation into the Kimmeridge clay above. —(*Phillips*).

Characteristic Fossils.

Plants: Carpolithes Bucklandi, conicus.

Sponges: Manon foliaceum; Scyphia cylindrica; Spongia floriceps.

Corals: Calamophyllia Stokesii; Cladophyllia Conybeari; Comoseris irradians; Dentipora glomerata; Goniocora socialis; Isastræa explanata, Greenhoughii, helianthoides; Montlivaltia dispar; Petroseris Waltoni; Rhabdophyllia Phillipsi; Stylina Delabechei, tubulifera; Thamnastræa arachnoides and rotata; Thecosmilia annularis.

Polyzoa: Terebellaria antilope.

Brachiopoda: Discina radiata; Terebratula bucculenta.

Conchifera: Avicula elegantissima, ovalis, tonsipluma; Crenatula Listeri; Exogyra nana; Gryphæa chamæformis, inhærens, mima; Lima læviuscula; Ostræa duriuscula, gregaria, palmetta; Pecten articulatus, cancellatus, inæquicostatus, similis, vimineus; Pinna lanceolata; Trichites Plottii; Arca quadrisulcata; Astarte aliena, extensa; Cardium lobatum; Corbula curtansata; Cucullæa contracta, pectinata, triangularis; Isocardia rhomboidalis; Lithodomus amygdaloides; Modiola inclusa; Opis Phillipsi; Pholadomya æqualis, paucicostata; Tancredia curtansata; Tellina? ampliata.

Gasteropoda: Actæon retusus; Bulla elongata; Cerithium muricatum; Chemnitzia Heddingtonensis, melanoides; Cirrus cingulatus; Murex Haccanensis; Natica arguta, nodulata; Nerinæa fasciata, Goodhallii, Roemeri; Pleurotomaria bicarinata; Trochus tornatus; Turbo funiculatus; Turritella cingenda, muricata.

Cephalopoda: Ammonites perarmatus, plicatilis, retroflexus, solaris, Sutherlandiæ, triplex, Williamsoni; Belemnites abbreviatus.

Echinodermata: Acrosalenia decorata; Astropecten rectus; Cidaris Blumenbachii, coronata, florigemma; Diadema æquale, pseudo-diadema; Dysaster ovalis; Echinus gyratus; Hemicidaris stramonium; Hyboclypus stellatus; Nucleolites emarginatus, orbicularis, planulatus, scutatus; Pygurus Hausmanni.

Annelida: Serpula runcinata, squamosa; Vermicularia ovata; Vermilia sulcata.

Crustacea: Glyphæa scabrosa.

Fish: Gyrodus punctatus; Hybodus obtusus.

Characteristic Fossils of the whole of Group C:

The following fossils are common to both divisions (Oxford clay and Coral rag) of the Middle or Coralline oolite:—

Conchifera: Avicula expansa; Gryphæa dilatata; Anatina undulata; Corbis lævis.

Cephalopoda: Ammonites cordatus.

Echinodermata: Dysaster ovalis.

D. The Portland or Upper Oolite is composed of three principal groups, viz.—10. The Kimmeridge Clay; 11. The Portland beds; 12. The Purbeck beds.

10. The Kimmeridge Clay is in some places a dark grey shaly clay, in others brownish or yellowish, containing bands of sand, or of calcareous grit or ferruginous oolite, and layers of nodules of septaria. In some places, especially in the district about the Isle of Purbeck, it becomes very bituminous, and the bituminous shale sometimes passes into layers of "brown shaly coal." Layers of a particular kind of oyster, called the *Ostræa deltoidea*, occur abundantly in some places, always appearing "in broad continuous floors parallel to the planes of stratification, the valves usually together, with young ones occasionally adherent to them, and entirely embedded in clay, without nodules or stones of any kind, and without any other organic remains in the layers."—(*Phillips*).

Characteristic Fossils.

Brachiopoda: Discina Humphresiana; Rhynconella inconstans.

Conchifera: Exogyra virgula; Ostræa deltoidea, læviuscula; Pecten distriatus; Pinna granulata; Astarte Hartwellensis, lineata; Myacites oblata; Mytilus pectinatus; Pholas compressa.

Gasteropoda: Chemnitzia gigantea; Patella latissima; Pleurotomaria reticulata.

Cephalopoda: Ammonites anceps, plicomphalus, rotundus, triplicatus.

Echinodermata: Cidaris bacculifera, spinosa, trigonocantha.

Fish: Asteracanthus ornatissimus; Hybodus acutus, leptodus; Ischyodus Egertoni; Sphærodus gigas; Strophodus reticulatus.

Reptiles: Ichthyosaurus trigonus; Plesiosaurus affinis, brachyspondylus, dædicomus; Pliosaurus brachydeirus, trochanterius, etc.

11. The Portland Beds. These, like most of the other members of the Oolitic series, have a variable composition, consisting of sands and sandstones below, becoming calcareous and passing into oolitic limestone above. They are therefore divisible into

b. Portland stone, consisting of white oolite and beds locally termed "stonebrash" and "roche," etc., interstratified with clays, and containing layers of flint . . about 90 to 100 feet.

a. Portland sands, consisting of brown or yellow sands and sandstones, full of green grains, like those afterwards to be described in the Greensands . . . . . about 80 feet.

Characteristic Fossils.

Corals: Isastræa oblonga.

Brachiopoda: none.

Conchifera: Exogyra spiralis; Lima obliquata; Ostræa expansa; Pecten lamellosus; Astarte cuneata; Cardium dissimile; Lucina Portlandica; Modiola pallida; Trigonia elongata, gibbosa, incurva.

Gasteropoda: Buccinum? naticoides; Cerithium concavum, Portlandicum; Natica elegans; Pleurotomaria rugata; Turritella concava.

Cephalopoda: none.

Echinodermata: none.

Annelida: Serpula triserrata.

Fish: Caturus angustus; Hybodus strictus; Ischyodus Townshendi.

Reptiles: Chelone planiceps.

The following fossils are common to the Kimmeridge clay and Portland stone:—

Conchifera: Thracia depressa; Trigonia clavellata.

12. The Purbeck beds are remarkably distinguished from the Portland on which they rest, by being chiefly of fresh-water origin. They contain, however, some marine species, which are allied to Oolitic more closely than to any other types. Edward Forbes therefore detached them from the base of the succeeding formations, and placed them at the top of the Oolitic series. They are also distinguished from most other aqueous rocks by containing one or two beds of "vegetable soil," called by the quarrymen "dirt beds," with the stems of trees and cycadoid plants still erect, and the trunks of trees prostrate alongside of them. This clearly points to a tranquil and gradual elevation of the surface of the rock into dry land, the growth of a forest through hundreds or thousands of years, and its as tranquil and gentle submergence beneath some stagnant water without sufficient current to disturb the soil or carry off the buried plants.

Edward Forbes divided the Purbecks of Dorsetshire into three groups, each characterised by a peculiar assemblage of organic remains, without any other very marked distinction between them, and with no sign of any physical disturbance or denudation.

a. The Lowest division, seventy or eighty feet thick, consists of calcareous flags, marls, and limestones, with cypridiferous shales and some siliceous bands, with one large and two or three smaller "dirt beds" near its lower portion. These are all either fresh-water or aerial, except twenty feet in the centre of the group, which are brackish water deposits, containing Rissoæ (Hydrobia), Protocardium, and Serpulæ.

b. The Middle Purbecks, forty or fifty feet thick, consist first of shales and limestones with thick bands of cherty stone, with impressions of leaves and many fresh-water shells; then the conspicuous "cinder bed," a great heap of small shells of *Ostræa distorta*, over which are other limestones and shales, some fresh-water, some brackish, and some purely marine, containing yet undescribed species of Pecten, Modiola, Avicula, and Thracia, together with a Protocardium distinct from that in the Lower beds. Many fish, Lepidotus and Microdon radiatus, and reptiles of the genus Macrorhyncus also occur. It is in a little band not more than six inches thick, about twenty feet below the "cinder bed," that the very remarkable discoveries of a number of remains of mammalian animals belonging to several genera and species have been made.—(*Lyell's Supplement*).

c. The Upper Purbecks, twenty or thirty feet thick, are another series of beds full of fresh-water shells distinct from those below, and of new forms of fish. The fresh-water snail shells are sometimes so abundant as to form a hard limestone, much used formerly as Purbeck marble.

It is remarkable that the fresh-water shells have a much closer resemblance to those living at other and more recent periods, or those now existing, than the marine species have. The three changes of life in this small group of Purbecks appear to be due solely to lapse of time, and to the consequent slow and gradual changes in the physical geography of the district, and not to any sudden or violent revolutions or disturbances of which there is no trace.*

* Professor Forbes mentions one set of beds as curiously dislocated and disturbed, apparently by causes not affecting the beds below; but this band of local disturbance is included in the Lower division, and is not accompanied by any change in the species, while, on the other hand, the great changes in the species take place at certain lines, where there is no lithological or petrological boundary whatever.—(*Report of British Association*, 1850).

Characteristic Fossils.

Plants: Chara Purbeckensis; Cyadeoidea megalophylla and microphylla; Dammarites Fittoni; Zamiostrobus Fittoni.

Brachiopoda: none.

Conchifera: Gryphæa bulla; Ostræa distorta, Purbeckensis; Perna Austeni; Anodonta Purbeckensis; Cardium cæruleum, coriaceum; Cyclas sp.; Cyrena elongata and parva.

Gasteropoda: Limnæa sp.; Melanopsis harpæformis; Paludina carinifera, etc.; Physa sp.; Planorbis sp.; Valvata sp.

Cephalopoda: none.

Echinodermata: Hemicidaris Purbeckensis.

Crustacea: Cypridea granulosa; Cypris granulata, gibbosa, leguminella, tuberculata, etc.

Insecta: Carabus elongatus; Cerylon striatum; Colymbetes; Cyphon; Helophorus; Limnius; Rhyncophora; Coleoptera; and species of Neuroptera, Orthoptera, Homoptera, and Diptera.

Fish: Aspidorhyncus Fisheri; Asteracanthus semiverrucosus and verrucosus; Ceramurus macrocephalus; Lepidotus minor; Leptolepis Brodiei and nanus; Microdon radiatus; Ophiopsis breviceps, dorsalis, pencillatus; Oxygonius tenuis; Pholidophorus granulatus and ornatus; Pleuropholis attenuatus.

Reptiles: Chelone obovata; Macellodus Brodiei; Macrorhyncus sp.; Nothetes destructor; Pleurosternon concinnum, emarginatum, latiocutatum, ovatum; Trettosternon Bakewelli.

Mammalia: Spalacotherium Brodiei; Triconodon sp.; Plagiaulax sp.; and four or five other genera yet unnamed.

In giving the lists of fossils characteristic of each set of beds, I kept out those common to the different members of the larger groups. There are still a few fossils to be mentioned which range from one of these groups into another, and thus link the whole Oolitic system together. With the exception of the Megalosaurus and some species said to be common to the Purbeck and Wealden beds, I believe there is no one species found in any rock deposited during the Oolitic period which has also been found in any rock deposited during any other periods.

Species common to the Lias (A) and the Bath Oolite (B):

Brachiopoda: Lingula Beanii.

Conchifera: Lima gigantea, punctata; Pecten cingulatus; Cardinia abducta, crassissima.

Species common to A and C (Coralline Oolite):

Conchifera: Modiola cuneata.

Species common to B and C:

Corals: Thamnastræa concinna.

Bryozoa: Heteropora ramosa.

Brachiopoda: Rhynconella varians; Terebratula impressa, ornithocephala.

Conchifera: Avicula inæquivalvis; Gervillia siliqua; Lima duplicata, pectiniformis, rigida; Pecten annulatus, demissus; Pinna mitis; Arca æmula; Cucullæa elongata, oblonga; Goniomya litterata and scripta; Isocardia tenera; Lithodomus inclusus; Lucina crassa; Myacites calceiformis; Tancredia curtansata; Trigonia costata and pullus.

Gasteropoda: Alaria trifida; Phasianella striata; Pleurotomaria granulata; Purpurina nodulata.

Cephalopoda: Ammonites macrocephalus.

Echinodermata: Echinus perlatus; Hemicidaris intermedia; Nucleolites orbicularis, scutatus, and sinuatus; Pygaster semisulcatus; Pygurus pentagonalis.

Crustacea: Glyphæa rostrata.

Species common to B and D (the Portland Oolite):

Conchifera: Pecten arcuatus; Cardium striatulum; Pholadomya ovalis.

Species common to C and D:

Brachiopoda: Lingula ovalis.

Conchifera: Exogyra nana; Gervillia aviculoides; Lima rustica; Ostræa solitaria; Astarte ovata.

Ireland.—The Oolitic series is represented in Ireland by a few thin beds of Lias only, not exceeding thirty feet in thickness, resting on the summit of the red saliferous marls of the Trias of the county of Antrim. It contains, however, a considerable abundance of characteristic Lias shells.

Scotland.—On the west coast, opposite the north-east of Ireland, Lias is found also in Scotland, together with Oxford clay, and other representatives of the Oolitic series; while on the east coast at Brora, etc., representatives of the Yorkshire oolites are found, containing also impure coal.

The series of rocks deposited in the British Islands during the Oolitic period is so complete, both petrologically and palæontologically, that they serve as a type for those known all over the world. In Europe, the term Jurassic is commonly used instead of Oolitic, the Jura mountain being principally composed of rocks belonging to this period. In tracing the rocks across Europe, differences, both lithological and palæontological, occur, as might be naturally expected; but, on the whole, a wonderful similarity in both characters extends over very large areas.

It will perhaps be most useful to give a few of the foreign synonyms of the different rock groups adopted by different Continental geologists.

A 1. Lower Lias.—Terrain sinémurien, grès du Luxembourg, calcaire de Valognes, grès de Lincksfield, Gryphiten kalk. Lower black Jura.

A 2. Marlstone.—Terrain liasien, marnes de Balingen, Amaltheen thon, Numismalen mergel. Middle black Jura.

A 3. Upper Lias.—Terrain toarcien, schistes de Boll, Posidonomya schiefer, Jurensis mergel, Opalinus thon. Upper black Jura and Lower brown Jura.

B 4. Inferior Oolite.—Terrain Bajocien, calcaire Lædonien, calcaire à polypien, marnes vésuliennes, Eisen-Rogenstein, discoidien mergel. Middle brown Jura.

B 5. Fullers' Earth; 6. Great Oolite; and, 7. Cornbrash.—Terrain Bathonien, calcaire de Caen et Ranville, Parkinsoni Bank. Part of brown Jura.

C 8 *a*. Kelloway Rock.—Terrain Callovien, Oxfordien inferieur. Part of brown Jura.

C 8. Oxford Clay.—Terrain Oxfordien, terrain argovien, terrain à chailles, Ornaten thon, Impressa kalk, Spongiten lager. Part of brown Jura and Lower white Jura.

C 9. Coral Rag.—Terrain corallien, schistes de Nattheim, calcaire à nérinées. Middle white Jura. (The lithographic flags of Solenhofen are believed to be in this group).

D 10. Kimmeridge Clay.—Terrain Kimméridgien, argiles noirs de Honfleur, marnes du Banné, calcaire à astartes. Part of the terrain portlandien of the geologists of the Swiss Jura, who call the lower part Terrain Séquanien; part of Upper white Jura.

D 11. Portland Beds.—Terrain portlandien, Upper white Jura, calcaire à tortues de Soleure.

D 12. Purbeck Beds.—These do not receive any exact synonym either in Pictet or in Vogt, the only two authorities accessible to me.

In other parts of the world, the rocks of the Oolitic (or Jurassic) period appear chiefly in their Yorkshire type—that is to say, as sandstones and shales with beds of coal and ironstone, or as Oolitic coal measures. Sir Charles Lyell gives a brief description of the Oolitic coal-field of Richmond in Virginia, which has one bed of coal forty feet thick. In India also coal occurs in beds, some of which contain ammonites, shells, and plants very similar to those found in the Oolitic rocks of Britain.

One of the most remarkable localities for rocks of the Oolitic period to occur in, with fossils very closely allied to those of Europe, is the Arctic regions. Captain M'Clintock brought home several fossils from the Arctic regions, consisting of ammonites and other shells, closely analogous to Oolitic species; and Captain Sir E. Belcher brought part of the remains of an ichthyosaurus from the same regions.

The questions thus raised as to the climate of the globe, when cephalopods and reptiles, such as we should expect to find only in warm or temperate seas, could live in such high latitudes, are not very easy to answer.

During the Oolitic period the following generic forms became extinct, in addition to those which were marked with an asterisk at its commencement:—

Plants: Calamites, Cyclopteris, Hymenophyllites, Otopteris, Pecopteris, Sphenopteris.

Brachiopoda: Leptæna, Spirifer—(neither seem to have survived the early part of the period, that in which the Lias was deposited).

Conchifera: Posidonomya, Cardinia.

Fish: Nemacanthus.

With these exceptions, none of the great genera of animals or plants that lived so abundantly during the Palæozoic epoch survived into this period, except some which lived still longer, a few even surviving to our own times.

CRETACEOUS PERIOD.

It is perhaps doubtful whether it would not be more advisable to divide the Oolitic period into two, calling the first portion Liassic, and treating it by itself. It is still more doubtful whether it would not be advisable to do the same with that on which we are now commencing, and treat the early part of the period as a distinct one, under the name of the Neocomian, or some other designation. For the present, however, it will be best to follow the classification adopted by Sir C. Lyell and others, calling the whole Cretaceous, but dividing the series of rocks into two strongly-marked divisions, called Lower and Upper, or the period of time into Earlier and Later Cretaceous.

The life of the period was abundant, as the known fossils within the British area contain land plants, fresh-water and marine shells and fish, large terrestrial and marine reptiles, and species of every class of animal that had hard parts capable of preservation, except birds and mammals, and even as regards these we must believe their absence to be accidental, since we have seen that they both existed during the preceding period, though their fossil remains are very rare.

The generic forms that first came into existence during this period are the following, those marked with an asterisk being peculiar to it, *i.e.*, becoming extinct or dying out at its close.

Plants: * Abietites, * Clathraria, Dracæna.

Amorphozoa: * Achilleum, * Brachiolites, * Cephalites, Chenedopora, * Choanites, * Cæloptychium, * Guettardia, Hippalimus, * Jerea, * Paramoudra, * Plocoscyphia, * Polypothecia, * Siphonia, Udotea, * Ventriculites.

Foraminifera: Gaudryina, Globigerina, Guttulina, Lingulina, Lituola, Orbitolina, Orbitolites? * Planulina, * Pyrulina, Quinqueloculina, Rosalina, Truncatulina, Verneuilina.

Zoophyta: Alcyonium? * Axogaster, * Chisma, * Choristopetalum, * Cœlosmilia, * Cyathina, * Cyclocyathus, * Diblasus, * Epiphaxum, * Holocystis, * Micrabacia, * Parasmilia, * Parastræa, * Peplosmilia, * Siphonodictyum, * Smilotrochus, * Spinopora, Stephanophyllia, * Synhelia.

Polyzoa: * Actinopora, * Atagma, * Ceriocava, * Clypeina, * Demeopora, * Domopora, * Entalophora, Eschara, Flustra, * Holostoma, * Homæosolen, Lunulites, * Multicrescis, * Proboscina, * Radiopora, * Reptocea, * Reptomulticava, * Reptotubigera, * Siphoniotyphlus, * Zonopora.

Brachiopoda: Argiope, * Magas, * Kingeana, Terebratulina.

Conchifera: Amphidesma, * Caprina, * Caprinella, * Caprotina, Chama, Cryptodon, Diceras (Requienia), Gastrochæna, * Hippurites, Neæra? Pachymya, Petricola, * Radiolites, Solecurtus, Spondylus, Tellina,[1] Teredo,[1] Thetis, Venus.[1]

Gasteropoda: Aporrhais, * Avellana, Cassidaria? Dolium? * Hipponyx, Nassa, Phorus, Pyrula, Rostellaria, Scalaria, Teredo,[2] Tylostoma, Voluta.

Heteropoda: * Bellerophina.

Cephalopoda: * Baculites, * Belemnitella, * Crioceras, * Hamites, * Helicoceras, * Ptychoceras, * Scaphites, * Turrilites.[3]

Echinodermata: * Ananchytes, * Arthraster, Bourgueticrinus, * Cardiaster, * Caratomus, * Catopygus, * Cyphosoma, * Discoidea, * Galerites, Goniaster (subgen. Astrogonium, * Goniodiscus, * Stellaster), Hemiaster, * Hemipneustes (or Toxaster), * Marsupites, * Micraster, * Oreaster, * Pyrina, * Salenia.

Cirripedia: Loricula, Scalpellum, Verruca.

Crustacea: Cythereis, Cytherella, Cythereidea, * Euoploclyttia, Grapsus? Mesostylus, * Meyeria, * Notopocorystes, Palinurus, Platypodia.

Fish: * Acrognathus, * Acrotemnus, * Aulodus, * Aulolepis, * Berycopsis, * Beryx, * Calamopleurus, Cestracion, * Cladocyclus, Cœlorhynchus, * Corax, * Decretis, Edaphodon, * Enchodus, * Homonotus, Hypsodon, Lamna, * Lophiostomus, * Macropoma, Notidanus, Orthagoriscus, * Osmeroides, Otodus, * Oxyrhina, * Pachyrizodus, * Phacodus, * Plethodus, * Pomognathus, * Prionolepis, * Ptychodus, * Saurocephalus, * Saurodon, * Scylliodus, * Stenostoma, Tetrapterus, * Tomognathus.

Reptiles: * Coniosaurus, * Dolichosaurus, * Hylæosaurus, * Iguanodon, * Leiodon, * Mosasaurus, Platemys, * Pœcilopleuron, * Pelorosaurus, * Polyptychodon, * Protemys, * Raphiosaurus, * Regnosaurus, * Suchosaurus.

TYPICAL GROUPS OF ROCK.—*S.E. England, N.W. France, Belgium, etc.*—The following is the entire series

[1] Unless the shells so called in older rocks be rightly named.
[2] Unless one so called in a Carboniferous rock be rightly named.
[3] Unless one reported from the Lias be truly named.

of rocks deposited during the great Cretaceous period in this area :—

		Feet.
UPPER CRETACEOUS.	8. Maestricht and Faxoe beds, pisolitic chalk	100
	7. White chalk, with flints	500
	6. White chalk, without flints	600
	5. Chalk marl	100
	4. Upper greensand	100
	3. Gault	150
LOWER CRETACEOUS or NEOCOMIAN.	2. Lower greensand	850
	2 *a.* Speeton clay[1]	60
	1. Wealden beds	1300

This classification is derived from the study of different parts of the area lying between Yorkshire and Orleans, and Dorsetshire and Denmark. As happens in other cases, there is no place where the whole series is present at once, and some of the members are very local and inconstant. The middle part of the Upper Cretaceous series is the most constant and best marked part of the group, giving us generally an easily recognisable geological horizon or band of demarcation between the beds below and above it.

We saw that at the close of the Oolitic period fresh-water deposits began to prevail within the area we principally contemplate. This involves the existence of large spaces of dry land in the neighbourhood, some of the surfaces of which have even their "soils" still preserved. It appears that a very large portion of the earth's surface must have been converted into dry land at this time in the neighbourhood of our area, for we have in the commencement of this period evidence of the existence of a great river, and the earliest deposit of this period appears to have been formed by the matter thrown down at the mouth of this river, and to be in fact a *fossil delta* as large as that of the Ganges or Mississippi. As, however, marine depositions must have been taking place in some other localities, it is to these that we should look if we wish to carry on our history with equipollent data; and it is believed that certain marine rocks, known as Neocomian,

[1] The exact position of the Speeton clay is a little uncertain. Professor E. Forbes, in Johnston's Physical Atlas, placed it at or below the base of the Lower greensand, on palæontological evidence alone.

from their occurring at Neufchatel (Neocomiensis) in Switzerland, are those which were the contemporaries of our fresh-water beds.

We will, however, first describe the beds of our own area, and take separately the Lower Cretaceous (or Neocomian) beds to begin with.

1. THE WEALDEN BEDS, so called from their now forming a district known as the Weald of Kent and Sussex, consist of a great series of sandstones and shales, with a few beds of limestone and ironstone occasionally, often full of large fragments of drift wood, and of the remains of fresh-water shells, and of some fresh-water and some land animals (reptiles). In general appearance the Wealden rocks not unfrequently resemble some of the coal measures of the true Carboniferous period.

The Wealden rocks are commonly divided into two groups:

	Feet.
b. The Weald clay	280
a. The Hastings' sand	1000

These distinctions, however, seem hardly to be carried out by any precise line of demarcation. The lower beds are more arenaceous, and the upper more argillaceous; but great beds of clay occur interstratified with the sandstones of the Hastings' sands, and beds of sandstone with the clays of the Weald clay. It is probable that these beds change their character laterally as well as vertically, great banks of sand and large deposits of mud having been formed side by side. The sandstones are sometimes impregnated with carbonate of lime, so as to become calciferous grits, and small beds of limestone (forming Petworth or Sussex marble), chiefly consisting of fresh-water snail shells (Paludina), occur here and there. Local names are given to the different parts of the Wealden series in different places, as Ashburnham beds, Worth sands, Tilgate beds, Horsham beds, etc.—(*Phillips*).

Characteristic Fossils.

Plants: Abietites Dunkeri, Linkii; Alethopteris elegans; Carpolithes Mantelli, sertum; Chara Valdensis; Clathraria Lyellii; Endogenites erosa; Equisetites Burchardi, Lyellii; Pterophyllum Brongniarti;

Sphenopteris gracilis, Mantelli, Sillimani; Thuytes Kurrianus; Zamiostrobus crassus, Pippingfordensis.

Conchifera: Corbula alata; Cyrena angulata, major, media, membranacea, subquadrata; Mytilus Lyellii; Psammobia Tellinoides; Unio aduncus, antiquus, compressus, cordiformis, Gualterii, Mantelli, Martini, porrectus, subtruncatus, Valdensis.

Gasteropoda: Actæon Popii; Bulla Mantelliana; Cerithium carbonarium; Melanopsis attenuata; Neritina Fittoni; Paludina elongata, fluviorum, Sussexiensis.

Crustacea: Cypridea Fittoni, granulosa? spinigera, tuberculata, Valdensis; Estheria elliptica, membranacea?

Fish: Acrodus Hirudo; Æchmodus mastodonteus; Asteracanthus granulosus; Hybodus dubius, striatulus, subcarinatus; Lepidotus Fittoni, Mantelli; Pycnodus Mantelli; Sphenonchus elongatus.

Reptiles: Cetiosaurus brachyurus, brevis; Chelone Mantelli; Goniopholis crassidens; Hylæosaurus Owenii; Iguanodon Mantelli; Pelorosaurus Becklesii, Conybeari; Platemys Dixoni, Mantelli; Pœcilopleuron Bucklandi; Pterodactylus Cliftii; Regnosaurus Northamptoni; Streptospondylus major; Suchosaurus cultridens.

The Megalosaurus Bucklandi occurs in the Wealden as well as in the Great Oolite of Stonesfield. The reptiles called Tretosternon Bakewelli and Goniopholis crassidens occur both in the Wealden and the Purbeck beds. These, with some shells that are nearly if not quite the same as some of those of the Purbecks, form a connection between the Wealden beds and those of the Oolitic series below. On the other hand, there is a still closer union with the beds above, in consequence of the close connection between the Wealden beds and the Lower Greensand, and between that and the Cretaceous rocks, as will be seen presently.

2. THE LOWER GREENSAND was formerly considered the base of the Cretaceous series, separated only by the occasional bed of clay called Gault from the Upper Greensand. When the Gault is absent, and the Upper rests on the Lower Greensand, it is difficult to separate them by any lithological distinctions, but when they are separated they are found to be very distinct palæontologically.

Where best shown (as at Atherfield, Isle of Wight, and Hythe, Kent; Fitton and Forbes and Ibbetson, J. of G. S., vols. i. and iii.), the Lower Greensand is found to be a great series of alternations of sands, sandstones, and clays, with occasional calcareous bands. The calcareous sandstones form hard bands, known as Kentish Rag; the clays are sometimes excellent fullers' earth, 60 feet in thickness, and are most abundant in the lower part of the formation, the upper being almost entirely sands. The general colour is dark brown, sometimes red, and the sands are often bound together by an abundance of oxide of iron, from which the formation was formerly called Iron Sand. It derives its name of Greensand from the occurrence of a number of little dark green specks (silicate of iron) which are sometimes so abundant as to give a greenish tinge to some of the beds; but the term "green" is generally quite inapplicable as a *description*, though it still remains as a commonly received *name*. The whole formation in Britain is very various in character. Its maximum thickness is 843 feet.

The beds immediately above the Wealden show sometimes a sort of passage lithologically, as if partly made up of those below, while the fossils are quite distinct, being entirely marine. It appears that a depression had taken place and allowed the sea to flow over the area which had been previously covered with fresh water. The change may thus be one of conditions rather than one of great lapse of time—a supposition strengthened by the fact of the bones of the Iguanodon Mantelli being found in the Lower Greensand, showing that that great reptile still lived on some neighbouring land, and that an occasional carcass of it was swept out to sea.

Characteristic Fossils.

Plants: Abietites Benstedi; Dracæna Benstedii; Zamiostrobus Sussexiensis.

Sponges, etc.: Conis contortoplicata.

Corals: Chisma furcillatum; Choristopetalum impar; Holocystis elegans; Siphodictyum gracile.

Brachiopoda: Discina lævigata; Lingula truncata; Rhynconella depressa, elegans, Gibbsiana, parvirostrum; Terebratula celtica, Faba, lentoidea, oblonga, prælonga, sella, Tamarindus.

Conchifera: Mon—Anomia asperrima, convexa, lævigata, radiata; Avicula depressa, ephemera, lanceolata, pectinata; Exogyra harpa, sinuata; Gervillia alæformis, anceps, linguloides; Hinnites Leymeriei; Inoceramus Neocomiensis; Lima Dupiniana, expansa, lingua, semisulcata, undata; Ostræa Leymeriei, retusa; Pecten Robinaldinus striato-punctatus; Perna Ricordiana; Pinna crassa, sulcifera; Spondylus complanatus. *Dim*—Arca Carteroni, Cornueliana, Dupiniana, Marrullensis, Raulini, securis; Astarte Beaumontii, obovata, striato-costata, substriata; Cardita Neocomiensis, quadrata; Cardium Austeni, Benstedi, Cornuelianum, Ibbetsoni, imbricatorium, Michelini, peregrinosum, Raulinianum, sphæroideum, subhillanum; Cyprina angulata; Corbis fibrosa; Corbula striatula; Crassatella Robinaldina; Cucullæa costellata, Gabrielis; Cypricardia undulata; Cyprina angulata; Diceras Lonsdalei; Gastrochæna dilatata; Isocardia ornata, similis; Leda scapha, spatulata; Lithodomus avellana, oblongus; Lucina globiformis, solidula; Modiola æqualis, bella, Carteroni, lineata, simplex; Myacites elongata, Neocomiensis, rotundata; Mytilus cuneatus; Nucula antiquata, impressa, obtusa; Pholadomya Agassizii, gigantea, Martini; Pholas prisca; Solecurtus Warburtoni; Sphæra corrugata; Tellina angulata, Vectiana; Thetis minor; Thracia Nicoletii; Trigonia alæformis, carinata, caudata, dædalea, nodosa, ornata; Venus Brongniartiana, Faba, Orbigniana, ovalis, Vectensis.

Gasteropoda: Actæon Albensis, marginatus; Cerithium attenuatum, Clementinum, Neocomiense, Phillipsi, turriculatum; Dentalium medium; Emarginula Neocomiensis; Eulima melanoides; Littorina conica, rotundata; Natica Cornuelliana, lævigata; Pleurotomaria Anstedi, gigantea; Pteroceras bicarinatum, Fittoni, Moreausianum; Rostellaria glabra, Robinaldina; Solarium Benstedi, minimum; Trochus Albensis; decussatus; Turbo munitus, Yonninus; Turritella Dupiniana.

Cephalopoda: Ammonites Carteroni, Cornuelianus, Deshayesii, furcatus, Hambrovii, Martini, Nutfieldensis; Ancyloceras gigas, grande, Hillsii, Matheronianus; Crioceras Bowerbankii; Nautilus inæqualis, plicatus, Saxbii.

Echinodermata: Cardiaster Benstedi; Diadema Antissodorense, Ibbetsoni, Mackesoni; Echinus? arenosus; Hemipneustes Fittoni; Nucleolites Olfersii; Salenia punctata.

Annelida: Serpula variabilis; Vermicularia polygonalis.

Cirrhipedia: Scalpellum simplex.

Crustacea: Meyeria magna.

Fish: Strophodus sulcatus.

Reptiles: Iguanodon Mantelli; Protemys serrata.

2 *a*. THE SPEETON CLAY of Yorkshire, a local band of dark clay, is almost certainly of the same age as the Lower Greensand, if not, as thought by Professor Forbes, a little older than it. It contains the following

Characteristic Fossils.

Conchifera: Astarte lævis; Corbula punctum; Cryptodon sculptum; Isocardia angulata; Mya phaseolina; Nucula subrecurva; Thracia Phillipsi.

Gasteropoda: Solarium tubulatum; Turbo pulcherrimus; Turritella Phillipsi.

Cephalopoda: Ammonites curvinodus, fissicostatus, hystrix, marginatus, nisus, nucleus, rotula, venustus; Ancyloceras Beanii, intermedium, Phillipsii; Belemnites jaculum; Crioceras Duvali, plicatilis; Hamites alternatus, raricostatus.

Echinodermata: Cidaris Phillipsii.

Annelida: Vermicularia Phillipsii.

Crustacea: Hoploparia prismatica; Meyeria mucronata, ornata; Palinurus uncinatus.

Fish: Macropoma Egertoni.

The only species common to the Lower Greensand and the Speeton Clay is the very characteristic Neocomian fossil, *Exogyra sinuata*.

From the nature of the beds, one being of fresh and the other of salt water origin, it is not likely that any aquatic species should be common to the Wealden and Lower Greensand. But the plant Lonchopteris Mantelli is found in both, as well as the Iguanodon.

The following species, however, are common to the Neocomian beds, and some member of the Upper Cretaceous series, and show a very close connection, in time, between the deposition of the rocks:—

Common to Wealden and Upper Greensand:—

Plants: Clathraria Lyellii.

Common to Lower Greensand and Gault:—

Conchifera: Gervillia solenoides; Lima Cottaldina; Ostræa macroptera; Myacites plicata; Cerithium Lallierianum.

Echinodermata: Pentacrinus Fittoni.

Cirrhipedia: Pollicipes unguis.

Common to Lower Greensand and Upper Greensand, or Lower Chalk:—

Plants: Chondrites fastigiatus.

Conchifera: Exogyra plicata; Pecten atavus, interstriatus, orbicularis, quinquecostatus; Myacites mandibula.

Cephalopoda: Nautilus Neocomiensis, pseudo-elegans, radiatus, undulatus.

Reptiles: Polyptychodon continuus.

Common to Lower Greensand and Upper Chalk, and intermediate beds :—

Polyzoa : Heteropora cryptopora.

Brachiopoda : Terebratella Menardi.

Echinodermata : Discoidea subuculus.

Crustacea : Cythereis interrupta, quadrilatera, triplicata; Cythere punctatula, which also ranges into the Eocene rocks.

Common to the Speeton Clay and the Gault :—

Coral : Trochocyathus conulus.

Conchifera : Rostellaria Parkinsoni ?

Cephalopoda : Ammonites planus.

Common to the Speeton Clay and Upper Greensand :—

Brachiopoda : Rhynconella lineolata.

Common to Speeton Clay and Lower and Upper Chalk :—

Foraminifera : Cristellaria rotulata.

Brachiopoda : Terebratulina striata.

I have so far, by the help of Morris' Catalogue, laid the state of the case before the student, as regards these beds in the British Islands. There are, however, some still unsolved difficulties with respect to these, inasmuch as in some Greensand deposits at Blackdown in Devonshire, fossils of the Lower Greensand, Gault, and Upper Greensand, seem to be curiously intermixed in such a way as to make the age of the deposit very doubtful. There are also some sands and gravels near Farringdon in Wiltshire, where Lower Greensand fossils are also mingled with others belonging to Upper Cretaceous rocks. Mr. Sharp believed these Farringdon gravel beds to be of more recent date than the chalk itself, though still belonging to the Cretaceous period.

As the fossils from these and from some other localities are often quoted as Greensand fossils, they are calculated to confuse our classification. I have, therefore, in the preceding lists omitted all such as are derived from the above-mentioned or other doubtful localities.

NOTE.—The existence of local groups of rock that will not exactly fit into the general series, either from their containing fossils different from those found in any other group, or from their uniting parts of two sets of fossils which are elsewhere distinct,—although sometimes perplexing, is neither unnatural nor different from what might be expected. It merely shows us that which has been often before insisted on, namely, that our series is a series of fragments, and not one of absolutely continuous succession. The intervals between beds have been often very great, those between formations incalculable, the local deposits formed here and there in these intervals will of course often have characteristics different from, or intermediate between, the preceding and following groups.

Switzerland.—The rocks of Neufchatel in Switzerland, which are looked upon as one of the best continental types of the beds deposited during this part of the Cretaceous period, are the following:—

		Feet.
5.	Yellow limestone, ... at least	130
4.	Yellow limestone, with siliceous masses .	43
3.	Yellow limestone, in broken beds . .	22
2.	Blue marl	32
1.	Lower yellow limestone . . .	22

These beds rest *unconformably* on the beds of the Portland oolite.—(*D'Archiac*, vol. iv. p. 556).

France.—D'Archiac gives the following as the type of the rocks of this period in the basin of the Seine.

C.	6. Green and ferruginous sand.
	5. Clay, with *Plicatula* and *Exogyra sinuata.*
B.	4. Variegated sands and sandy clays, with iron ore.
	3. Clays, with oyster shells, etc.
A.	2. Neocomian limestone and blue marl.
	1. White sand and ferruginous sand, with iron geodes.

He says that these groups overlap each other from east to west, but that the upper group (C) also spreads much more widely than the rest from north to south.

The following continental names for groups of rock belong to this part of the period, being more or less nearly contemporary with Lower Greensand:—Hils clay and Hils conglomerat; Biancone; Spatangus and Exogyra limestone; Marls of Hautrive; Terrain Urgonien, or "premier zone de rudistes;" and Terrain Aptien,* or argile à plicatules of D'Orbigny; the Hippurite limestone; etc.

* M. Renevier, after a detailed comparison of the British and Continental rocks, determined that the Lower Greensand of England was

Vogt gives the following as characteristic fossils for the following groups of this period:—

For Lower Neocomian:—

Brachiopoda: Rhynconella depressa.

Conchifera: Exogyra Couloni; Perna Mulleti; Trigonia carinata.

Cephalopoda: Ammonites radiatus; Belemnites binervius; Crioceras Duvali; Ptychoceras Emerici; Toxoceras elegans.

Echinodermata: Holaster L'Hardy; Pyrina pygæa; Toxaster complanatus.

For Upper Neocomian (Urgonien):—

Brachiopoda: Terebratula hippopus, sella.

Conchifera: Ostræa Leymerii; Caprotina ammonia, Lonsdalei; Caprinella Doublieri; Radiolites Neocomiensis.

Cephalopoda: Ammonites fascicularis, Dumasianus, ligatus; Ancyloceras Emerici; Scaphites Juani; Turrilites Emerici.

Echinodermata: Catopygus Renaudi; Cidaris cornifera.

For the Hils rocks:—

Brachiopoda: Terebratula sella, oblonga, tamarindus.

Conchifera: Perna Mulleti; Exogyra Couloni.

Cephalopoda: Ammonites radiatus, Asterianus, splendens, interruptus; Belemnites subquadratus; Nautilus elegans.

Echinodermata: Pyrina pygæa; Toxaster complanatus.

Annelida: Serpula antiquata, Phillipsii, reticulata.

For the Aptien:—

Brachiopoda: Terebratula sella.

Conchifera: Ostræa aquila, macroptera; Plicatula placunea; Thetis lævigata.

Gasteropoda: Avellana incrassata.

Cephalopoda: Ammonites Cornuellianus, fissicostatus, Matheroni, Royerianus; Ancyloceras gigas, Matheronianus; Hamulina Royeriana.

strictly contemporaneous with the Aptian beds, and, therefore, not according to him Neocomian, of which he says the Urgonian is the upper part. I should be inclined, however, to give a wider sense to the term Neocomian (in default of a better), and to include in it all beds of an age intermediate between the Purbecks and the Gault. If M. Renevier be right, it is probable that the Urgonian and other Neocomian beds of Switzerland, etc., are the exact marine representatives of the fresh water Wealden series.

UPPER CRETACEOUS BEDS.—We may now proceed to the examination of the Upper Cretaceous beds of our original area.

3'. GAULT. This is a stiff dark grey, blue, or brown clay, often used for brick-making. It can be seen very well at Cambridge and at Folkestone, but is by no means invariably present. The shells in it are often beautifully preserved, having been well packed and protected from atmospheric or other influences.

Mr. Sharpe was inclined to the opinion that the sands of Blackdown were of the same age as the Gault, being the littoral deposits of the same sea, in the deeper parts of which the clay was deposited.

Characteristic Fossils of the Gault* of this area.

Foraminifera: Cristellaria obsoleta; Dentalina legumen; Frondicularia inversa; Rotulina caracolla, etc.

Zoophyta (Corals): Bathycyathus Sowerbyi; Cyathina Bowerbankii; Cyclocyathus Fittoni; Trochocyathus Harveyanus, Kœnigi, Warburtoni; Trochosmilia truncata.

Brachiopoda: Rhynconella sulcata, antidichotoma; Terebratula obtusa.

Conchifera: Mon—Inoceramus sulcatus; Perna Rauliniana; Plicatula pectinoides. *Dim*—Anatina simplex; Cardita tenuicosta; Gastrochæna pyriformis; Mytilus Galliennei; Neæra? undulata; Nucula bivirgata, ornatissima, ovata, pectinata; Pectunculus umbonatus; Pholas constricta; Venus? tenera.

Gasteropoda: Actæon affinis, Vibrayeanus; Avellana Clementina, incrassata, inflata; Cerithium trimonile; Dentalium decussatum, ellipticum; Natica Cassisina, Clementina, gaultina; Pleurotomaria Gibbsii; Pyrula Smithii; Rostellaria buccinoides, calcarata, carinata, elongata, marginata, Parkinsoni; Scalaria Clementina, Dupiniana, gaultina.

Pteropoda: Bellerophina minuta.

Cephalopoda: Ammonites Beudantii, biplicatus, Bouchardianus, circularis, crenatus, cristatus, decipiens, denarius, lautus, ornatus, parvus,

* The fossils to which G. S. alone is appended in Morris' Catalogue, many of which are from Blackdown, are omitted. They are for the most part specifically different from those of the Gault, and often generically, but this may arise from their being of sand or shore loving species and genera, as well as from a difference in the age of the deposit. M. Renevier, however, says that there are Lower and Upper Greensand species mingled with those of the Gault in the Blackdown sands, so that the exact age of that deposit seems still to be doubtful.

Raulinianus, symmetricus, tuberculatus, varicosus; Ancyloceras spinigerum; Belemnites attenuatus; Hamites compressus, elegans, intermedius, maximus, nodosus, tuberculatus, turgidus; Helicoceras rotundus; Nautilus Clementinus; Ptychoceras adpressum; Turrilites bituberculatus, catenatus, elegans, Emericianus.

Echinodermata: Cardiaster bisulcatus; Cidaris gaultina; Hemiaster asterias, Baileyi, minimus.

Cirripedia: Pollicipes politus, rigidus; Scalpellum arcuatum.

Crustacea: Cythereis ciliata, gaultina; Cytherella appendiculata; Etyus? martini; Notopocorystes Bechei, Broderipii, Stokesii.

Fish: Ischyodus brevirostris; Ptychodus acutus.

The following fossils are also found in the Gault, but survived to a later part of the period, and are found in the Chalk :—

Foraminifera: Dentalina gracilis, sulcata; Flabellina cordata; Frondicularia Cordai; Nodosaria obscura; Rotalina umbilicata (also Tertiary and living); Vaginulina costulata; Verneuilina tricarinata.

Brachiopoda: Terebratella lima.

Conchifera: Exogyra conica; Inoceramus concentricus, Crispi; Lima elongata.

Gasteropoda: Solarium conoideum, ornatum.

Cephalopoda: Belemnites ultimus; Hamites armatus, attenuatus.

Annelida: Serpula antiquata; Vermicularia umbonata.

Crustacea: Cythereis cornuta (and Eocene); Cytherella Munsteri (and Miocene), ovata (and Eocene).

4. Upper Greensand. This set of beds often resembles the Lower Greensand in lithological character, but the same caution is to be used in taking its designation for a *name* only and not for a *description.* The sands are by no means always green, and other sands, especially some Tertiary sands, are to be found quite as green, or greener, than those which have received the name of Greensand. Beds and concretionary masses of calcareous grit occur in it, sometimes called Firestone, sometimes Malm rock. Concretions, probably coprolitic, containing phosphate of lime, also occur, and are valuable to the agriculturist. It has been surmised that the Upper Greensand may be in part a shore deposit, and therefore contemporaneous with, rather than preceding, the lowest

beds of the chalk, but wherever the two are together, we always find the Upper Greensand underneath the Chalk Marl.

Characteristic Fossils of the Upper Greensand.

Plants: Chondrites fastigiatus; Clathraria Lyellii; Strobilites Bucklandi.

Amorphozoa: Chenendopora complexa, fungiformis, etc.; Cnemidium astrophorum, cepæforme; Hippalimus fungoides; Jerea Carteri, etc.; Plocoscyphia meandroides, morchella; Polypothecia dichotoma, gregarea; Siphonia costata, pyriformis, etc.; Verticillites anastamosans.

Foraminifera: Orbitolina concava, plana.

Zoophyta: Micrabacia coronula; Parastræa stricta; Peplosmilia Austeni; Trochosmilia tuberosa.

Polyzoa: Ceriopora mammillosa, ramulosa; Cricopora gracilis; Domopora tuberculata.

Brachiopoda: Argiope megatrema; Lingula subovalis; Rhynconella Grasiana; Terebratula biplicata, ovata.

Conchifera: Mon—Avicula gryphæoides; Exogyra haliotoidea; Gryphæa vesiculosa; Inoceramus Coquandianus, cuneiformis, gryphæoides, lævigatus; Lima cenomanensis, ornata, semiornata, simplex; Ostræa canaliculata; Pecten asper, elongatus, quadricostatus, striato-costatus; Pinna Gallienni, Moreana. *Dim*—Arca carinata; Cardium Gentianum; Cucullæa glabra; Cyprina globosa, orbiculata; Lucina globosa; Pholadomya Mailleana; Thetis major; Trigonia Archiaci.

Gasteropoda: Natica Gentii; Pleurotomaria Rhodani; Pterodonta elongata?; Solarium granulatum; Turritella granulata.

Cephalopoda: Ammonites catillus, mammillaris, Renauxianus; Nautilus simplex.

Echinodermata: Ananchytes lævis; Caratomus rostratus; Cardiaster fossarius, suborbicularis; Cidaris insignis; Diadema Bennettiæ, Bonei, Desori, Rhodani, rotatum, subnudum, variolare; Discoidea minima; Echinus granulosus, inflatus; Goniopygus peltatus; Nucleolites cordatus, lacunosus, Morrisii; Salenia clathrata, lunulata, stellulata, umbrella.

Annelida: Serpula filiformis, rustica; Vermicularia concava, radiata.

Cirripedia: Pollicipes lævis.

Fish: Edaphodon Sedgwickii.

Reptile: Plesiosaurus pachyomus.

The following fossils are common to the Gault and Upper Greensand:—

Cephalopoda: Ammonites auritus, Beudantii, denarius, lautus, rostratus, Selliguinus, serratus, splendens.

Echinodermata: Cardiaster bisulcatus.

Annelida: Serpula articulata.

The following fossils are also found in the Upper Greensand, but survived to a later part of the period, and are found in the Chalk:—

Polyzoa: Ceriopora polymorpha.

Brachiopoda: Crania Parisiensis; Rhynconella compressa, latissima, nuciformis, triangularis; Terebratella pectita, lyra; Thecidium Wetherelli.

Conchifera: Inoceramus Cuvieri, mytiloides; Lima Hoperi, Mantelli; Ostræa frons, Normaniana, vesicularis; Pecten æquicostatus; Plicatula inflata; Spondylus striatus.

Cephalopoda: Ammonites falcatus, Mantelli, planulatus, varians; Nautilus Fittoni.

Echinodermata: Catopygus carinatus; Diadema M'Coyi; Galerites castanea; Salenia petallifera.

Annelida: Serpula plexus.

Crustacea: Bairdia subdeltoidea (and Tertiary and recent).

5. Chalk Marl. The top of the Upper Greensand becomes argillaceous, and passes upwards into a pale buff-coloured marl or argillaceous limestone, sometimes of sufficient consistency to be used as a building stone. This in its higher portion begins to lose the argillaceous character, and gradually passes into the soft white pulverulent limestone familiar to every one as chalk.

The only fossils which in Morris' Catalogue are mentioned as confined to the Chalk Marl are the following:—

Cephalopoda: Ammonites Mayorianus, Rhotomagensis; Turrilites Scheuchzerianus.

Echinodermata: Diadema Brongniarti, pustulatum, tumidum; Discoidea Favrina; Goniaster (Astrogonium) mosaicus; Hemiaster Morrisii.

6. WHITE CHALK WITHOUT FLINTS. This is a great mass of soft and often pulverulent limestone, thick bedded, the stratification often obscure, partly from the obliteration of the bedding planes, partly from the abundance of quadrangular and diagonal joints, the surfaces of which are often weather-stained, dirty green, or yellow. Nodular balls of iron pyrites, radiated internally, are frequent in it, and produce rusty stains about the rock.

7. WHITE CHALK WITH FLINTS. There are no lithological distinctions between the Lower and Upper Chalk, except the occurrence in the latter of rows of nodules of black flint, and occasionally of seams and layers of the same substance. These occur either along the planes of stratification or parallel to them, so that they point clearly out the original bedding of the rock.

It is rare to find, either in the Upper or Lower Chalk, anything but pure limestone or pure flint. Little pebbles,* however, sometimes occur in it, probably carried by the roots of plants; and in a cliff a little east of Dieppe, I once observed in the heart of the Upper Chalk, a little band, about 8 inches thick and 20 feet long, of brown clay or marl, perfectly inter-stratified with the chalk.

Although the Chalk and the Carboniferous Limestone are so different in texture and induration, there is yet a certain resemblance in the forms of the country they produce. Their hills have equally broad undulating grassy downs, the escarpments of which are quite smooth in the chalk, while they are notched into steps in the mountain limestone. Their valleys are equally marked by scaurs, and tors and pinnacles, as any one may see by comparing the forms of the rocks on the sides of the valley of the Seine with those in the valleys of Derbyshire. The forms are, of course, bolder, larger, and more durable in the latter than the former.

* At the recent meeting of the British Association at Dublin, Mr. Godwin Austen described a large boulder of granite, apparently of Scandinavian origin, as having been found in the chalk near London, together with many smaller fragments of the same rock.

Characteristic Fossils of the Lower Chalk.

Amorphozoa: Brachiolites fenestratus, Fittoni, etc.; Manon megastoma; Spongia paradoxica.

Foraminifera: Dentalina Lorneiana; Globigerina cretacea; Spirolina irregularis; Textularia trochus.

Zoophyta: Synhelia Sharpeana.

Brachiopoda: Rhynconella Cuvieri, Martini; Terebratella incerta; Terebratula albensis, capillata, rugulosa, semiglobosa, sulcifera.

Rudistes: Radiolites Mortoni.

Conchifera: Mon—Inoceramus latus, pictus, striatus, tenuis, undulatus, Websterii; Lima aspera, Galliennei, granosa, intermedia, Rauliniana, spinosa; Ostræa virgata; Pecten Beaveri, subinterstriatus; Spondylus fimbriatus, latus. *Dim*—Arca subacuta; Lutraria carinifera; Pholadomya decussata.

Gasteropoda: Actæon elongatus; Aporrhais stenopteris; Avellana cassis; Cassidaria? incerta; Dentalium difforme; Dolium? nodosum; Emarginula affinis, Guerangeri; Natica Dupinii; Phorus canaliculatus; Pleurotomaria Gurgitis; Scalaria compacta; Solarium catenatum, dentatum; Trochus Girondinus; Turbo gemmatus, Goupilianus, Mailleanus; Turritella turbinata; Tylostoma sp.; Voluta Mantelli.

Cephalopoda: Ammonites Austeni, cinctus, complanatus, Coupei, falcatus, Lewesiensis, navicularis, peramplus, rusticus, Sussexiensis, undatus, Woollgari; Baculites baculoides; Belemnitella plena; Hamites simplex; Nautilus Deslongchampsianus, elegans, expansus, Fleuriausianus, Largilliertianus; Scaphites æqualis, constrictus; Turrillites Bergeri, costatus, Desnoyersii, triplicatus, tuberculatus.

Echinodermata: Ananchytus planus, subglobosus, Trecensis; Cidaris dissimilis; Diadema ornatum; Discoidea cylindrica; Galerites subrotundus; Goniaster (Astrogonium) Coombii, latus; Micraster acutus; Oriaster coronatus; Pygurus Kœnigi; Pyrina ovulum, Pratti; Salenia Austeni, granulosa, etc.

Annelida: Serpula obtusa, unisulcata.

Cirripedia: Loricula pulchella; Pollicipes acuminatus; Scalpellum hastatum, lineatum, etc.

Crustacea: Enoploclytia Leachii, Sussexiensis, etc.; Grapsus? sp.

Fish: Acrognathus boops; Ischyodus Agassizii; Pycnodus marginalis.

Reptiles: Chelone Benstedi; Dolichosaurus longicollis; Ichthyosaurus campylodon; Plesiosaurus Bernardi, constrictus; Pterodactylus compressirostris, Cuvieri, giganteus; Raphiosaurus subulidens.

Characteristic Fossils of the Upper Chalk.

Plants: Carpolithes Smithiæ; Confervites fasciculata, Woodwardi.

Amorphozoa: Achilleum perreticulatum; Brachiolites elegans, labyrinthicus, etc.; Cephalites Bennettiæ, campanulatus, subrotundus, etc.; Chenendopora obliqua; Choanites Kœnigii; Cliona cretacea, glomerata, etc.; Cæloptychium agariciodes; Coscinopora globularis, pileolus, etc.; Guettardia angularis; Hippalimus radiciformis; Manon marginatum, osculiferum, etc.; Paramoudra Bucklandi; Polypothecia fissa, palmata, etc.; Scyphia tubulosa; Siphonia anguilla, clava, Morrissii, etc.; Spongia capitata, ramosa, etc.; Talpina dendrina, etc.; Udotea cancellata; Ventriculites alcyonoides, alternans, flexuosus, radiatus, Townsendi, etc.; Verticillites cretacea.

Zoophyta: Axogaster cretacea; Cælosmilia laxa; Diablasus Gravensis; Epiphaxum auloporoides; Parasmilia centralis, cultrata, etc.; Spinopora Dixoni.

Polyzoa: Actinopora Brongniarti, etc.; Alecto ramea; Atagma papularium; Cellepora megastoma; Clypeina tubæformis; Desmeopora semicylindrica; Diastopora grandis, ramosa, etc.; Discopora? radiata; Eschara cancellata, sexangularis, etc.; Escharina intricata; Flustra inelegans, tessellata, etc.; Hippothoa Johnstoni; Holostoma contingens; Homæosolen ramulosus; Idmonæa cretacea, etc.; Lunulites cretaceus; Marginaria Roemeri; Petalopora pulchella; Pustulopora pustulosa, etc.; Retepora? Gualteriana; Siphoniotyphlus plumatus; Tubulipora Brongniartii; Vincularia Bronnii.

Brachiopoda: Argiope Buchii; Crania costata, Ignabergensis, Parisiensis; Magas pumila; Rhynconella octoplicata, plicatilis, subplicata; Terebratella elegans; Kingeana pentangulata; Terebratula carnea, lentiformis; Thecidium Wetherellii.

Conchifera: Mon — Exogyra auricularis; Inoceramus annulatus, Brongniartii, cordiformis, digitatus, involutus, Lamarckii; Ostræa curvirostris, hippopodium, inæquicostata, semiplana, triangularis; Pecten atavus, concentricus, Dujardini, Marrottianus, nitidus, sexcostatus, virgatus; Pinna decussata, sulcata; Spondylus Brightoniensis, spinosus; Vulsella sp. *Dim* *—Chama inæquirostrata; Modiola quadrata; Teredo rotundus.

Gasteropoda: Hipponyx sp.; Nerinæa unicarinata.

Cephalopoda: Ammonites Griffithii, Oldhami; Belemnitella lanceolata, mucronata, quadrata.

Echinodermata: Arthraster Dixoni; Bourgueticrinus æqualis, ellipticus, etc.; Cardiaster excentricus, granulosus, etc.; Cidaris clavigera,

* The rarity of these, the higher class of bivalves, in the Upper and Lower Chalk, and that of Gasteropoda in the Upper Chalk, is very curious, and requires explanation.

sceptrifera, serrifera, vesiculosa, etc; Cyphosoma Kœnigi, ornatissimum, etc.; Discoidea Dixoni; Echinopsis pusillæ; Galerites abbreviatus, albo-galerus, etc.; Glenotremites paradoxus; Goniaster (Astrogonium) angustatus, lunatus, (Goniodiscus) compactus, Mantelli, rugatus, etc.; Marsupites lævigatus, Milleri, ornatus; Micraster cor-anguinum, cor-bovis, etc.; Ophiura serrata; Oriaster bulbiferus, pistilliferus, etc.; Pentacrinus Agassizii; Salenia Portlockii.

Annelida: Serpula amphisbæna, plana, vortex, etc.; Vermilia pentangulata, triata, etc.

Cirripedia: Pollicipes fallax, striatus; Scalpellum angustum, fossula, maximum, etc.

Crustacea: Cythere faba; Cythereis alata, macrophthalma; Mesostylus Faujasii; Pagurus Faujasii.

Fossils common to Upper and Lower Chalk, or of which it is not stated which they belong to:—

Plants: Cycadeoidea Saxbyanus?

Amorphozoa: Scyphia angustata, pedunculata.

Foraminifera: Bulimina brevis, ovulum, etc.; Cristellaria navicula; Dentalina affinis, lineolata; Flabellina elliptica, pulchra, etc.; Frondicularia striatula, etc.; Gaudryina rugosa; Globigerina cretacea; Lingulina sp.; Marginalina elongata, etc.; Nodosaria limbata, Zippei; Planulina turgida; Pyrulina acuminata; Rosalina marginata, etc.; Rotalina crassa, etc.; Spirillina cretacea; Spirolina irregularis; Textularia aciculata, etc.; Vaginulina strigilata; Verneuilina Bronnii.

Brachiopoda: Rhynconella Mantelliana; Terebratulina gracilis.

Conchifera: *Mon*—Exogyra laciniata; Inoceramus Cuvieri; Ostræa acutirostris; Pecten asellus, cretosus; Spondylus obliquus. *Dim*—Astarte lenticularis; Teredo amphisbæna.

Gasteropoda: Pleurotomaria perspectiva.

Cephalopoda: Baculites anceps, Faujasii; Nautilus lævigatus.

Echinodermata: Ananchytes ovatus, pillula; Goniodiscus Parkinsoni.

Cirripedia: Pollicipes glaber.

Crustacea: Bairdia siliqua; Cythere faba, umbonata.

Fish: Acrodus cretaceus, Illingworthi, transversus; Acrotemnus faba; Aulodus Agassizi; Aulolepis typus; Belonostomus attenuatus, cinctus; Berycopsis elegans; Beryx Lewesiensis, microcephalus, radians, superbus; Calamopleurus anglicus; Caturus similis; Cestracion canaliculatus; Cladocyclus Lewesiensis; Cælorhyncus cretaceus; Corax fulcatus, maximus; Dercetis elongatus; Edaphodon gigas, Mantelli; Enchodus halocyon; Gyrodus angustus, conicus, cretaceus; Homonotus dorsalis; Hybodus sulcatus; Hypsodon Lewesiensis; Lamna acuminata, raphiodon; Lepidotus punctatus; Lophiostomus Dixoni; Macropoma Mantelli; Microdon nuchalis, occipitalis; Notidanus microdon, pectinatus; Odontaspis raphiodon; Osmeroides crassus, granulatus, Lewesiensis, Mantelli; Otodus appendiculatus, crassus; Oxyrhina crassidens, Mantelli; Pachyrizodus basalis; Phacodus punctatus; Plethodus expansus, oblongus; Pomognathus eupterygius; Prionolepis angustus; Ptychodus altior, arcuatus, articulatus, decurrens, depressus, gibberulus, mammillaris, Oweni, paucisulcatus, polygyrus, rugosus, spectabilis; Pycnodus angustus, cretaceus, parallelus; Saurocephalus lanciformis, striatus; Saurodon Leanus; Scylliodus antiquus; Stenostoma pulchellum; Strophodus asper; Tetrapterus minor; Tomognathus leiodus, mordax.

Reptiles: Chelone Camperi; Coniosaurus crassidens; Leiodon anceps; Mosasaurus gracilis.

8. MAESTRICHT OR PISOLITIC CHALK. In parts of the North of France there occur curious banks of a white pisolitic limestone, resting apparently in hollows of the chalk, not always on exactly the upper portion of it, and being therefore apparently slightly unconformable to it. It occurs also sometimes on the same level as the lower beds of the Tertiary rocks about it. The fossils are rather peculiar, but some of them are true Cretaceous, while none I believe are Tertiary.

Near Maestricht, in Holland, also the chalk with flints (No. 7) is covered by a kind of chalky rock with grey flints, over which are some loose yellowish limestones, without flints, and being sometimes almost made up of fossils.

Similar beds containing some of the same fossils occur also at Faxoe in Denmark.

Characteristic Fossils.—Together with several true Cretaceous fossils, such as *Pecten quadricostatus, Belemnites mucronatus, Terebratula carnea,* etc., these beds contain species of the genera Voluta, Fasciolaria, Cypræa, Oliva, Mitra, Cerithium, Fusus, Trochus, Patella, Emarginula, etc., several of which genera are only elsewhere found in Tertiary rocks.

North of Ireland.—Some of the univalve shells just mentioned occur in the Chalk of the north of Ireland, which is generally a rather hard compact stone, and usually goes by the name of "the White Limestone." It contains flints and a large assemblage of the characteristic fossils mentioned previously. Its thickness, however, rarely if ever exceeds 150 feet. Underneath it occur occasionally some beds of a whitish sandstone speckled with green, very much resembling some of the beds of Greensand in the S.E. of England. Professor E. Forbes, however, once remarked to me that he thought it was more nearly of the age of the Gault from its fossils. It is called in the country "Mulatto stone." Its thickness is rarely more than 15 or 20 feet.

At the close of the Cretaceous period, the following generic forms, dating their origin from still earlier times, became finally extinct:—

Plants: Alethopteris, C; Chondrites,[1] S; Confervites, P; Cycadeoidea, O; Endogenites, C; Lonchopteris, O; Sphenopteris, O; Thuytes, O; Zamiostrobus, O.

Amorphozoa: Cnemidium, S; Coscinopora, D; Manon, O; Scyphia, D; Verticlites, S?

Foraminifera: Bulimina, O; Flabellina, O; Frondicularia, O; Sagrina, O; Vaginulina, O.

Zoophyta: Trochocyathus, O.

Polyzoa: Alecto, O; Ceriopora, S; Pustulopora, C; Vincularia, C.

Brachiopoda: There are no generic forms found fossil in the Chalk that are not living at the present day; the Cretaceous species only being extinct.

Rudistes: The whole order (if it be one) confined to the Cretaceous period, none being known of either earlier or later date.

Conchifera: Mon—Exogyra, O; Gervillia, C? or O; Gryphæa, O; Inoceramus, C? or O; *Dim*—Myacites, S; Opis, T; Sphæra, T.

Gasteropoda: Nerinæa, O; Pleurotomaria, S.

Pteropoda: No extinct genus survived into the Cretaceous period.

Cephalopoda: Ammonites, T; Ancyloceras, O; Belemnites, T; Turrilites,[2] L?

Echinodermata: Diadema? O; Goniopygus, O?; Nucleolites, O; Pygurus, O.

Fish: Acrodus, T; Æchmodus, L; Asteracanthus, L; Belonostomus, L; Caturus, L; Hybodus, T; Ischyodus, L; Lepidotus, L; Microdon, u O; Sphenonchus, L; Strophodus, O.

Reptiles: Cetiosaurus, O; Goniopholis, u O; Ichthyosaurus, L; Megolosaurus, O; Plesiosaurus, L; Pterodactylus, L; Streptospondylus, O; Tretosternon, O.

[1] These plants do not range higher than the Wealden and Lower Greensand; this and the three following are not genera in the ordinary sense of the term, but merely provisional groups.

[2] Provided the Turrilites Valdani for the Lias be rightly determined.

CHAPTER XIV.

TERTIARY EPOCH.

Preliminary Observations.

THE nomenclature of the Tertiary periods proposed by Sir C. Lyell, and now all but universally adopted, is more systematic than that of the Primary or Secondary periods. It is based on the gradual increase of recent (*i. e.*, living) species in the newer rocks. The earliest of the periods is termed Eocene, from the Greek words ἠώς and καινός, signifying the dawn of the recent; the second, Miocene, from μείων the minority; the third, Pliocene, from πλείων the plurality of recent species; and the next, Pleistocene, which expresses the recentness of the great majority of the species.

To these we may add the present period itself, which we may perhaps most conveniently designate as the Recent or the Human Period.

The adoption of this principle of classification was rendered more necessary in the case of the Tertiary than the preceding epochs, from the nature of the physical conditions of Western Europe, on the structure of which our classification is chiefly based.

In the Primary and Secondary epochs, the part now occupied by Western Europe seems to have always contained more sea than land, and the rocks deposited are accordingly so widely spread as frequently to overlie and rest one upon the other. We can therefore often determine their order of superposition by their geognostic relations only, that is by actually tracing each group of beds till we find it plunging under the superior group on the one side, or till the inferior group rises up to the surface from underneath it on the other. When, however, we come to examine the Tertiary rocks of the same area, we find them more isolated and occurring in smaller and more detached patches, each patch ending before it comes in contact with the rest, so that their order of superposition can rarely be determined by simple inspection. To take a conspicuous instance at once:—The Chalk of the S.E. of England is continuous with that of France * and Belgium, and no mistake could possibly be made as to the relative position of the beds above and below it. The Oolites below the Chalk are even still more extensive, and can be traced both geognostically and palæontologically. The Tertiary beds above the Chalk, however, form isolated districts in the hollows of the Chalk, one being called the Hampshire basin, another the London, and a third the Paris basin; and if we wish to determine whether the beds of these three districts are of the same age, or whether one be older than another, it is obvious that we can no longer employ the positive evidence of an inspection of their superposition, but must have recourse either to the petrographical evidence of their being made exactly of the same kinds of rock occurring in the same order, or to the palæontological evidence of their containing the same assemblages of fossils occurring in the same order; or if neither rocks nor fossils were the same, then we should have to fall back on the general rule or principle just spoken of, and see which contained an assemblage of fossils having the greatest approximation to living forms, and this in the case of Tertiary rocks is most easily determined by the relative percentage of actually existing species.

* That the shallow furrow of the Straits of Dover has been worn down a little way below the level of the sea into the body of the Chalk does not of course affect this assertion.

THE EOCENE PERIOD.

Life of the Period.—The general character of the life of the period was so obviously identical with that of the life of our own days, that any summary respecting what is known of it either in the British or other provinces, is no longer necessary. The number of living species among the fossils of this period does not exceed five per cent, but in the earliest rocks of the period there is scarcely one living species (if indeed there be one) to be found.

The new generic forms now for the first time making their appearance within the British area during this period are the following, those confined to the period being distinguished as before by an asterisk :—

Plants : * Callitrites, * Cupanoides, * Frenelites, * Hightea, * Leguminosites, * Mimosites, * Nipadites, * Petrophiloides, * Solenostrobus, * Tricarpellites, * Wetherellia, * Xulionosprionites.

Foraminifera : Alveolina, Biloculina, Globulina, * Nummulites, Operculina, Robulina, Triloculina.

Zoophyta : * Astrocœnia, Balanophyllia, * Dasmia, * Dendrophyllia, * Diphelia, * Holaræa, * Litharea, * Mopsea, Oculina, * Paracyathus, * Stereopsammia, Stylophora, Turbinolia, * Websteria.

Polyzoa and Brachiopoda: No genera of the first apparently, certainly none of the latter originated in Eocene times. No undoubted genus of Brachiopoda has been produced since the Cretaceous period, most of the genera being of Palæozoic date.

Conchifera: Dim—Cardilia, Clavagella, Cyclas, Diplodonta, Dreissena, Kellia, Glycimeris, Nucinella, Panopæa, Solen,[1] Syndosmya, Teredina.

Gasteropoda: Achatina, Adeorbis, Ancillaria, Ancylus, Auricula, Bifrontia, Bulimus, Calyptræa, Cancellaria, Clausilia, Conus, Craspedopoma, Crepidula, Cuma, Cyclostoma, Cypræa, Fasciolaria, Helix, Limnæa, Marginella, Melampus, Melania,[2] Mitra, * Nematura, Niso, Odostomia, Oliva, Ovula, Pedipes, Planorbis,

[1] Unless the shell called Solen, from the Carboniferous limestone, be a true Solen.

[2] Unless a doubtful species from the Carboniferous limestone be a true Melania.

Pleurotoma, Pseudoliva, Pupa, Pyramidella, Ringicula, Rotella, Sigaretus, Strombus, Succinea, Terebellum, Terebra, Triton, Typhis, Volvaria.

Pteropoda: No new forms known.

Cephalopoda: * Beloptera, * Belosepia.

Echinodermata: * Eupatagus, * Schizaster, Spatangus.

Annelida: Ditrupa.

Cirripedia: Balanus.

Crustacea: * Archæocarabus, * Basinotopus.

Fish: * Acestrus, Accipenser, Ætobatis, * Ampheristus, * Auchenilabrus, * Bothrosteus, * Brachygnathus, * Calopomus, Carcharodon, * Calocephalus, * Cœloperca, * Cœlopoma, Elasmodus, * Eurygnathus, * Glyphis, * Goniognathus, * Halecopsis, * Labrophagus, * Laparus, Lepidosteus, * Loxostomus, Megalops, Merlinus, Myliobatis, Myripristis, * Naisia, * Pachycephalus, * Percostoma, * Periodus, * Phalacrus, * Phasganus, * Phyllodus, * Pisodus, * Platylæmus, * Podocephalus, * Pomophractus, Pristis, * Psaliodus, * Ptychocephalus, * Rhinocephalus, * Rhipidolepis, * Rhoncus, * Rhyncorhinus, * Sciænurus, * Scombrinus, Silurus, * Sphyrænodus, Spinax, * Teratichthys.

Reptiles: Alligator, Crocodilus,[1] Emys, Gavialis, * Palæophis, * Paleryx, Trionyx.[2]

Birds: * Halcyornis, * Lithornis, * Gastornis (France).

Mammalia: * Anoplotherium, * Chæropotamus, * Coryphodon, Dichobune, * Dichodon, Didelphys, * Hyopotamus, * Hyracotherium, * Lophiodon, Macacus, * Microchærus, * Palæotherium, * Paloplotherium, * Spalacodon, Vespertilio?

The following additional genera of Mammalia have been found in rocks of this period in France:—

* Adapis, * Aphelotherium, * Anchilopus, Anchitherium, Canis, Cynodon, * Eurytherium, Halitherium, * Lophiotherium, Myoxus, Oplotherium. * Pachynolophus, Palæonyctis, Propalæotherium, Sciurus, * Xiphodon.

[1] Unless certain fragments from the Wealden be true Crocodiles.

[2] Unless fragments from the Oolitic rocks of Scotland be those of true Trionyx.

TYPICAL GROUPS OF ROCK.—*S.E. of England, London and Hampshire basin*—

				Feet.	
UPPER EOCENE.	8. Hempstead series.	*d.* Corbula beds .	25	175	
		c. Upper fresh-water and estuary marls	40		
		b. Middle . .	50		
		a. Lower . . .	65		
	7. Bembridge series.	*d.* Upper marls .	90	115	
		c. Lower marls .			
		b. Oyster bed .			
		a. Limestone .	25		
					290
MIDDLE, OR PARIS EOCENES.	6. Osborne series.	*b.* St. Helen's sands	50	70	
		a. Nettlestone grits	20		
	5. Headon series.*	*c.* "Upper fresh-water" . .	85	182	
		b. Middle marine	30		
		a. "Lower fresh-water" . .	67		
	4. Bagshot series.	*d.* Upper Bagshot	200	1270	
		c. Barton clay .	300		
		b. Bracklesham beds . . .	110		
		a. Lower Bagshot	660		
					1522
LOWER, OR LONDON EOCENES.	3. London clay, or Bognor series.	. . . . . .			480
	2. Plastic clay .	. . . . . .			160
	1. Thanet sands.	. . . . . .			90
					2547

THE LOWER EOCENE GROUP.

The surface of the chalk on which the Eocene beds rest is generally eroded into hollows and undulations, showing a marked but not a very wide unconformity, as when the chalk is greatly tilted, the Lower Eocene beds partake of the disturbance to an equal amount.

1. THANET SANDS. Light coloured quartzose sand, mixed in the lower beds with much argillaceous matter, but never

* The total thickness of the fluvio-marine strata of the Isle of Wight, reckoning from the base of the Headon series, will be about 540 feet.

passing into actual clay; containing occasionally dark green grains, like those mentioned before in the Greensands. It rests almost invariably on a stratum of chalk flints, from which the chalk seems to have been washed away without wearing or fracturing the flints, and these are of a bright olive colour externally, by which they may be recognised in other beds (tertiary or drift), to which they may have been subsequently carried. The Thanet sands are very constant in character from the Isle of Thanet throughout the London basin, but thin out to the westward, till a little north of Windsor they are only four feet thick, shortly beyond which the beds disappear entirely.—(Prestwich, *Geological Journal*, 1852, p. 235).

Characteristic Fossils.

Plants: Traces of carbonised plants and fragmentary vegetable impressions.

Amorphozoa: Long tubular casts, probably fucoidal or spongiform. Sponge spiculæ.

Foraminifera: Cristellaria **platypleura**; Rosalina **Mariæ**; Polymorphina **ampulla**.

Conchifera: Arca **one or two small species**; Cardium **large sp.**; Crassatella **sp.**; Cyprina **sp.**; Cytherea **orbicularis**; Leda **substriata**; Nucula **fragilis**; Ostræa **small species**; Panopæa **granulata**; Pecten **Prestwichii**; Pholadomya **cuneata, Koninckii**; Sanguinolaria **Edwardsii**; Saxicava **compressa.**

Gasteropoda: Ampullaria (Natica) **subdepressa**; Scalaria **Bowerbankii**; Trophon **subnodosum.**

Crustacea: Cythereis **small species.**

Fish: Scales and small bones.

In addition to the above, the following fossils are found in the Thanet sands, which survived to still later periods, viz.—

Up to the Plastic clay only :—

Conchifera: Cucullæa **crassatina**; Glycimeris **Rutupiensis.**

Up to the basement bed of the London clay :—

Conchifera: Astarte **tenera**; Cyprina **Morrisii.**

Up to the London clay :—

Foraminifera: Nodosaria **bacillum**; Cristellaria **Wetherelli.**

Conchifera: Nucula **Bowerbankii**; Thracia **oblata.**

Up to the Bracklesham beds :—

Conchifera: Corbula longirostris.

Up to the Barton clay :—

Conchifera: Corbula globosa; Nucula margaritacea; Ringicula turgida

Gasteropoda: Calyptræa trochiformis; Dentalium nitens.

2. The Plastic Clay, or the Woolwich and Reading series of Prestwich. This group is more variable in character than that of the Thanet sands, and also more widely extended, becoming thicker from east to west or in the opposite direction to the Thanet sands.

On the east, near Herne Bay, we have in it—

	Feet.
c. Argillaceous greensand	12
b. Dark grey argillaceous sand with nodules of iron pyrites	7
a. Light ash green and yellow sands	9
	28

At Black Heath it consists of—

	Feet.
Pebble beds	12
Brownish sand	2
Comminuted shells in light coloured clay with pebbles	6
Light green sandy clays	7
Light green sands with pebbles	6
	33

Near Reading the beds are—

	Feet.
e. Mottled red and light bluish grey clay	20
d. Laminated yellow sands	2
c. Light grey and greenish sandy clay	4
b. Fine yellow sand	8
a. Greensand with Ostræa Bellovacina	2
	36

But these beds are more than fifty feet thick in other parts of the district.

At New Haven, an outlier of the Hampshire district—

		Feet.
i.	Grey clay and dark yellow sand	12
h.	Round flint pebbles in grey clay and yellow sand .	1
g.	Laminated grey clay with seams of yellow sand .	8
f.	Concreted oyster rock (O. Bellovacina) . .	2
e.	Comminuted shells in yellow sand and grey clay .	6
d.	Yellow, brown, and red sand in layers . .	5
c.	Dark grey clays with ironstone	20
b.	White, ochreous, and green sand	25
a.	Green and ferruginous coated flints in sand . .	2
		81

In Alum Bay, Isle of Wight, these beds are from 90 to 140 feet thick, consisting of bright-coloured tenacious mottled clays, the prevailing colour being blood-red, but having mixtures of light-bluish grey and yellow, light and dark slate colour, lavender, puce, yellow and brown—almost free from any admixture of sand.*—(Prestwich, *G. J.*, 1854, vol. x. p. 75.)

The Druid Sandstones, Grey Weathers, Sarsenstones, and Puddingstones, scattered in loose blocks over many of the chalk downs around the London basin, are believed by Mr. Prestwich to be consolidated portions of the sands and gravels of the Plastic clay series.

Characteristic Fossils.

Plants: Many beautiful leaves and some stems from the clays near Reading, etc.

Amorphozoa: Spiculæ of sponges.

Conchifera: Mon—Avicula arcuata, papyracea; Ostræa Bellovacina, cariosa, edulina, elephantopus, pulchra, tabulata. *Dim*—Arca depressa, impolita, nitens; Astarte donacina, tenera; Cardium Laytoni, Plumsteadiense; Corbula Arnouldii, Regulbiensis; Cyprina Morrissi, nana, planata; Cyrena cordata, cuneiformis, deperdita, tellinella; Cytherea Bellovacina, convexa, obliqua; Dreissena serrata; Leda striata; Modiola Mitchelli, dorsata, simplex, subcarinata; Nucula amygdaloides, Bowerbankii, compressa, inflata, Wetherellii; Panopæa puella; Pectunculus Plumsteadiensis; Pholadomya Dixoni, margaritacea, virgulosa; Psammobia Condamini; Syndosmya splendens; Unio Deshayesi?

* I have given these beds in a little more detail than their relative importance deserves, as a good example of the variable character of some of the Tertiary beds of W. Europe.

Gasteropoda: Auricula pygmæa; Buccinum (Pseudoliva) fissuratum; Cerithium Bowerbankii, funatum, gracile, Lunnii; Fusus gradatus, latus, planicostatus; Hydrobia Parkinsoni, Websteri; Melania inquinata; Melanopsis buccinoidea; Murex foliaceus; Neritina consobrina, globulus, pisiformis, vicina; Planorbis hemistoma, lævigatus; Triton fasciatus.

Crustacea: Candona Richardsoni; Cythere angulatopora, Kostellensis, Mulleri, plicata, torosa, Wetherellii.

Fish: Edaphodon sp.; Lamna dubia? Lepidosteus sp.; Myliobatis sp.

Reptiles: Chelone, fragments of.

Birds: First phalangeal bone of a bird's foot.

Mammalia: Hyracotherium cuniculus; Lophiodon or Coryphodon, fragments of.

Besides the preceding fossils, the following also occur in the Plastic clay group, but survived into later periods, viz.—

Up to the London Clay:—

Conchifera: Teredina personata; Teredo antenautæ.

Fish: Lamna Hopei.

Up to the Bracklesham beds:—

Conchifera: Ostræa tenera.

Up to the Barton beds:—

Conchifera: Ostræa gigantea; Lucina mitis; Modiola elegans; Nucula minima, similis; Melanopsis ancillaroides; Natica Hantoniensis, labellata (or glaucinoides).

Gasteropoda: Buccinum junceum; Natica labellata; Pleurotoma comma.

Up to the present day (in the Nile):—

Gasteropoda: Paludina lenta.

3. The London Clay. In the London basin this consists of—

b. Dark grey and brown clay, with layers of septaria or cement-stones, varying from 200 feet on the west to 480 on the east about Sheppey Island.

a. Basement bed, yellow, green, and ferruginous sands, and occasionally clays with layers of rounded flint pebbles, having a total thickness of about five feet, and resting on the slightly eroded surface of the beds below.

In the Hampshire basin we have—

b. Dark blue clays and sands, containing nodules of argillaceous ironstone with bands of grey clayey sands and dark-greenish sands, sometimes compacted into hard stone called Bognor rock, having a total thickness varying from 193 to 363 feet.

a. Basement bed of sand and clay, with a conglomerate of round flint pebbles and partly rounded fragments of chalk and of the mottled clays below, 4 to 5 feet.

Characteristic Fossils.

Plants: Callitrites Comptoni, crassus, etc.; Cupanoides corrugatus, etc.; Frenelites elongatus, etc.; Hightea attenuata, elegans, etc.; Leguminosites cordatus, gracilis, planus, etc.; Nipadites acutus, Burtini, etc.; Petrophylloides cellularis, oviformis, etc.; Solenostrobus corrugatus, etc.; Tricarpellites aciculatus, curtus, rugosus, etc.; Wetherellia variabilis; Xulionosprionites latus, etc.

Foraminifera: Anomalina sp.; Dentalina acuta, adolphina, consobrina, etc.; Frondicularia sp.; Marginulina Wetherellii; Nodosaria affinis, rustica, etc.; Textularia carinata.

Zoophyta: Dasmia Sowerbyi; Leptocyathus elegans; Mopsea costata; Paracyathus brevis, caryophyllus; Turbinolia minor, Prestwichii; Websteria crisoides.

Polyzoa: Eschara Brongniarti; Flustra crassa.

Brachiopoda: Lingula tenuis; Terebratulina striatula.

Conchifera: Mon—Pecten duplicatus; Pinna affinis, arcuata. *Dim*—Astarte rugata; Cardita Brongniartii; Cardium nitens semigranulatum; Corbula globosa; Cryptodon angulatum, Goodhalli; Cytherea tenuistriata; Isocardia sulcata; Lucina Goodhalli; Modiola depressa; Neæra inflata; Pectunculus brevirostrum, decussatus; Tellina subrotunda.

Gasteropoda: Aporrhais Sowerbyi; Buccinum? junceum; Cancellaria læviuscula; Cassidaria Smithii, striata; Cypræa oviformis, Wetherellii; Dentalium anceps, nitens; Eulima subulata; Fusus bifasciatus, complanatus, coniferus, curtus, trilineatus, tuberosus; Murex coronatus, cristatus, spinulosus; Natica microstoma; Ovula retusum; Phorus extensus; Pleurotoma acuminata, fusiformis, Volgeri, Waterkeynii, etc.; Pyrula Smithii; Rostellaria lucida; Scalaria reticulata; Solarium bistriatum; Turritella? scalaroides; Typhis muticus; Voluta denudata, elevata, protensa, tricorona, Wetherellii.

Cephalopoda: Belemnosis plicata; Beloptera Levesquei; Nautilus centralis, imperialis, regalis, Sowerbyi, urbanus.

Echinodermata: Astropecten armatus, Colei, crispatus; Cainocrinus tintinabulum; Cœlopleurus Wetherellii; Goniaster (Astrogonium) marginatus, Stokesii, tuberculatus; Hemiaster Bowerbankii, Prestwichii; Pentacrinus Okeshottianus, Sowerbyi, subbasaltiformis; Schizaster D'Urbani.

Annelida: Ditrupa plana; Serpula prismatica, trilineata; Vermicularia Bognoriensis; Vermilia crassa.

Cirripedia: Scalpellum quadratum.

Crustacea: Archæocarabus Bowerbankii; Basinotopus Lamarckii; Cythere barbata; Hoploparia Bellii, gamaroides; Zanthopsis bispinosa, hispidiformis, tuberculata, unispinosa.

Fish: Acestrus ornatus; Accipenser Toliapicus; Ampheristus Toliapicus; Auchenilabrus frontalis; Bothrosteus minor; Brachygnathus Mulleri; Calapomus porosus; Carcharodon subserratus; Cœlocephalus salmoneus; Cœloperca latifrons; Cœlopoma Colei, læve; Cybium macropomum; Eurygnathus cavifrons; Goniognathus coryphænoides, maxillaris; Gyrodus lævior; Halicopsis lævis; Hypsodon oblongus, Toliapicus; Labrophagus esocinus; Lamna compressa, subulata, verticalis; Laparus alticeps; Loxostomus mancus; Megalops priscus; Merlinus cristatus; Myliobatis acutus, canaliculatus, Colei, goniopleurus, gyratus, heteropleurus, jugalis, lateralis, Oweni, punctatus, striatus; Myripristis Toliapicus; Otodus macrodus; Pachycephalus cristatus; Percostoma angustum; Phalacrus cymbioides; Phasganus declivis; Phyllodus irregularis, marginalis, medius, planus, polyodus, Toliapicus; Pisodus politus; Podocephalus nitidus; Pomophractus Egertoni; ? Pristis bisulcatus; Psaliodus compressus; Ptychocephalus radiatus; Pycnodus Toliapicus; Rhinocephalus planiceps; Rhipidolepis elegans; Rhoncus carangoides; Rhyncorhinus branchialis; Sciænurus Bowerbankii, crassior; Scombrinus nuchalis; Sphyrænodus crassidens, priscus; Teratichthys antiquitatis; Tetrapterus priscus.

Reptiles: Chelone breviceps, convexa, crassicostata, cuneiceps, latiscutata, longiceps, planimentum, subcarinata, subcristata; Crocodilus champsoides, Toliapicus; Emys bicarinatus, Comptoni, Delabechei, lævis, testudiniformis; Palæophis Toliapicus; Platemys Bowerbankii, Bullockii; Trionyx pustulatus.

Birds: Halcyornis Toliapicus; Lithornis vulturinus, etc.

Mammalia: Coryphodon eocænus, etc.; Hyracotherium leporinum.

Besides the preceding fossils, the following are also found in the London clay, but survived into still later periods, viz.—

Up to the Bracklesham beds only:—

Plant: Cucumites variabilis.

Gasteropoda: Cypræa Bowerbankii; Pseudoliva obtusa; Pyrula tricostata.

Cephalopoda: Belosepia sepioides; Nautilus zic-zac.

Fish: Carcharodon angustidens; Cœlorhyncus rectus; Lamna elegans; Myliobatis Dixoni, Toliapicus; Otodus obliquus; Periodus Kœnigi.

Up to the Barton beds:—

Zoophyta: Graphularia Wetherellii.

Conchifera: Anomia lineata; Avicula media; Panopæa intermedia; Sanguinolaria compressa; Solen affinis; Tellina donacialis.

Gasteropoda: Actæon simulatus; Bulla attenuata; Cancellaria quadrata? Cassidaria carinata; Cerithium concinnum; Fusus bulbus? carinella, interruptus, porrectus, regularis; Marginella bifido-plicata; Mitra parva; Murex frondosus, minax; Natica Hantoniensis, sigaretina; Pleurotoma prisca, colon; Rostellaria ampla; Scalaria undosa; Sigaretus canaliculatus; Solarium canaliculatum; Voluta nodosa.

Echinodermata: Cidaris Websteriana; Hemiaster Branderianus? Ophiura Wetherellii.

Annelida: Ditrupa strangulata; Serpula heptagona.

Crustacea: Cytheridea perforata; Cytherella Munsteri.

Fish: Myliobatis nitidus; Ætobatis subarcuatus; Notidamus serratissimus.

Up to the Upper Eocene (Bembridge beds):—

Gasteropoda: Bulimus ellipticus.

Up to the Red Crag:—

Gasteropoda: Turritella imbricataria.

The Middle Eocene Groups.

4. The Bagshot Series, which takes its name from Bagshot Heath, but is best seen in the Isle of Wight. These consist of four groups, namely:—

4 *a*. The Lower Bagshot beds, composed of alternations of sand and clay; the sands generally pale yellow or grey, but sometimes dark and ferruginous, at others fawn coloured or rose-coloured; the clays are white pipe-clay, or grey or chocolate coloured clay. Thickness, 660 feet.

4 *b*. The Bracklesham beds, so called from Bracklesham in Sussex, dark chocolate-coloured marls and carbonaceous clays below, over which are whitish marly clay and white sands capped by a band of conglomerate of flint pebbles. Thickness, 110 feet.

4 *c*. The Barton beds, greenish-grey sandy clay below, passing up into bluish-green and brown clay, interstratified occasionally with beds of sand and loam. Thickness, 300 feet. This was formerly supposed to be the London clay.

4 *d*. Upper Bagshot beds, yellow and white sands with ferruginous stains. Occasionally 120 feet.

(*Mr. Bristow's section in Mems. Geol. Survey*, 1856. *Forbes' Isle of Wight Mem.*)

This arrangement is different from that given by Mr. Prestwich in his papers in the Geological Journal. It appears that No. 16 of Mr. Bristow's section, p. 157, is the same as No. 24 of Mr. Prestwich's in Geological Journal, vol. ii. p. 258. All below that, Mr. Bristow calls Lower Bagshot, while Mr. Prestwich includes many of the sands below in his Bracklesham series.—*Geological Journal*, vol. xiii. p. 99.

Characteristic Fossils.

4 *a* has no fossils except beautifully-preserved leaves of trees in some of the pipeclays.

4 *b*. The Bracklesham beds contain—

Plants: Comptonia dryandrifolia; Pinites Dixoni.

Amorphozoa: Cliona Parisiensis.

Foraminifera: Alveolina fusiformis, etc.; Nummulites lævigatus, ? planulatus, scaber; Quinqueloculina Hauerina; Rotalina obscura; Triloculina cor-anguinum.

Zoophyta: Balanophyllia desmophyllum; Dendrophyllia dendrophylloides; Diphelia papillosa; Litharea Websteri; Oculina conferta, raristella; Paracyathus crassus; Stereopsammia humilis; Stylophora emarciata, monticularia; Turbinolia Dixoni, sulcata.

Polyzoa: Cellepora petiolus; Lunulites urceolatus.

Conchifera: Mon—Ostræa elegans, inflata, longirostris, picta, radiosa; Pecten corneus, multistriatus, quadraginta-radiatus, squamosa, triginta-radiatus; Pinna margaritacea; Spondylus rarispina. *Dim*—Arca interrupta, modioliformis; Cardilia læviuscula; Cardita elegans, imbricata, mitis, planicosta; Cardium alternatum, hippopæum, ordinatum, semistriatum; Chama calcarata, gigas; Corbula longirostra, rugosa; Crassatella compressa, rostrata, tenuistriata; Cypricardia carinata, oblonga; Cytheræa lucida, nitidula, obliqua, striatula, suberycinoides, sulcataria, semisulcata, trigonula; Gastrochæna corallium; Leda serrata; Limopsis (Pectunculus) granulatus; Lucina immersa, serrata; Mactra depressa, semisulcata; Modiola lithophaga;

Nucula ovata, striata; Pectunculus pulvinatus; Solen Dixoni, obliquus; Tellina canaliculata, concinna, dis-stria, lamellosa, lunulata, obovata, plagia, reflexa, rhomboidalis, speciosa, tenuistriata, textilis, tumescens; Thracia sulcata.

Gasteropoda: Actæon sulcatus; Adeorbis planorbicularis; Ampullaria (Natica) patula; Ancillaria fusiformis, obtusa; Bifrontia bifrons, disjuncta, Laudinensis, marginata; Buccinum stromboides; Bulla Edwardsii, expansa, uniplicata; Cancellaria costulata, striatulata; Cassidaria coronata; Cerithium calcitrapoides, cancellatum, Cordieri, cornucopia, cristata, echidnoides, Geslini, giganteum, incoruptum, lima, marginatum, muricoides, nudum, papale, parvirostrum, semicoronatum, semigranulosum, tuberculatum, turris, unisulcatum; Conus antediluvianus, deperditus, diversiformis, pyriformis, velatus; Crepidula elongata; Cypræa globosa, inflata, tuberculosa; Delphinula Warnii; Dentalium costatum, eburneum; Fasciolaria biplicata, uniplicata; Fissurella Edwardsii; Fusus Gothicus, incultus, læviusculus, Noæ, polygonus, rugosus, scalaris, serratus, undosus, unicarinatus; Hipponyx cornucopiæ; Marginella dentifera, eburnea, ovulata; Melania costellata, lævigata; Mitra labratula, monodonta; Natica conoidea, hybrida, lineolata, obovata, ponderosa, pachycheila, Parisiensis, scalariformis, Sphærica, turgida, Willemettii; Nerita tricarinata; Niso terebellata; Orbis patellatus; Parmophorus elongatus; Pileopsis squaliformis; Pleurotoma acuminata, acutangularis, amphiconus, curvicosta, dentata, gentilis, obscurata, plebeia, textiliosa, transversaria; Pseudoliva ovalis, semicostata; Pyrula lævigata; Ringicula ringens; Rissoa cochlearia; Rostellaria arcuata; Solarium pulchrum, spectabile; Strepsidura turgida; Triton expansus; Turbo plicatus; Turritella abbreviata, carinifera, contracta, fasciata, intermedia, marginata, multisulcata, nexilis, sulcata, sulcifera; Voluta angusta, Branderi, calva, cithara, crenulata, horrida, muricina, recticostata, Selseiensis, platyspina, uniplicata.

Cephalopoda: Beloptera belemnitoides; Belosepia Cuvieri.

Annelida: Serpula flagelliformis.

Fish: Ætobatis convexus, marginalis, rectus, subconvexus; Cœlorhyncus sinuatus; Edaphodon Bucklandi, eurygnathus, leptognathus; Elasmodus Hunteri; Galeocerdo latidens; Lamna contortidens; Myliobatis contractus, Edwardsii, irregularis; Naisia? apicalis; Otodus lanceolatus; Platylæmus Colei; Pristis contortus, Hastingsiæ, Sibthorpi; Silurus Egertoni; Sphyrænodus gracilis.

Reptiles: Chelone trigoniceps; Gavialis Dixoni; Palæophis porcatus, Typhæus; Paleryx depressus, rhombifer.

Mammalia: Lophiodon minimus.

Besides the preceding fossils, the following are also found in the

Bracklesham beds, but survived into the Barton beds, in which they are also found:—

Foraminifera: Nummulites variolaris.

Conchifera: Mon—Ostræa dorsata, flabellula; Pecten plebeius, reconditus. *Dim*—Arca barbatula, Branderi, duplicata; Cardita acuticosta; Cardium porulosum, semigranulosum? Clavagella coronata; Corbula costata, Gallica, pisum, striata; Crassatella plicata; Cypricardia pectinifera; Cytherea elegans; Lucina mitis, radiata, spinulosa; Neæra argentea; Nucula bisulcata; Solen vaginalis; Solenocurtus Parisiensis; Tellina filosa, scalaroides.

Gasteropoda: Actæon elongatus, fenestratus, inflatus; Ancillaria buccinoides, canalifera; Bulla Defrancii, elliptica, extensa, lanceolata; Cancellaria crenulata, evulsa, umbilicata; Cassidaria ambigua; Cerithium angulatum; Conus lineatus? Dentalium striatum; Fusus porrectus, errans, ficulneus, longævus, pyrus (or bulbiformis); Hipponyx squamiformis; Littorina sulcata; Melania marginata; Mitra porrecta; Murex asper; Natica ambulacrum, epiglottina, patula; Pleurotoma exorta, granulata, invexa, macilenta, microdonta; Pyrula nexilis; Rotella minuta; Scalaria acuta, interrupta, reticula (or semicostata), tenuilamella; Solarium plicatum, spiratum; Terebellum fusiforme; Triton argutus; Trochus (Phorus) agglutinans; Voluta humerosa, digitalina, luctatrix, maga.

Echinodermata: Echinopsis Edwardsii.

Annelida: Serpula ornata.

Crustacea: Cythere striato-punctata, plicata; Cythereis horrescens.

In addition to these, the following species, which are found in the Bracklesham beds, survived to the Middle Headon period, in which beds their remains are also enclosed:—

Plant: Chara Wrightii.

Conchifera: Panopæa corrugata.

Gasteropoda: Natica depressa; Voluta spinosa.

Cirripedia: Pollicipes reflexus.

And the following plant into the Hempstead beds:—

Carpolithes (Folliculites) thalictroides.

The following even into the Crag:—

Conchifera: Diplodonta dilatata.

4 c. *Characteristic Fossils* of the Barton beds are—

Zoophyta: Turbinolia Bowerbankii, firma, Fredericiana, humilis.

Brachiopoda: Terebratula bisinuata.

Conchifera: Mon—Lima obliqua; Pecten carinatus; Vulsella deperdita; *Dim*—Arca appendiculata; Capsa tenera; Cardilia radiata; Cardita deltoidea, oblonga, sulcata; Cardium discors, turgidum; Chama squamosa; Corbula Ficus; Crassatella sulcata, tenuisulcata; Cyrena cycladiformis; Cytherea pusilla, rotundata, tellinaria, transversa; Gastrochæna ampullaria, contorta; Isocardia sp.; Kellia pisiformis; Limopsis (Pectunculus) scalaris; Lucina albella, ambigua, concentrica, gigantea, Menardi, Saxorum; Modiola seminuda, sulcata; Neæra cochlearella; Nucula trigona; Pectunculus deletus; Pholas conoidea; Psammobia rudis; Solen gracilis; Syndosmya convexa; Tellina Branderi, granulosa, Hantoniensis, lævis, lamellulata, squamula.

Gasteropoda: Adeorbis elegans; Ancylus elegans; Buccinum lavatum; Bulla conulus, coronata, constricta, filosa, incisa, ovulata, Sowerbyi: Calyptræa obliqua; Cancellaria canaliculata, microstoma; Capulus squamiformis; Cerithium cinctum, emarginatum, filosum, geminatum, rigidum; Chemnitzia rudis; Conus dormitor, scabriculus; Cuma Charlesworthi; Cypræa Bartonensis, platystoma; Dentalium acuminatum; Eulima gracilis, macrostoma, polygyra; Fasciolaria funiculosa; Fusus asper, canaliculatus, lima; Marginella gracilis; Melampus tridentatus; Melania carinata, fasciata? Mitra obesa, scabra, volutiformis; Murex bispinosus, contabulatus, crispus, defossus, tricarinoides, tripteroides; Nassa obtusa; Natica mutabilis; Nerita globosa; Odostomia pupa, turgida; Oliva aveniformis, Branderi, Salisburiana; Paludina concinna; Patella striata? Pedipes glaber; Pleurotoma brevirostrum, conoides, ctenata? desmia, formosa, lævigata, turbida? turrella; Pyrula Greenwoodi; Ringicula parva, turgida; Rissoa Bartonensis; Rostellaria Comptoni, rimosa; Rotella dubia; Solarium discoideum, distinctum, trochiforme; Strombus Bartonensis; Terebellum sopita; Terebra plicatula; Trochus monilifer, patellatus; Turritella brevis; Typhis fistulosus, pungens; Voluta ambigua, athleta, costata, scalaris, Solandri, suspensa; Volvaria acutiuscula.

Echinodermata: Echinus Dixonianus; Eupatagus Hastingsiæ; Schizaster D'Urbani; Spatangus Omalii.

Annelida: Serpula crassa, exigua, extensa.

Fish: Myliobatis marginalis.

Reptiles: Alligator Hantoniensis; Crocodilus Hastingsiæ; Emys crassus; Trionyx Barbaræ, circumsulcatus, Henrici, marginatus, planus, rivosus.

Besides the above, there are also found the following fossils, which survived into later periods, viz.—

Into the Middle Headon beds:—

Conchifera: Nucula deltoidea; Tellina ambigua.

Gasteropoda: Marginella pusilla; Voluta depauperata.

Into the Bembridge beds:—

Conchifera: Cyrena obovata.

Gasteropoda: Melania costata; Melanopsis fusiformis.

Into the Hempstead beds:—

Gasteropoda: Cerithium mutabile; Melania fasciata.

Cirripedia: Balanus unguiformis.

4 *d.* The Upper Bagshot beds are unfossiliferous, or nearly so, except at Whitecliff Bay, Isle of Wight, where they are very fossiliferous; the species apparently Barton species, but in too friable a condition to bear transport or examination.—(*M. G. S.* p. 86).

5. The Headon Series. All the beds hitherto examined, except part of the Plastic Clay series, are of marine origin. With the commencement of the Headon series, however, we meet with indications of fresh water having prevailed over what is now the Hampshire area, as well as at the corresponding period of the Paris tertiaries. In the London area no beds higher than the Bagshots are known.

5 *a.* The Lower Headon beds consist of clays and marls in Whitecliff Bay, while at Headon Hill and Colwell Bay they contain thick limestones; and they are still more varied at Hordwell on the opposite coast. They are the "Lower Freshwater formation" of Webster.

5 *b.* The Middle Headon beds consist principally of sands, showing at Headon Hill brackish water conditions, but containing beds of oysters; while at Colwell Bay and Hordwell, and still more strongly at Whitecliff Bay, the beds have a purely marine character. Webster called them the "Upper Marine formation."

5 *c.* The Upper Headon beds contain the strongest limestones of Headon Hill, which, however, thin out rapidly towards the north. They are represented by a few very thin and inconspicuous sandy concretionary bands in Whitecliff Bay. The uppermost beds of the group are marls. Webster gave the name of "Upper Freshwater formation" to this group.

Characteristic Fossils of the whole group, the marine shells being confined to the middle division:—

Plants: Carpolithes ovulum.

Conchifera: Mon—Ostræa flabellula, gryphina; Pecten sp. *Dim*—Corbula cuspidata, nitida; Cyclas sp.; Cyrena arenaria, cycladiformis, deperdita, gibbosula, Wrightii; Dreissena Brardii; Mya angustata; Nucula Headonensis; Potamomya gregaria; Psammobia compressa, solida; Unio Solandri.

Gasteropoda: Actæon sp.; Ancillaria subulata; Borsonia sulcata; Buccinum desertum, labiatum; Cancellaria elongata, muricata; Cerithium acutum, concavum, duplex, margaritaceum, trizonatum, ventricosum; Limnæa angusta, arenularia caudata, cincta, columellaris, convexa, costellata, fabula, fusiformis, gibbosula, minima, mixta, ovum, pyramidalis, recta, sublata, subquadrata, sulcata, tenuis, tumida; Marginella vittata; Melania minima, peracuminata; Melanopsis subcarinata, subfusiformis, subulata; Murex sexdentatus; Natica glaucinoides, similis; Nematura parvula; Nerita aperta; Neritina concava; Paludina concinna; Planorbis elegans; Pleurotoma Headonensis, innexa, plebeia; Succinea imperspicua.

Annelida: Serpula corrugata, tenuis.

Fish: Myliobatis and Squalus teeth.

Mammalia: Dichodon cuspidatus; Microchærus erinaceus; Paloplotherium annectens; Spalacodon sp., etc.

Besides the foregoing, there are also found in the Headon beds the following fossils, which survived into later periods, and are found in higher beds, viz.—

In the Osborne series:—

Conchifer: Potamomya plana.

Gasteropod: Planorbis euomphalus.

In the Bembridge series:—

Conchifer: Cytherea incrassata.

Gasteropoda: Helix Headonensis, labyrinthicus; Limnæa longiscata; Melanopsis brevis; Planorbis obtusus, rotundatus.

In the Hempstead series:—

Gasteropoda: Cerithium plicatum, pseudo-cinctum; Melania muricata; Melanopsis carinata; Natica labellata; Paludina lenta; Planorbis lens, platystoma.

6. Osborne (or St. Helen's) Series. **This is divisible into two groups, of which the first or lowest is**

6 *a*. The Nettlestone grits, consisting of hard rag and shelly sandstone below, capped by marl and bright yellow limestone. The whole about twenty feet in thickness.

6 *b*. The uppermost has an alternation of white, and green, and yellow sands, with blue, white, and yellowish clays and marls, having a total thickness of about fifty feet.

Characteristic Fossils.

Plants: Chara Lyelli.

Conchifera: Unio sp.

Gasteropoda: Cerithium small sp.; Hydrobia sp.; Paludina species like lenta.

Crustacea: Cythercideis unisulcata.

The following fossils, which are also found in the Osborne beds, survived into the Upper Eocene, and are found

In the Bembridge beds :—

Gasteropoda: Achatina costellata; Paludina globuloides; Planorbis discus, oligyratus.

In the Hempstead beds :—

Crustacea: Candona Forbesii; Cytheridea Mulleri.

THE UPPER EOCENE GROUPS.

The fluvio-marine conditions are still continued in the Isle of Wight district without any very marked line of distinction, between the top of the Middle and the base of the Upper Eocene groups.

7. THE BEMBRIDGE SERIES, containing the following subdivisions, beginning with the lowest :—

7 *a.* The Bembridge limestone. A pale yellow or cream-coloured limestone, interstratified with clay or crumbling marl—the limestone full of cavities, and often quite tufaceous and concretionary, and sometimes conglomeritic, sometimes a true travertine; contains siliceous or cherty bands in some places. Thickness, twenty to twenty-five feet.

7 *b.* The oyster bed. A few feet of greenish sands containing oysters (*Ostræa Vectensis*) in great abundance, capped by a band of hard septarian stone, which is constant over a large area. About ten feet altogether.

7 *c.* Unfossiliferous mottled clays, alternating with fossiliferous laminated clays and marls. Containing Cyrena pulchra.

7 *d.* Marls and laminated grey clays, containing Melania turritissima. Capped by the *Black band* forming the base of the Hempstead series.

Characteristic Fossils.

Conchifera: Ostræa Vectensis; Arca Websteri; Cyrena obtusa, pulchra; Lucina Theierensis; Mytilus affinis; Nucula similis.

Gasteropoda: Cerithium Austenii; Clausilia striatula; Craspedopoma Elizabethæ; Cyclostoma mumia; Cyclotus cinctus, nudus; Helix D'Urbani, globosa, occlusa, omphalus, tropifera, Vectensis; Melania Forbesii; Murex ribbed species; Paludina orbicularis; Planorbis Sowerbyi; Pupa perdentata; Succinea Edwardsi.

The following fossils found in the Bembridge occur also in the Hempstead series:—

Plants: Chara medicaginula, tuberculata.

Conchifera: Corbula pisum; Cyrena semistriata, transversa; Mya minor.

Gasteropoda: Melania fasciata, turritissima; Melanopsis subulata.

8. The Hempstead Series—the three lower divisions of freshwater and estuary origin.

8 *a.* The lowest bed of this group is a firm carbonaceous laminated clay, highly fossiliferous, about two feet thick, known as the Black band; over which are pale bluish and yellow shaly marls, with ironstone concretions. The whole about forty feet thick.

8 *b.* The base of this group, called the White band, is a bed of mingled broken and entire shells, more or less consolidated, often very ferruginous, from six inches to two feet thick; over which are mottled, yellow, and pale green marls, capped by shaly clays and dark marls, and blue green ferruginous clays, with ironstone concretions. Total thickness about fifty feet.

8 *c.* Variegated red and green marls and grey clays, covered by greenish clay, passing up into pale and dark grey or lead-coloured clays. Thickness about forty feet.

8 *d.* Clays with septaria, and grey and bluish clays with concretions containing abundance of Corbula; marine. About twenty-five feet thick.

Characteristic Fossils.

Plants: Chara helicteres; Taxites (or Glyptostrobites) Parisiensis.

Conchifera: Ostræa callifera, etc.; Corbula Vectensis; Cyclas Bristovii; Cytherea Lyellii; Modiola Prestwichii; Unio Austenii, Gibbsii.

Gasteropoda: Aporrhais species; Cuma Charlesworthii (much eroded); Cerithium inornatum, Lamarckii? Sedgwickii, subcostellatum; Fusus Edwardsii; Hydropia (Pupa?) small species; Limnæa species; Melania inflata; Murex Forbesii; Nematura parvula; Neritina tristis, etc.; Rissoa Castellii; Voluta Ruthieri.

Crustacea: Cythereideis unicornis.

Reptiles: Trionyx incrassatus.

Mammalia: Hyopotamus bovinus, Vectianus.

France and Belgium.—The labours of Mr. Prestwich, continued so long and assiduously, have gradually made plain to us the correlation of the English and French Eocene beds, and, joined with those of Sir C. Lyell and M. Dumont, have also taught us the relation of these with those of Belgium. The following table exhibits these relations as they are now believed to be, taking Mr. Prestwich's classification for all below the Upper Bagshot sands, and Professor Edward Forbes' for those and all above them :—

England.	Belgium.	France.
11. Hempstead.	Rupelien.	Calcaire de la Beauce. Grès de Fontainebleau. Sables et bancs de coquilles, marnes marines.
10. Bembridge.	Tongrien.	Calcaire siliceux, calcaire lacustre moyenne, Gypseous series of Montmartre, etc.
9. Osborne. 8. Headon.	Laeckenien, part of?	Calcaire marin et Grès de Beauchamp.
7. Upper Bagshot.	Système Laeckenien superieur?	Sables moyennes, upper zone.
6. Barton clay.	Système Laeckenien inferieur?	Sables moyennes, lower zone.
5. Bracklesham.	Système Bruxellien.	Calcaire grossier,* and Glauconie grossière.
4. Lower Bagshot.	Système Ypresien superieur?	Lits coquillières, and Glauconie moyenne.
3. London clay.	Système Ypresien inferieur.	Wanting.†
2. Woolwich and Reading.	Système Landenien superieur.	Grès de Pondingues, Lignites et Argile Plastique, Glauconie inferieur.
1. Thanet sands.	Système Landenien inferieur.	Wanting.

* Mr. Prestwich gives (Geol. Jour., vol. xiii. p. 99) the following detailed description of the Calcaire grossier:—

	Feet.
4. Compact white marls, passing down into alternations of greenish marls and thin yellow limestones, with seams of chert . .	20
3. Thin bedded fissile calcareous flags and sandstones, alternating with white marls and limestones	15
2. Thick main mass of soft, light-yellow calcareous freestone (the building stone of Paris got by mining or subterranean quarrying), passing sometimes into calcareous sands . . .	40
1. Variable, more or less calcareous, green sands, sometimes concreted, flint pebbles often at base	25
	100

† Some part of it, however, formerly extended into Normandy, as some clay at the top of the cliff of Ailly, near Dieppe, is believed to be London clay.—(Prestwich, *Geol. Jour.* vol. xi. p. 230).

According to Mr. Prestwich, the London Tertiaries were deposited in a sea open to the north, spreading at least over S.E. England, Belgium, and north of France, whilst to the south of that area, dry land prevailed over the great part of the Paris Tertiary district and still farther south. Gradual depression then took place, extending the limits of the sea over the Paris area, leading to the introduction of Nummulites and more southern forms of marine life than had hitherto prevailed. Dry land was still in the immediate neighbourhood, as shown by the occasional presence of terrestrial forms, and alternations of elevation and depression doubtless took place, modifying here and there the physical geography of the district. The Barton Clay, for instance, seems to have been deposited in a sea of a more northern character than that in which the Bracklesham clays and sand were formed. Fresh-water conditions finally became prevalent, large estuaries opened into the seas over the British and north of France areas, while large lakes existed in the centre and south of France, where, soon after, volcanic eruptions commenced to break forth, and continued for many thousand years in subsequent periods. Edward Forbes pointed out that the upper part of the Bembridge series was probably of the same age as the Molasse of Fronsadais and associated beds, and also as the Calcaire à Astéries of the S.W. of France; part of the Tertiary beds of Malta, Corsica, Greece, Crete, Cerigo, S. of Spain and Portugal, Azores and N. Africa, were also considered to be contemporaneous with the Hempstead series. Contemporaneous with the Hempstead also were the Molasse ossifère and the Faluns jaunes of Dax, the lower division of the Vienna Tertiariés and the marine beds, the Cerithium kalk and Upper brown coal of Mayence.—(*Mems. Geol. Soc.* 1856, p. 100.)

Sir C. Lyell, however, in his Supplement, thinks that it would be more convenient to retain a nomenclature common on the Continent, and to class the Hempstead series and its contemporaneous beds as Lower Miocene, making the beds from the Barton Clay to the Bembridge series inclusive Upper Eocene, and taking the Bracklesham and Lower Bagshot beds only as Middle Eocene. He remarks, however, that we must in this case look on the boundary between Eocene and Miocene as an arbitrary and purely conventional line.

Certainly, as far as England (Isle of Wight) is concerned, the Hempstead beds are linked to those below by a greater number of species than they have peculiar to themselves.

The Alps, the Borders of the Mediterranean, Egypt, India.—Through these countries from the Alps to the Himalayas, occurring at intervals through 25° of lat. and near 100° of long., are found great masses of rock, sometimes even thousands of feet in thickness, crowded with nummulites and sometimes almost made up of them. These are of Middle Eocene age. Associated with these are still higher beds called Flysch and Macigno in the north of Italy, and the black slates or shales of Glarus containing quantities of fossil fish, etc. The Monte Bolca fish beds are also of about this age.—(Murchison, *Geol. Jour.*, vol. v. p. 157, etc.)

North America.—Sir C. Lyell places the Claiborne and Alabama beds among the productions of the Middle Eocene period.

Extinction of Life at the Close of this Period.—The only generic forms dating from a pre-Tertiary period which survived into the Eocene and did not also survive into later periods, and almost all to the present day, are the following :—

Plants : Flabellaria, Lycopodites.

Foraminifera : Frondicularia, Marginulina.

Fish : Cœlorhyncus, Cr ; Edaphodon, Cr ; Gyrodus, O ; Hypsodon, Cr ; Notidanus, Cr.

THE MIOCENE PERIOD.

The proportion of living to extinct species is taken at about 25 per cent. If we include the Hempstead series in the deposits of the Eocene period, we have no stratified rocks in the British Islands representative of the formations of the Miocene period, unless it be the "ash" beds and lignites associated with the basalts of the north of Ireland and west of Scotland. Edward Forbes thought that the fossil leaves found by the Duke of Argyll in the Isle of Mull more nearly resembled Miocene forms than any other, and were certainly not the same with those of any known Eocene forms.

If we adopt the classification usual on the Continent, and consider the Hempstead beds and their equivalents the earliest of the Miocene beds, then the Bembridge series of the Isle of Wight and the Gypseous series of Montmartre will be the uppermost or newest of the Eocene period. There is, it appears, a palæontological reason for this arrangement on the Continent, inasmuch as if we draw the line at the top of the Montmartre beds, and at the base of the Calcaire lacustre superieur (or Calcaire de la Beauce), certain generic and even specific forms of Mammalia are kept wholly within the Miocene groups, which otherwise would be made common to the Eocene and Miocene periods. The genera Dorcatherium, Cainotherium, Anchitherium, and Titanomys, and the species Rhinoceros incisivus, and others, are examples—(M. Lartet, in *Lyell's Supplement*).

We shall then have the following as

Typical Groups of Rock of the Miocene Period.

Belgium and France.—Limburg beds, Rupelian of Dumont, the Bolderburg beds, the Faluns of Touraine and Bourdeaux, the principal part of the lacustrine strata of Auvergne and central France. Associated with the latter were the earliest beds of lava and volcanic breccias, which began now to be poured forth in the districts of Auvergne,* Velay, and Cantal, and continued to break forth at intervals to far later times.

Germany and Switzerland.—The Mayence basin, the principal part of the Vienna basin, part of the molasse of Switzerland, containing the "nagel-flue," a conglomerate 6000 or 8000 feet thick.

Italy.—Part of the beds in the hill of Superga, near Turin.

* It is, however, most probable that the great volcanoes of the Mont d'Or, and the Cantal, etc., are of a still earlier period, as may be surmised from their more ruined and eroded character, the obliteration of their craters, and the great valleys worn deep into the flanks of their wide spread mounds.

North America.—The sands of Richmond, and the James River in Virginia.

India.—The Sewalik formations, which compose the sub-Himalayan range south of hills.—(*Lyell's Manual*).

Characteristic Fossils.—I shall not pretend to give lists of these. Sir C. Lyell says that the fossils of the "faluns" have a more extra-European facies than those of the crag presently to be described. They contain seven species of Cypræa, some larger than any Mediterranean cowry, and several species of the genera Oliva, Ancillaria, Mitra, Terebra, Pyrula, Fasciolaria, and Conus. There are eight cones, some very large, and the species of Nerita are more like those of the tropics than of the Mediterranean.

Out of 290 species of shells collected by Sir C. Lyell to the south of Tours, 72 only could be identified as living species, which is about 25 per cent; among a total of 302 in his possession, 45 only are to be found in the Suffolk crag, or 15 per cent; and a similar small per centage in the Bryozoa and Zoantharia. If we compared the fossils of the "faluns" with those of living British species, we should doubtless have very few in common, the living species found in the Faluns being to be sought in more tropical provinces, while those of the Crag have a more northern "facies" impressed upon them. The Faluns have a few terrestrial species of shells, among which is the Helix turonensis and remains of Mammalia belonging to the genera Deinotherium, Mastodon, Hippopotamus, Chæropotamus, Dichobune, Deer, and others, together with some Cetaceans, Lamartine, Morse, etc.—(*Lyell's Manual*, p. 180, etc.)

The very remarkable Sirenian animal Deinotherium is believed to be very characteristic of the Miocene beds. It has been found also at Perim Island in the Gulf of Cambay.

In the Sewalik Hills of India, Dr. Falconer and Colonel Cautley found, together with portions of Mastodon, five extinct elephants (three of them, Stegodon, intermediate between Elephas and Mastodon), a Hexaprotodon (extinct hippopotamus), a Chalicotherium and extinct Giraffe, Camel and large Ostrich, the very remarkable genus Sivatherium, together with Carnivora and Monkeys, great Crocodiles and a Tortoise, the curved shell of which was 20 feet across. Fifteen species of fresh-water shells also occur, of which all but four are extinct, giving a percentage of about 25 : 100.—(*Lyell's Supplement.*)

In North America are many shells of the genera Natica, Fissurella, Artemis, Lucina, Chama, Pectunculus and Pecten, and one, Astarte undulata, very like the A. bipartita of the Suffolk Crag. "Out of 147 of these American fossils, I could only find thirteen species common to Europe, and these occur partly in the Suffolk Crag and partly in the Faluns of Touraine; but it is an important characteristic of the American group that it not only contains many peculiar extinct forms, such as Fusus quadricostatus and Venus tridacnoides, abundant in these same formations, but also some shells which, like Fulgur carica and canaliculatus, Calyptræa costata, Venus mercenaria, Modiola glandula, and Pecten magellanicus, are recent species, yet of forms now confined to the western side of the Atlantic, a fact implying that some traces of the beginning of the present geographical distribution of Mollusca date back to a period as remote as that of the Miocene strata."—(*Lyell's Manual*, p. 182.)

PLIOCENE PERIOD.

LIFE OF THE PERIOD.—The number of existing forms among the fossils of this period is believed to be at least half, ranging from 50 to 70 per cent.

The generic forms that date their existence within the British area from this or from the Miocene period are—

Foraminifera: Amphistegina, Biloculina, Glandulina, Lagena, Noniona, Planorbulina, Polystomella, Spiroloculina.

Zoophyta: * Cryptangia, Flabellum, * Sphenotrochus.

Bryozoa: Cellaria, Crisia, Fascicularia, Filicella, Lepralia, Melicertina, Membranipora.

Conchifera: Mon—none; *Dim*—Artemis, Cochleodesma, Coralliophaga, Cyamium, Donax,[1] Erycinella, Lepton, Lucinopsis, Montacuta, [1] Pandora, Saxicava, Scrobicularia, Sphenia, Tapes, Venerupis, Verticordia.

Gasteropoda: Aclis, Bullæa, Cæcum, Chiton, Columbella, Conovulus, Erato, Fossarus, Litiopa, Margarita, Marsenia, Purpura, Rissoa,[2] Scissurella, Trichotropis, Velutina.

Pteropoda: Cleodora.

Cephalopoda: No new testaceous forms.

Echinodermata: Amphidetus, Brissus, Comatula, Echinarachnius Echinocyamus, Temnechinus.

Annelida: Cyclogyra.

Cirripedia: Acasta, Coronula, Pyrgonia.

Crustacea: Atelecyclus, Cancer, Ebalia, Portunus.

Fish: Platax, Raia, Zygobates.

Mammalia: Balænodon, Felis.

[1] Unless shells so called by M'Coy from the Carboniferous Limestone were in reality of these genera.

[2] Five species of Rissoa are described as Permian. As the genus does not occur again in any rocks earlier than the Crag, it may reasonably be doubted whether those Permian species be really Rissoa.

Typical Groups of Rock.

	Feet.
2. Red Crag	50
1. Coralline Crag	40

1. The Coralline Crag is composed chiefly of soft marly sands of a white colour, sometimes speckled with green, containing occasionally thin bands of flaggy limestone. It is generally about 20 feet, but sometimes as much as 50 feet in thickness. Near Ipswich it has been denuded, and the Red Crag is seen to lie in the hollows that have been eroded in it, which is the only direct evidence of the superposition of the Red Crag on the Coralline; otherwise they lie side by side, the Coralline[1] Crag being confined to a strip of country twenty miles long by three or four wide, stretching through Ipswich from the Stour river to the Alde river.

2. The Red Crag consists of beds of red quartzose sands and gravel, with accumulations of rolled shells. It is very variable in character, sometimes regularly stratified, sometimes more confused.

Both groups resemble the deposits which we may now suppose to be taking place in the shallow bed of the German Ocean.

Characteristic Fossils of the Coralline Crag:

Foraminifera: Biloculina bulloides L,[2] lævis L, opposita L, simplex L; Dentalina communis L, jugosa L; Glandulina lævigata L; Globigerina bulloides L; Globulina gibba L; Guttulina communis L, crassa? teretiuscula; Lagena lævis L, striata L; Nodosaria radicula L; Operculina complanata; Orbitolites complanatus L; Planorbulina Mediterraniensis L; Polymorphina acuta; Polystomella crispa L; Quinqueloculina rotunda, sulcifera, trisulcata; Robulina cultrata L; Rotalina elliptica? rosea L, subtortuosa? Spiroloculina depressa; Textularia aciculata L, Partschii; Triloculina oblonga L, tricarinata L; Truncatulina parisiensis?

Zoophyta: Alveolites clavata; Cryptangia Woodii*; Flabellum Woodii.

[1] It appears that this term of Coralline is a mistake, inasmuch as true Corals are rare in both the divisions of Crag, while the Coral-like bodies which are common in the Lower Crag are Polyzoa, and are also found, though not so abundantly, in the Red Crag.—(*Edwards and Haime, Palæontograph.*, vol. i.)

[2] The capital letter L after a species denotes the species to be still a living one.

Polyzoa: Cellaria fistulosa L; Cellepora cellulosa, coronopus, mammillata, ramulosa L; Crisia eburnea L, luxata L; Diastopora meandrina; Eschara foliacea L, pertusa, porosa, Sedgwickii; Filicella anguinea; Flustra coriacea, holostoma, membranacea L, trifolium; Heteropora setosa L; Hornera striata; Lepralia catena, ciliata L, coccinea L, geniculata L, puncterrata L, pyriformis, umbonella, variolosa L; Lunulites Owenii; Melicertina Charlesworthii; Membranipora dentata L, pilosa L; Tubulipora agaricia, arborea, intricaria, serpens L.

Brachiopoda: Argiope cistellula L; Discina (Orbicula) lamellosa, Norvegica L; Lingula Dumortieri; Terebratulina caput-serpentis L.

Conchifera: Mon—Anomia squamula L, striata L, undulata L; Avicula tarentina; Hinnites Cortesyi; Lima hians L, ovata, plicatula, subauriculata L; Pecten Bruei L, Gerardii, princeps, similis L. *Dim*—Arca pectunculoides L; Astarte gracilis, incerta, parva, parvula, pygmæa; Cardium decorticatum, strigiliferum; Coralliophaga cyprinoides; Cryptodon ferruginosum L, sinuosum L; Cyamium eximium; Cytherea chione L; Donax politus L; Erycinella ovalis; Gastrochæna pholadia; Kellia coarctata, cycladia, elliptica L, orbicularis, pumila, rubra L; Leda pygmæa L, semistriata; Lepton depressum, nitidum L, squamosum L; Limopsis aurita, pygmæa; Lucina crenulata, decorata; Modiola phaseolina L, rhombea L, sericea; Montacuta donacina, ferruginosa L, substriata L, truncata; Mytilus Hesperianus L; Neæra cuspidata, sulcata; Nucinella miliaris; Nucula trigonula; Pectunculus pygmæus; Pholadomya hesterna; Psammobia Ferroensis, florida, vespertina; Solecurtus candidus, quadratus, sigillatus L; Spherica Binghami; Syndosmya prismatica; Tapes perovalis; Tellina balaustina L, donacilla, donacina L; Teredo navalis L; Thetis granulata L; Thracia Conradi, inflata, phaseolina L, ventricosa; Verticordia cardiiformis.

Gasteropoda: Aclis ascaris L; Actæon levidensis; Adeorbis pulchralis, striatus, supranitidus, tricarinatus; Bulla acuminata L, concinna, conulus, Lajonkaireana L, nana, truncata L; Bullæa quadrata L, scabra L, sculpta, ventrosa; Cæcum glabrum L, ? incurvatum, mammillatum, trachæa L; Cancellaria subangulosa; Capulus fallax; Cerithium adversum L, cribarium, metaxa, perpulchrum, trilineatum L, tuberculare L; Chemnitzia costaria, curvicosta, densicostata L, elegantissima L, filosa, nitidissima L, rufa L, similis L, unica L, varicula; Chiton Rissoi, strigillatus; Cypræa affinis; Dentalium bifissum; Eulima glabella, subulata L; Fossarus sulcatus L; Fusus gracilior, imperspicuus, paululus; Helix nemoralis L; Hydrobia ulvæ; Lacuna reticulata; Litiopa papillosa; Margarita maculata, trochoidea; Marsenia tentaculata L; Mitra plicifera; Natica cirriformis, proxima; Odostomia pellucida L, plicata L, pupa, simillima; Patella fulva L; Pleurotoma brachystoma L, castanea, concinnata, perpulchra, Philberti L, porrecta; Pyramidella læviuscula; Pyrula reticulata L; Rissoa confinis, costulata, crassistriata, obsoleta, punctura L, reticulata L, striata L, supracostata, vitrea, Zetlandica L; Scalaria cancellata, clathratula L, fimbriosa, frondicula, frondosa, hamulifera, obtusicostata, subulata, varicosa L; Scissurella crispata; Sigaretus excavatus; Terebra canalis; Terebra inversa; Triton heptagonus; Trochus conulus, crenularis, ditropis, millegranus L, obconicus; Turritella planispira; Velutina virgata.

Pteropoda: Cleodora infundibulum.

Echinodermata: Amphidetus cordatus; Brissus Scillæ; Comatula Brownii, Ransomi, Woodwardi; Echinocyamus hispidulus, oviformis; Echinus Charlesworthii, Lyellii, melo, Woodwardi; Spatangus purpureus, Regina; Temnechinus excavatus, globosus, melocactus; Uraster rubens.

Annelida: Cyclogyra multiplex; Ditrupa polita, subulata; Spirorbis granulatus, heterostrophus, sinistrorsus L; Vermilia tricuspidata L, vermicularis L.

Cirripedia: Acasta undulata; Balanus bisulcatus, calceolus L, concavus L, inclusus, spongicola L; Coronula barbara; Pyrgoma anglica L.

Crustacea: Atelecyclus species; Cancer pagurus L; Ebalia Bryerii; Pagurus Bernhardus.

The following fossils, which are also found in the Coralline Crag, survived into later periods, and are met with in the Red Crag:—

Foraminifera: Quinqueloculina seminulun L; Rosalina Beccarii L; Textularia sagittula L; Truncatulina tuberculata L.

Zoophyta: Alcyonium circumvestens; Sphenotrochus intermedius.

Polyzoa: Cellaria crassa; Discopora hispida; Eschara monilifera; Fascicularia aurantium; Hornera reteporacea; Lunulites alveolatus; Retepora cellulosa L; Theonoa globosa; Tubulipora obelia L; Palmata patina L, repens.

Brachiopoda: Terebratula grandis.

Conchifera: Mon—Anomia patelliformis L; Lima exilis, Loscombii L; Ostræa edulis L, princeps; Pecten dubius, maximus L, opercularis L, pusio L, tigrinus L; Pinna pectinata. *Dim*—Arca lactea L, tetragona L; Artemis lentiformis; Astarte Basterotii, Burtini, digitaria L, incrassata, mutabilis, Omalii, sulcata L, triangularis L; Cardita chamæformis, corbis, orbicularis, senilis; Cardium nodosum L; Chama gryphæoides L; Cochleodesma prætenerum; Cyprina rustica; Cytheræa minima L, rudis L; Diplodonta astartea, dilatata, rotundata L; Gastrochæna hians; Glycimeris angusta; Isocardia Cor L; Kellia suborbicularis L; Lepton deltoideum; Lucinopsis Lajonkairii L; Modiola costulata, marmorata L; Nucula lævigata;

Pandora margaritacea; Petricola laminosa; Pholas cylindrica; Thracia pubescens L; Venus imbricata, turgida.

Gasteropoda: Actæon tornatilis; Adeorbis subcarinatus L; Buccinum Dalei; Bulla cylindracea, lignaria L; Calyptræa Chinensis L; Cancellaria mitræformis; Capulus militaris L, hungaricus L; Cassidaria bicarenata; Cerithium granosum; Chemnitzia internodula; Cypræa avellana, retusa; Dentalium costatum L; Emarginula crassa L, fissurella L; Erato lævis L, Mangeriæ L; Eulima polita L; Fusus alveolatus, cancellatus, consocialis, costiferus; Murex tortuosus; Nassa consociata, labiosa, prismatica L; Natica multipunctata, varians; Ovula Leathesii L; Patella virginea L; Pleurotoma cancellata, carinata, costata L, linearis L, mitrula; Ringicula buccinea, ventricosa; Scalaria foliacea, similis; Trochus Adansoni L, formosus L, Kicksii, Montacuti L, vilicus; Turritella bicincta; Vermetus intortus; Voluta Lamberti.

In addition to the preceding, there are also the following fossils, which are found not only in the Coralline and Red Crags, but also in some beds still more recent, called the Mammaliferous or Norwich Crag:—

Conchifera: Kellia ambigua; Lucina borealis L; Mactra arcuata, ovalis L, solida L; Modiola modiolus L; Nucula tenuis L; Pectunculus glycimeris L; Pholas lata L; Saxicava rugosa L; Scrobicularia piperata L; Syndosmya alba; Tapes virginea L; Tellina obliqua; Venus casina L.

Gasteropoda: Buccinum undatum L; Cancellaria costellifera; Fusus gracilis L; Trichotropis borealis.

Cirripedia: Balanus crenatus L.

The living species found in the Coralline Crag, which are not also found in the Red Crag, are scarcely any of them living in the British seas, but mostly in the Mediterranean. Some of the Foraminifera live now in the Red Sea; but the Mollusca generally belong to the Lusitanian province of Forbes.

The following fossils, however, are common to the Coralline and Red Crags, and are found in the Glacial (Pleistocene) deposits, but not in the Mammaliferous Crag, though they doubtless lived during the period. They are all, except Cardita scalaris, species still existing, and all in our own seas, except Turritella incassata, which is Lusitanian.

Polyzoa: Cellepora pumicosa.

Conchifera: Abra alba, prismatica; Artemis lincta L; Astarte compressa L; Cardita scalaris; Cardium edule L; Cyprina islandica L; Lutraria elliptica L; Montacuta bidentata L; Mya truncata L; Nucula nucleus L; Psammobia feroensis L; Pholas crispata L; Solen ensis L; Venus ovata L.

Gasteropoda: Aporrhais pes-pelecani L; Cypræa Europæa L; Fissurella Græca L; Fusus muricatus L; Nassa incrassata L; Trochus ziziphinus L; Turritella incrassata L.

One shell has been found in the Coralline Crag and in the Glacial beds, but not in any intermediate deposits, viz., the

Conchifera: Leda pygmæa, now living in the seas of Greenland and the Sound of Skye.

2. *Characteristic Fossils* of the Red Crag, which do not occur in any earlier beds:—

Foraminifera: Cristellaria rotulata; Globigerina cretacea; Polymorphina communis L, lactea L; Quinqueloculina subrotunda; Robulina calcar? L; Rotalina armata? L.

Zoophyta: Balanophyllia calyculus.

Polyzoa: Flustra distans L; Hippothoa dentata; Lepralia abstersa.

Conchifera: *Mon*—Pecten gracilis. *Dim*—Astarte crebrilirata L, excurrens, obliquata; Cardium angustatum, echinatum L, interruptum, nodosulum, venustum; Cochleodesma Leanum; Corbula complanata; Mactra deaurata, glauca; Modiola barbata L; Panopæa gentilis, Ipsviciensis, Norvegica L; Solen cultellatus; Tapes texturata; Tellina Benedenii; Venerupis Irus L.

Gasteropoda: Actæon Noæ, subulatus; Cancellaria coronata; Capulus obliquus; Columbella sulcata; Conovulus myosotis L; Cypræa Angliæ; Fusus altus, elegans; Hydrobia pendula, terebellata; Nassa conglobata, elegans, monensis, propinqua, reticosa, reticulata; Natica Guillemini L, hemiclausa; Patella vulgata L; Pleurotoma Boothii L, intorta, nebula L, plicifera; Purpura tetragona; Rissoa pulchella; Scalaria Trevelyana L; Trochus cinerarius L, cineroides, multigranus, papillosus L, subexcavatus.

Echinodermata: Echinarachnius Woodii; Echinocyamus pusillus, Suffolciensis; Echinus Henslovii; Temnechinus turbinatus.

Annelida: Vermicularia triquetra; Balanus tintinnabulum L.

Fish: Platax Woodwardi; Raia antiqua; Zygobates Woodwardi.

Mammalia: Balænodon affinis, definita, emarginata, gibbosa, physaloides; Felis pardoides.

The living species which are found in the Red Crag, and not earlier, have a rather more northern character than those of the Coralline, many of them being such as inhabit our own coasts and belong to the Celtic province; others again are southern forms.

In addition to these are the following fossils, found in the Red Crag, and not earlier, but occurring also in the later Norwich Crag. As, however, most of these are existing species, it is clear that they might easily occur in any deposit of an age subsequent to the period of the formation of the Red Crag, without our deducing from that circumstance alone any very close approximation in age to the Red Crag. So far as the occurrence of living species is concerned, they might have been deposited at any period since that of the Red Crag, and the number of species in common with the Red Crag, if that community is confined to the living species, proves nothing as to their intimate connection in time for one deposit more than another:—

Conchifera: Abra intermedia L; Cardium Greenlandicum L, Parkinsoni; Leda caudata L, lanceolata L, myalis L; Lucina divaricata L; Lutraria compressa; Mactra stultorum L, lata, ovalis L.

Gasteropoda: Cerithium tricinctum; Conovulus pyramidalis; Natica catena L, catenoides, helicoides L; Planorbis complanatus L; Pleurotoma Trevelliana; Trochus tumidus L; Turritella communis L.

Cirripedia: Balanus dolosus, porcatus L.

Mr. Searles Wood and Mr. Charlesworth are the principal authorities as regards the Crag. The latter pointed out that in some cases the fossils which are found common to two groups may have been washed out of the older into the newer, having been already fossil at the time of the deposition of the newer.

The following fossils occur in the Red and Mammaliferous Crags, and also in the Glacial beds:—

Conchifera: Corbula nucleus; Donax trunculus; Mactra subtruncata: Mya arenaria; Mytellus edulis; Nucula Cobboldiæ; Solen siliqua; Tellina calcaria, crassa; Venus fasciata.

Gasteropoda: Fusus antiquus, scalariformis; Littorina littorea; Nassa granulata; Natica clausa; Pleurotoma turricula; Purpura lapillus; Scalaria Greenlandica.

These are all living species except Nucula Cobboldiæ and Nassa granulata, and all the living species inhabit our own seas except Tellina calcarea, Fusus scalariformis, Natica clausa, and Scalaria Greenlandica, which are Boreal or Arctic.

Antwerp.—Sir C. Lyell (Manual, p. 174) describes strata around Antwerp and on the banks of the Scheldt below that city, containing 200 species of shells, of which two-thirds are the same as those of the Crag of Suffolk, more than half are living species, principally belonging to the Celtic, though some are Lusitanian (Mediterranean) species.

Normandy.—The same authority mentions a patch of Crag near Valognes in Normandy, and at other places, extending to a little south of Carentace, but none farther.

Italy.—The sub-Apennines or low hills intervening between the Apennines and the sea, on each side of Italy, are made of Tertiary strata, of which part are of Miocene, part of Pliocene, and part of a still more recent period. The beds of Asti and Parma, and the blue marl of Sienna, which near Parma is 2000 feet thick, over which are yellow sands and conglomerates formed on the shallowing of the sea, belong to this period, as do the Tertiary marine beds forming the base of the seven hills of Rome.

S. Russia.—Sir R. I. Murchison and M. de Verneuil describe limestone and sands, rising occasionally to the height of several hundred feet above the sea around the coasts of the Caspian and Aral seas, and the north-western parts of the Black Sea, as belonging to this period. They call them the Aralo-Caspian formation. The fossils are partly fresh water, partly marine.

Extinction of Life at the Close of this Period.—It would be a very difficult task to point out what generic forms of earlier date died out about the time when this period drew to a close. Among known fossils, this extinction would probably take place principally among the Mammalia, no genus of Mollusca probably dying out now, though many species became extinct. It was formerly pointed out, that species of Mollusca were more long-lived than those of Mammalia; the duration of the species being generally greater in proportion to the lowness of its place in the zoological scale.

PLEISTOCENE PERIOD.

Without attempting to draw any very nice or accurate distinction between the deposits of this and the preceding period, we may take, as a rough definition of the Pleistocene deposits, "those in which more than three-fourths of the fossils are of existing species."

We know of no remarkable living generic forms, with the exception only of man, that may not have been in existence during this period. The horse, the ox, the dog, and all the variety of terrestrial Mammalia, seem now to have been disseminated over the earth, each species in its own province, very much as they are now distributed. The species of Mammalia were almost always, and in some cases even the genera were, different from those now occupying the province, while the species of Mollusca, etc., were nearly the same.

TYPICAL GROUPS OF ROCK.—*Britain.*—The assemblage of sands and gravels about the county of Norfolk, known as the Mammaliferous or Norwich Crag, containing both marine and fresh-water shells, and the bones of mammoths, together with those of the horse, dog, pig, deer, etc.—deposits of Brentford (Middlesex), of Gray's (Essex), and of Maidstone (Kent), containing the bones of the mammoth, or woolly elephant (Elephas primigenius), the extinct, woolly rhinoceros (Rhinoceros tichorhinus), a monkey (Macacus pliocenus), and fresh-water shells, which, though not extinct entirely, are no longer inhabitants of Britain, one of them, for instance, (Cyrena consobrina) being now only found in the Nile; the elephant bed near Happisburgh (Norfolk), underlying "the drift" there, and stretching under the sea, from which, according to Woodward, 2000 mammoths' grinders were dredged up by the fishermen in 13 years; the clay deposit at Chillesford, Suffolk, described by Prestwich (*Journal Geol. Soc.* vol. v. p. 345); other similar partial superficial patches of clays, sands, and gravels, some of the gravels being widely spread over high ground, and known as the "high level gravels," having the present river valleys excavated through them, others occupying these valleys and the lower grounds, and known as the "low level" gravels. Some of these deposits are older, and some newer than the Glacial beds to be mentioned presently.

Characteristic Fossils of the Mammaliferous Crag:

Conchifera: Astarte borealis L, elliptica L; Cardita analis; Cyrena consobrina L; Donax anatinus; Leda pernula; Modiola discors, vulgaris L; Mytilus antiquorum; Psammobia solidula; Tellina fabula L, prætenuis.

Gasteropoda: Bulla Regulbiensis; Helix arbustorum L, hispida, plebeia L; Hydrobia subumbilicata; Limnæa palustris L, pereger L, truncatula L; Margarita elegantissima; Natica occlusa; Paludina lenta L, obsoleta, tentaculata; Planorbis corneus L, spirorbis L;

Rissoa semicostata; Succinea oblonga L, putris L; Valvata piscinalis L.

Mammalia: Castor Europæus L; Elephas primigenius; Lutra vulgaris L; Mastodon angustidens; Asinus sp.; Sus sp., etc.

Besides the preceding, the following fossils are found in the Norwich Crag, and also in the Glacial deposits of a later date, all living, and all inhabitants of our own seas, except Cemoria Noachina and Velutina undata, which are Arctic forms:—

Conchifera: Tapes aurea.

Gasteropoda: Cemoria Noachina; Dentalium entale; Murex erinaceus; Natica Greenlandica; Velutina lævigata, undata.

It was about this time, perhaps, unless it were still later after the close of the Glacial period, that the caves of the British Islands were inhabited by large hyænas and bears (Hyæna spelæus and Ursus spelæus and priscus). Into these dens many bones of other animals then inhabiting the neighbourhood were dragged by them. These remains are generally found in mud, under a layer of stalagmite.

The following species have been found in caverns only:—

Birds: Alauda arvensis; Anas sponsor; Columba species; Corvus corax; Perdix cinerea.

Mammals: Arvicola pratensis; Asinus fossilis; Bison minor; Canis familiaris, lupus; Cervus Bucklandi, Dama; Equus plicidens; Lagomys spelæus; Lepus cuniculus, timidus; Machairodus latidens, megantereon; Meles taxus; Mus musculus; Putorius ermineus, vulgaris; Rhinolophus ferrum-equinum; Sorex vulgaris; Strongyloceros spelæus; Ursus priscus; Vespertilio noctula; Vulpes vulgaris.

The following fossils have been found in Pleistocene deposits, and not in caverns:—

Mammalia: Bison priscus; Bos longifrons, primigenius; Bubulus moschatus; Capra hircus; Cervus elaphus, tarandus; Elephas antiquus, primigenius (Mammoth), priscus; Felis catus, leo; Macacus pliocænus; Megaceros Hibernicus;* Palæospalax magnus; Rhinoceros leptorhinus; Sorex fodiens, remifer; Sus scrofa; Trogontherium Cuvieri; Ursus arctos.

* The Irish elk, though more abundant in Ireland than elsewhere, is found in the Isle of Man, at Folkestone, and in Essex, Norfolk, and Lancashire.

The following species have been found both in caverns and in Pleistocene deposits elsewhere:—

Mammalia: Arvicola agrestis, amphibia; Cervus capreolus; Equus fossilis; Felis spelæa; Hippopotamus major; Hyæna spelæa; Rhinoceros tichorhinus; Talpa vulgaris; Ursus spelæus.

The Glacial Deposits are chiefly clays, sands, and gravels, sometimes stratified, sometimes rudely piled together, and containing great blocks of rock, which also sometimes occur scattered loosely over the bare rock surface. These deposits are variously called by the terms of "Great Northern Drift," "Till" (in Scotland), a brown clay with boulders; "Marls" in Wexford and Wicklow, where fossiliferous marl is interstratified with sand and gravel; "Limestone Gravel" in Central Ireland, chiefly consisting of pebbles of carboniferous limestone, heaped sometimes into narrow ridges 40 to 80 feet high, and from one to twenty miles long, which are called "Escars;" "the Boulder Clay" in northern and central England, etc.; and "Drift" almost universally. The "Erratic block group" of Delabeche is likewise a well-known name for these deposits.

The southern character of the Coralline Crag, and the more northern aspect of the fossils in the Red Crag, has been already mentioned. The fossils just spoken of as occurring at Gray's, etc., still point to a climate more like that of the south of Europe than our own, though as far as the woolly elephant and woolly rhinoceros are concerned, they might well have inhabited Britain at the present day, or even countries with a still severer climate.

A change, however, now took place, of a kind different from any we have yet met with, unless Professor Ramsay's ideas as to the glacial origin of the Permian and other old conglomerates be well founded. Simultaneously with a gradual, but eventually a great and wide-spread, depression of land, amounting in many places to 2000 or 2500 feet, there was a refrigeration of the climate of our own latitudes, so that the glens of our present mountains were encumbered with glaciers, even where their valleys were penetrated by the sea, and our low lands were entirely submerged. By the action of these glaciers, the rocks were scored and rounded, polished and grooved, and masses of rock carried down and heaped into moraines; while great blocks of rock were transported on fragments of those glaciers which dipped into the sea and formed icebergs, being often carried far over the shallow seas, and dropped many miles from their parent sites,* sometimes resting on hill tops, which were then banks and shallows in the sea, and so arrested the laden icebergs in their course. Alternations of elevation and depression doubtless took place, and the ordinary action of the breakers along the beach was aided by the quantity of detritus poured into the sea by the glaciers, and modified by that of the shore ice which formed along it in the winter seasons.

The Escars of Ireland were probably formed in the eddies at the margins of opposing and conflicting currents, the materials being piled up from each side.

Characteristic Fossils of the Glacial deposits:

Besides those mentioned before as found in still earlier beds are the following; those to which the letter E is appended being extinct species so far as is at present known, those to which A is added being Arctic species, the rest occurring in our own seas:—

Polyzoa: Tubulipora verrucaria.

Brachiopoda: Terebratula psittacea A.

Conchifera: Mon—Anomia ephippium, squamula; Ostræa edulis; Pecten islandicus A, maximus, opercularis, sinuosus, triradiatus, varius. *Dim*—Artemis exoleta; Astarte danmoniensis; Cardium edule, lævigatum; Leda minuta, oblongoides A, rostrata A; Lucina flexuosa, radula; Mactra truncata; Mytilus vulgaris; Nucula proxima (seas of Massachusetts); Pectunculus pilosus; Saxicava sulcata A; Tapes pullastra; Tellina baltica, Grœnlandica A, tenuis; Thracia declivis; Venus (Tapes) decussata, gallina, verrucosa.

Gasteropoda: Buccinum ciliatum A; Fusus Bamfius, Barvicensis, crispus? (Lusitanian), despectus, Fabricii A, Forbesi (American), imbricatus

* The largest boulder I know in the British Islands is near the head of the Devil's Glen in county Wicklow. It is 27 feet long, by 18 wide, and 15 high. It is of granite, resting on Cambrian grits and slates, six or eight miles from the nearest granite in situ, with a wide shallow valley between the hill on which it now stands and the granite district.

At the recent meeting of the British Association at Dublin, Mr. Godwin Austen described a large boulder of granite (apparently Scandinavian) found in the chalk near Croydon, showing that occasional icebergs wandered southwards, even in the Cretaceous period.

A, islandicus, Sabini A; Lacuna Montacuti, vincta; Littorina littorea, palliata A, rudis; Lottia virginea; Margarita undulata A; Mitra cornea? (Mediterranean); Nassa pliocena E, semistriata (Ægean); Natica Alderi, Bowerbankii E, monilifera, Smithii E (? flava, American); Patella lævis, pellucida; Pleurotoma discrepans (Boreal, America), linearis? rufa, septangularis; Tornatella pyramidata E; Trochus exasperatus (Lusitanian), tumidus (Lusitanian); Turritella terebra.

Annelida: Serpula vermicularis; Spirorbis corrugatus? Vermilia triquetra.

Cirripedia: Balanus balanoides, communis, uddevallensis.

Mammalia: Balæna mysticetus; Balænoptera boops; Monodon monoceras; Phocæna crassidens; Physæter macrocephalus.

(*Forbes' Survey Memoirs*, vol. i.)

These Glacial deposits are not confined to the British Islands, but extend over all the north of Europe and North America, down to a certain curved boundary, which in Europe, according to Sir R. I. Murchison, only stretches so far south as latitude 50° in one part of its course, namely, near Cracow. Great blocks of Swedish or Norwegian rocks, as large as cottages, lie scattered over the plains of North Germany.

In addition to the fossils mentioned before in the Glacial deposits of the British Islands, the following have been found in them elsewhere:—

Brachiopoda: Terebratula caput-serpentis* (in Sweden, living in Loch Fine and in Boreal America).

Conchifera: Cardium islandicum (in Russia and Canada, living in Boreal and Arctic American seas), Greenlandicum (ditto).

Gasteropoda: Lottia testudinalis (in Sweden, living in Arctic and Boreal European seas; Emarginula crassa (in Norway, living in Scandinavian and Scottish seas); Scalaria borealis (in Canada and Sweden, living in Arctic seas); Coriocella perspicua (in Sweden, living in Boreal seas.

Echinodermata: Echinus neglectus (in Sweden, living in Zetland and Norway), granulatus (in Canada, living on the east coast of North America.

Fish: Mallotus villosus (in Canada, living in Greenland, the only fossil fish known to be still living).

* Edward Forbes thought this was the same species with the striata of the London clay, and even the striatula of the Chalk; if so, this would be the most anciently descended of all living animals, except, perhaps, some Foraminifera. According to Woodward, however, the T. caput-serpentis is of Miocene date.

Towards the close of the Glacial period, or after it, our present low lands seem to have been again above water, and to have been more extensive than they now are, the British Islands being probably united to each other, and to the Continent, by plains which have since been widely eroded, and the shallow seas formed out of them that now separate our present lands. On these plains, the Irish elk, the reindeer, the musk-ox, and other animals roamed, sometimes becoming drowned in the lakes, or mired in the swamps, and leaving their skeletons as records of their former existence.

During the prevalence of the cold climate of the Glacial period, many species of Molluscs which previously inhabited the British seas, and are found fossil in the Crag, retired southwards, and occur fossil in the Mediterranean Pleistocene deposits, but at the close of the Glacial periods they again came northwards, and are now inhabitants of our seas for the second time, while some of them no longer live in the Mediterranean.

Dr. Falconer has recently shown that a similar history might be told with respect to the Mammalia. The Elephas primigenius has, according to him, never been found south of the Alps, where an allied species, E. antiquus, has left its remains (*Lyell's Supplement*), that species having previously roamed much farther north, and left its remains in the earlier Pleistocene deposits of Britain. Mr. Godwin Austen informs me that Dr. Falconer believes that the relative ages of the different drifts or superficial deposits may ultimately be worked out by paying attention to the different species of elephant found in them. (Austen on Newer Tertiary Deposits of Sussex Coast—*Geological Journal*, vol. xiii. Part i., in which Mr. Austen now would write, E. antiquus for E. primigenius on p. 50, line 18, and p. 55, line 8 from bottom, on Dr. Falconer's authority).

In like manner, the Arctic or Boreal fauna and flora which prevailed over our islands and shores during the Glacial period, have receded towards the north again, but have left some traces of their former existence in the Arctic or Boreal plants which are found near the summits of our mountains, and the Boreal shells which may be dredged from certain deep hollows in our seas.

Edward Forbes showed that the present fauna and flora of the British Islands is derived from five sources:

1. The remnant of a Spanish (Lusitanian) flora in the west of Ireland, probably dating from the Miocene period.

2. A Gallican or Norman flora in the south-west of England and south-east of Ireland, with a remnant of a corresponding fauna.

3. A Kentish or North of France flora, and corresponding fauna, extending over the south-east of England.

These two may both perhaps be of Pliocene date.

4. The Arctic flora and fauna just spoken of, diminishing in numbers from the north of Scotland towards the south of England.

5. The great Germanic flora and terrestrial fauna, occupying all the central and northern parts of England and Ireland and south of Scotland, and spreading through the other districts in co-tenancy with the rest, dating from the time when the British Islands were united by the great plain to each other and the Continent.

The Celtic marine fauna comes in with this; its peculiar species being apparently created to occupy the shallow seas formed by the erosion of this great plain, and inhabiting them together with the Arctic or Boreal species that remained about the coasts and spread into the new sea, and such of the southern species as returned to it from the Lusitanian province. One or two Arctic or Boreal outliers occur in deep cold hollows of the British seas, containing species not found elsewhere till we go much farther north, just in the same way that the tops of our loftiest mountains have plants not found on our lower grounds and plains, but occurring down to the water edge in Scandinavia.

It appears that just as the present surface of all land is formed by the outcrop of a number of beds of different ages, the newest being generally the most widely spread, and concealing the others, except in some particular localities where they rise up to the view; so the population of animals and plants, the fauna and flora, of many countries may be made up of different assemblages of different dates and different origins, the newest perhaps spreading over, and more or less concealing the others, the oldest only perhaps becoming apparent in one or two separated and isolated localities.

Besides the "great northern drift," consisting of far-travelled boulders and fragments, there is also a much more generally diffused local drift, the materials of which are always derived from the immediate neighbourhood. This may be either contemporaneous with, or of earlier or later date than the Glacial period, but is most probably later, and much of it perhaps of subaerial origin. It is occasionally of very considerable thickness and importance in the British Islands, and similar "drifts" are found in other parts of the world in all latitudes, and not confined, like that of the Glacial period, to high northern or southern regions.

Raised Beaches and Submarine Forests.—Neither is our history brought to a close after the formation of all our present deposits, and the coming into existence of all our present species. Changes of level have since taken place, as shown by the occurrence of raised beaches, in the shape of banks of sand and shingle with shells, above high-water mark, round our coasts, containing just such species as occur in the beaches below them; and in the fact of peat bogs, containing the stumps and roots of oak and fir and other common trees, to be seen at dead low water, passing under the sea. In many of the bays along the south coast of Ireland, peat is dug from such situations at low water of spring tides, and dried and used as fuel.

These facts show us that some of our peat bogs, at all events, may date back from a considerable antiquity. Beds of peat, indeed, sometimes occur beneath the clay and gravel of the Glacial deposits, or interstratified with such deposits.

Soil and Subsoil, Vegetable Mould, etc.—As long as the geologist is engaged only with the broad facts, as to the formation of regularly stratified rocks, or of large masses of earthy matter, whether regularly or irregularly accumulated, he proceeds with pretty confident steps towards his conclusions. Those conclusions are general ones, and often of a sufficiently sweeping character. Certain districts, now high dry land, were formerly deep sea, in which certain beds were deposited, including the remains of creatures that lived in the sea. The time when these things took place was a very remote one, and the interval occupied by them a long one—hundreds, thousands, or millions of years, as the case may be. We are not compelled to be more definite, nor have we any inducement to be so. In proportion, however, as we approach the recent or human period, our steps necessarily become more cautious, since we have more of a personal interest in ascertaining precisely the nature of the processes, and the period of their occurrence.

We are naturally anxious to know, if possible, the actual date, in years, of the last elevation of the lands we inhabit, out of the sea in which they have been so often immerged, and what has taken place upon them between that last emergence and the historic times. Indications then, which would be at other times overlooked, become now of importance; but in proportion to the interest attached to the investigation becomes its difficulty, since observations now are required to be more accurate and minute, as well as more widely spread, and more strictly checked and compared, than when larger generalities are dealt with. Hence it arises that we have not yet arrived at any satisfactory union of the history of the pre-human and the human periods, and possibly no very satisfactory union may ever be arrived at.

The investigation of one strictly geological subject has yet scarcely been commenced, and that is the formation of Soil. The natural formation of soil is certainly not always a rapid one. On many coral islets, crowded with birds and covered with vegetation, some even having considerable trees, there is little that could be called soil. The loose coral fragments and coral sand are slightly discoloured, and from their interstices, small particles of "mould" could be picked up with the finger and thumb, but there is no layer of pure soil. Neither does soil always follow vegetation, however long continued. The great gum-tree forests of Australia rise from wide tracts of bare ironstone gravel or bare sandstone rock, slightly covered with an inch or two of rubble without anything that could be called soil for scores of miles at a stretch. The ground looks like a great untidy gravel walk, from which a few straggling blades of grass spring up here and there between the trees. Neither are even calcareous rocks always covered with vegetation. In Galway and Mayo, considerable flats of low ground may sometimes be seen made of horizontal sheets of Carboniferous limestone, perfectly bare except in the crevices of the joints, where a short sweet grass springs up. On some of the fine corn land of the Cotteswold Hills too, on the Oolitic limestones, the soil is not half an inch in thickness, and is composed principally of the rubble of the rock below, just such a soil as that of a coral islet would be if ploughed.

On some of the downs of the Carboniferous limestone, as also on Chalk downs, the soil consists of about an inch of close green turf, that may be cut with a knife and peeled off* the rock below in great rolls. I am not aware of any experiments for determining how long such bared spots would require to be reclothed with turf by unassisted nature.

Mr. Darwin formerly published some observations on the formation of mould (*Trans. Geol. Soc.*, vol. v. p. 505, and *Proc. Geol. Soc.*, vol. ii. p. 574), in which he attributed it to the digestive process of earth worms, who swallow fine earth, and after extracting the alimentative part, eject the remainder.

FOREIGN PLEISTOCENE DEPOSITS.

It has been said that, during the Glacial period, many of the Molluscs which previously inhabited the British seas retired southwards, and that their remains are to be found fossil in the Pleistocene deposits of the Mediterranean, while they do not now live in that sea, but have returned to their original province. In Sicily especially, there are two, if not more groups of rock, the lower argillaceous, the upper calcareous, consisting of thick beds of hard limestone, having an aggregate thickness of 700 or 800 feet. These beds cover half the island, and rise to a height of 3000 feet, the lower portions having as much as 30 per cent of extinct species,

* Excellent fossils may often be procured from the surface of the Carboniferous limestone by this process of stripping it.

while the upper parts contain shells mostly identical with species now living in the Mediterranean.—*Lyell's Manual*, chap. xii. Some of these beds appear to be interstratified with lavas, part of the early outflows of the volcanic focus of Ætna.

These thick deposits, and other similar ones which are found in Sicily and the Grecian Archipelago, and some of which may exist in Spain and Portugal, were shown by Edward Forbes to be the contemporaries of the Glacial deposits, or northern "drift" of higher latitudes, by the evidences already described.

It is perhaps to a later part of this period that we must assign the formation of the "loess" or "lehm" of the valley of the Rhine and its tributaries. This, as described by Sir C. Lyell in his Manual, p. 122, is a deposit of fine loam, of a yellowish grey colour, occasionally laminated, but never separated into distinct beds, although it is often 200 or 300 feet thick, and rises occasionally to a height of 1200 feet above the sea. It seems to have been formed in consequence of the gradual depression of the whole country, after it had assumed its present external shape and "mould," and the subsequent filling up of a great part of the Rhine valley and its tributaries with matter brought down by the floods of the upper parts of the rivers. These materials being then spread from side to side of the valleys, would again be greatly eroded on the gradual re-elevation of the country, when every stream would cut down through the soft loess, and re-occupy its old bed. Land and fresh-water shells of the same species that now inhabit the country are found in the loess; and in some places near the extinct volcanoes, layers of pumice and lapilli are found, seeming at first sight as if ejected during an eruption, but perhaps merely washed away from the old previously existing cones. One crater indeed, that of the Roderberg, near Bonn, is partly filled by the loess. Bones of the mammoth and other contemporaneous mammals have been found in it.

A similar deposit is described by Sir C. Lyell, as found in the valley of the Mississippi, and forming the cliffs called the "Bluffs," which often rise to a height of 200 feet above the present alluvial plain of the river.

It is also probably to the Pleistocene period that we must assign the deposits of clay and sand which spread over the plains called the Pampas in South America, in which the bones of the Megatherium, Mylodon, and Glyptodon have been found. Similar superficial deposits are found in most countries, and either in these or in the bottoms of caverns, mostly buried under stalagmite, are found more or less of the remains of the extinct animals that preceded the existing races in their occupation of the globe.

Although these animals are all extinct, yet each great geological province had, in the later Tertiary periods, the same generic or ordinal types as at the present day. The fossil monkeys of South America belonged to the platyrhine family of monkeys which is now restricted to South America, while the extinct genera Megatherium, Megalonyx, Scelidotherium, and Mylodon, were allied to the sloths (Bradypus), the Glyptodon to the armadillos (Dasypus), and the Glossotherium to the ant-eaters (Myrmecophaga), which are equally restricted to the same country. A fossil Marsupial also occurs there of the genus Didelphys * (opossum). In addition to these, peculiar species of more widely distributed genera also occur there, as Ursus Bonariensis, Canis protalopex, Felis atrox, Machairodus neogæus, Mastodon Andium, Tapirus Suinus, Equus curvidens, Macrauchenia Patachonica, Toxodon platensis, Nesodon imbricatus, and species of the genera Echimys, Ctenomys, Synetheres, Anæma, Cœlogenys, Hydrochœrus, etc.—(*Owen's Synopsis of Lectures in Jermyn St.*)

Some of the Edentata, as the Megalonyx, etc., have been found in North America as far as 30° N. latitude, but further north they are replaced by other species, such as the Mastodon giganteum, of which numerous skeletons have been found in swamps called Salt licks; one is mentioned by Sir C. Lyell as still retaining between its ribs a mass of vegetable matter where the stomach would have been, fragments of which were determined by Mr. A. Henfrey by microscopical examination to be probably portions of the white cedar (Thuja occidentalis) of North America. In addition to these, may also be mentioned the Castoroides Ohioensis, and other extinct animals.

It is probable that in India and Southern Asia, many of the fossil Mammalia and other animals belong to the Pliocene and Pleistocene periods in addition to those mentioned before as belonging to the Miocene. I am not aware, however, of any data yet enabling us to make this separation.

* During the earlier Eocene period, this genus was an inhabitant of Europe, since a species occurs fossil in the Paris basin.

The following species of Tertiary Mammalia were mentioned by Professor Owen in his recent lectures as peculiar to South Asia:—

Semnopithecus **magnus,** Amphiarctos **sivalensis,** Enhydriodon **ferox,** Lutra **palæindica,** Felis **cristata,** Machairodus **sivalensis,** Chalicotherium **sivalense,** Merycopotamus **dissimilis,** Hexaprotodon **sivalensis,** Camelus **sivalensis,** Sivatherium **sp.,** Bramatherium **sp.,** Hippotherium **antelopinum,** Rhinoceros **sivalensis,** Dinotherium **indicum,** besides fossil buffaloes, musk-deer and cameleopards, and numerous extinct species of Mastodon and Elephants. Most of these, however, were probably of Miocene age.

If we turn to Australia, we find similarly the remains of animals of the same great type as those now inhabiting the country among the most recent and superficial of the deposits.

Some of these animals were found by the late Sir T. Mitchell in caverns in Wellington valley, about the head-waters of the river Macquarrie; others have been found in gravels, clays, and sands in river valleys, and others, as I was once informed by a gentleman from Liverpool plains, lying loose on the bare earth, or just underneath the scanty soil of the higher grounds.

Those in the caverns were chiefly young individuals of large extinct species of kangaroo, potaroo, and wombat, probably caught, killed, and dragged into the caves by large carnivorous Dasyures and Thylacines now also extinct, such as the Thylacinus **spelæus,** the Dasyurus **laniarius,** and the Thylacoleo or Marsupial tiger. In addition to these, occur the gigantic Diprotodon, essentially allied to the kangaroos, but with some characteristics of the wombat, the Nototherium **inerme,** and the great wombat, Phascolomys **bovinus.** There was also a Mastodon then living in Australia.

Even in New Zealand, where before Cook's time no Mammal was ever found larger than a rat, the same law of the peculiar type-restriction is to be discovered. The largest living land animals were birds, and among them a peculiar wingless Struthious bird allied to the ostrich, emu, and cassowary, known as the Apteryx. Large bones of an extinct bird of the same great class have been discovered in the superficial deposits of the island, and called Dinornis * from the great size (11 feet in height) of one of the seven species which have been found. Along with these are two other allied genera, called

* The Maories (New Zealand aborigines) have a tradition that the Dinornis (which they call Moa) was exterminated by their ancestors; and some of them even maintain that it yet lives in some of the dark inaccessible ravines among the great and utterly unexplored mountain regions of the Middle Island, the west coast of which, as I was informed by Mr. Evans, R.N., who assisted in surveying it, is traversed by narrow fiords penetrating mountains of many thousand feet, covered by dark woods that encircle glaciers which come down from the heights.

Palapteryx, of which four species have been found, and Aptornis; and another genus was also discovered, called Notornis (of the order Grallatores), supposed at first to be equally extinct, till a living specimen was procured by Mr. W. Mantell.

The Dodo, a former inhabitant of the Mauritius, destroyed by the Dutch about 200 years ago, may be mentioned here, as its remains have been found under a bed of lava.

Dr. Mantell (*Medals*, vol. ii. p. 764) also mentions the fossil eggs and bones from Madagascar of a bird called Æpyornis still larger than the Dinornis.

There are two remarkable agencies now at work in various parts of the world, which are probably more or less intimately connected with the period we are now considering, or perhaps with still earlier periods. Many of our present coral reefs and many of our active volcanic districts are of an incalculable antiquity, if we measure them by mere years or centuries and not by geological periods.

Coral Reefs.—In a former part of this little work, these most singular, and at first sight most mysterious phenomena, were alluded to as illustrations of the method of formation of marine calcareous rocks. Mr. Darwin, however, has shown them to be also proofs of movements in the crust of the earth, and of great depression having taken place in the bed of the ocean where they prevail. He showed that since reef-making corals could not live at a greater depth than fifteen or twenty fathoms (Forbes' Circumlittoral zone) and since vast reefs, (Atolls and Barriers) now rose with steep wall-like sides from profound depths in the great Pacific and Indian Oceans, just to the level of low water, their existence was only to be accounted for on the supposition, that when these reefs commenced to grow, the water was shallow enough for the animals to live in it, near enough to the surface to enjoy that amount of light, heat, and play of the waves which is necessary for their existence. After the reef was thus commenced and built up to the level of low water (but how long after we cannot say), a slow and gradual motion of depression must have set in, either gentle and continuous, or acting by little fits and starts, never producing during any interval of time an amount of depression so great as to prevent the polyps continuing to raise the reef towards the surface, by the growth and multiplication of the calcareous framework of their own bodies. In this way, the ocean bed that was once only fifty or sixty feet is now hundreds or thousands of feet below the sea level; and vast masses of calcareous rock thus erected, either as barriers encircling islands, some of whose loftiest summits still rise above the water, or as great massive tombs utterly enveloping and burying in their secret recesses, the bodies of lands and islands, once rising high into the air, now lying enveloped in coral rock deep beneath the sea.

It may well be that in some, if not many, of these instances the first movement took place in Pleistocenė, Pliocene, or still earlier periods; it is possible even that some of these huge submarine masses of coral limestone may be based upon corals of species different from those that form their summits — species that have died out in the lapse of time; under any circumstances, the time required for their formation must have been enormous.

Volcanoes.—When we study the structure of a volcanic mountain such as Ætna, Teneriffe, or many others, and find that the lower parts of the volcanic rocks that are open to our observation are interstratified with marine limestones, or sandstones full of sea-shells, we perceive at once that great changes have taken place in the district since the first commencement of volcanic activity. In many instances, as in the Andes, in Java (See Horsfields' Map), and, perhaps, if they were worked out, in every large volcanic district now at work upon the globe, we are enabled to trace back the commencement of volcanic action to some Tertiary, sometimes, perhaps, to a rather early Tertiary period. One other result which we should arrive at is, that volcanic districts are, as pointed out by Darwin in his volume on Coral Reefs, districts of elevation, and that these in some parts of the world alternate with the districts of depression occupied by coral reefs. Volcanic districts never have Atolls and Barrier reefs in them. Great elevation requires time for its elaboration as well as great depression.

But even if we dismiss from consideration all the aqueous rocks with which volcanoes are connected, and look solely at the igneous products themselves, we are, in most instances, compelled to assign an age to the volcano far greater than any yet attributed to the duration of the human race.

Even so small an example as Ætna forms, compared with the gigantic volcanoes of Asia and America, will enable us to prove this. This mountain has a base of some thirty miles in diameter, and a height of about 11,000 feet. It has been built up by the ejection of ashes, dust, lapilli, and other fragmentary matter from the interior of the earth, aided by occasional outpourings of streams of molten rock. It is made up of an indefinite number of conical heaps of such materials, arranged variously around one central and dominant mound, from which the greatest quantity of matter has been ejected. Some of these external cones are fully shown; some are half buried by the ejectamenta from other cones, or from the central one; and many others are doubtless altogether concealed under the great piles of materials heaped over the central parts of the mountain. On one side a huge ravine, 3000 feet deep and five miles long, has either been scooped out of one side of the mountain by erosion or formed in it by subsidence.

Now the sensible additions made to this great mass of materials during the last 2000 or 2500 years, bear a very trifling and insignificant proportion to the whole mass; and yet nothing we know of the structure of Ætna, or of volcanic action in any other parts of the globe, would warrant us in concluding that the process of building up the mountain has ever been much more rapid in its action than it has been during the last 2500 years. Even if we make allowance for a considerably more energetic action during the earliest periods of its activity (which, however, nothing that *we know* of volcanic action would *compel* us to do), and suppose that it did not assume its present slow rate of growth till it became as large as Vesuvius, for instance; still the additional matter added to the bulk of Ætna since it attained that size must be so great that, judging from our experience of the rate of volcanic action all over the world, we could not allow a less period than one or two hundred thousand years for the process.

The mention, however, of such a period as a hundred thousand years is only introduced here to show the large quantity of time necessary; a million may have been nearer the truth for all anybody can show to the contrary; and if once even so much as 20,000 or 30,000 years be allowed as possible, no one would, I suppose, be inclined to stickle for any further restriction from any considerations of any portions of human history.

But if such conclusions may fairly be drawn from the consideration of the structure of the comparatively small mountain of Ætna, what period of time are we to allow for the slow and gradual piling up of the lofty cones of Chimborazo, Catopaxi, Aconcagua, and others of the Andes, rising to twice the height of Ætna, spreading their bases over a width equal to the whole island of Sicily, and running through hundreds and even thousands of miles in length. We cannot conceive all the vast chain of the Andes ever to have had all its fiery vents in fierce activity at once. We know that in all volcanic chains eruptions take place successively, now from one, now from another; their very number therefore increases the time we must allow for the gradual growth of the bulk of each, especially when we have to intercalate great spaces of time during which they may have been all quiescent together.

And yet these are the most recent of geological events, those of which we see the operation most obviously continued into our own times, most directly linking our own history with the far receding past.

These are not unnecessary or superfluous speculations, but considerations requisite to enable us the better to understand and appreciate the geological facts of our own islands. When we see that hundreds of thousands, or even millions, of years have probably elapsed, during which other countries have stood pretty much as we now see them, except that the grand volcanic monuments that rise from some of them have been slowly elaborated, we can make proper allowance for the great spaces of time which have elapsed during the process of the comparatively insignificant changes that have taken place in our own lands. We learn to look upon the Glacial period, for instance, as separated from our own days by the lapse probably of millions of years, and we begin to understand how it is that physical causes acting with infinitesimal slowness have so changed the climate and the physical geography of our own part of the world as to have caused the gradual extinction of whole races of large animals that once flourished in it.

Large indeed as the demands of the geologist may have been thought upon the bank of time, they probably fall far short of the capital stored up there at his disposal. Some of the more recent of geological events are probably in reality of as great an antiquity as we have been accustomed to assign in our imaginations to the most remote. The beginning of the Pleistocene period is probably really as far separated from us in past time as we have hitherto been accustomed to consider the Silurian or Cambrian periods removed from us. Geologists themselves have perhaps hardly formed adequate conceptions on this subject, and yet without those conceptions difficulties are perpetually rising in the science which with them would disappear.

Assuming the lapse of past time to be practically infinite, during which the earth has existed in its present state, so far as its physical constitution is concerned, and the distribution of its surface into land and water, mountain and plain, river, lake, and ocean; and allowing for the broken, fragmentary, and imperfect nature of our records, for their possible interruption by large unrecorded gaps, even when apparently most continuous and complete, there are no longer any difficulties in the way of that philosophy of geology which appeals to what we know and see going on around us for the explanation of that which is past, and selects for its teacher experience rather than imagination.

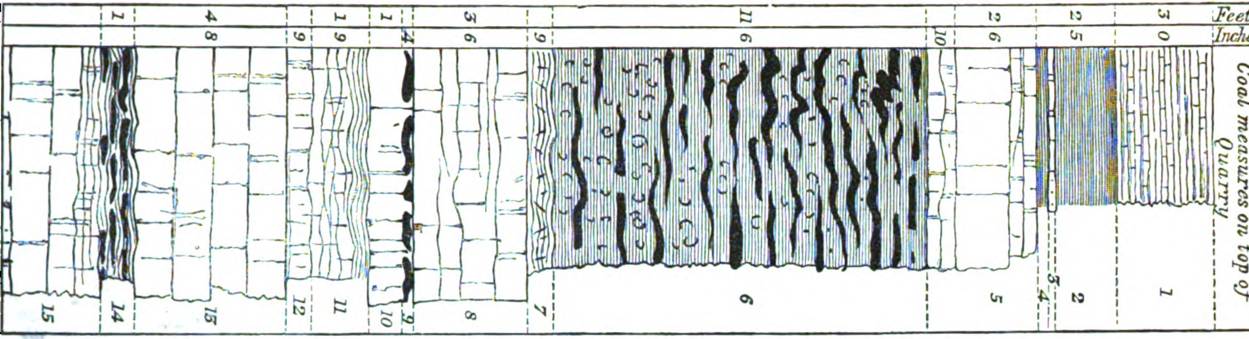

Fig. 12.

Section of quarry at Old Leighlin, referred to at pp. 181, 182.

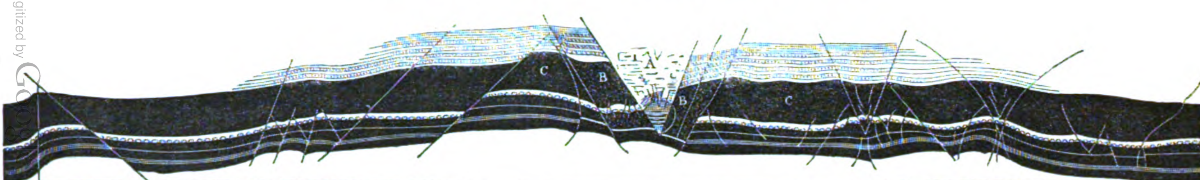

Fig. 55.

Section in the thick coal of South Staffordshire, referred to at p. 234. It illustrates the arched position which was given to the beds, the cracks that were formed in them, and the dislocations that took place, in consequence of the elevation, and as the fractured pieces endeavoured to settle down on the forces of elevation ceasing to act.

ADDENDA.

Cleavage.—In mentioning Professor Haughton's remarks on cleavage, at page 247, I should have added that he differs from both Mr. Sharpe and Mr. Sorby as to the direction of the lengthening of the particles along the cleavage planes. They suppose the extension to have been in the direction of the dip of the cleavage, while Professor Haughton believes it must necessarily have been in the direction of its strike, and that on an examination of fossils distorted by cleavage, they will always be found lengthened along the strike, and contracted in the direction of the dip.

Foliation.—I had overlooked an excellent paper on this subject by my friend Mr. D. Forbes (in the *Journal Geol. Soc.*, vol. xi. p. 166), in which he shows, partly from observation, partly from direct experiments, that foliation is the result of an entirely distinct operation from that which produces cleavage, being caused by a chemical action combined with a simultaneous arranging molecular force, developed at heats below the point of fusion of the mass. He points out that when foliation affects igneous rocks, it must be of subsequent origin to their consolidation, and shows that the planes of foliation have always a tendency to follow the planes of least resistance in the mass, whether those be planes of cleavage, of stratification, or those which he calls the striæ of fusion.

Oolitic or Jurassic Period.

I have just received, by the kindness of M. Jules Marcou, a copy of his *Lettres sur les Roches de Jura*, 1ère *Livraison*, which enables me to lay before the reader a little more precise information respecting the subdivisions of the Jurassic rocks of the true Jura district, and their co-relation with the English Oolites, than I was previously able to do.

M. Marcou establishes the following subdivisions:—

			Feet.
Upper Oolite 493 ft.	XI. Groupe de Salins.	26. Calcaire de Salins .	115
		25. Marnes de Salins .	11
	X. Groupe de Porrentruy.	24. Calcaire de Bauné .	131
		23. Marnes de Bauné .	16
	IX. Groupe de Besançon.	22. Calcaire de Besançon	98
		21. Marnes de Besançon	16
	VIII. Groupe Corallien.	20. Oolite corallienne .	24
		19. Coral rag de la Chapelle	82
Oxfordian 161 ft.	VII. Oxfordien superieur.	18. Couches d'Argovie .	98
	VI. Oxfordien inferieur.	17. Marnes Oxfordiennes	48
		16. Fer de Clucy . .	15
Lower Oolite 253 ft.	V. Groupe du departement de Doubs.	15. Calcaires de Palente	20
		14. Calcaires de la Citadelle (Besançon) .	65
		13. Calcaires de la porte de Tarragnoz . .	33
	IV. Groupe du departement du Jura.	12. Marnes de Plasne .	10
		11. Roches de corraux du fort St. André .	33
		10. Calcaires de la Roche pourrie . . .	59
		9. Fer de la Roche pourrie . . .	33
Lias 198 ft.	III. Lias superieur.	8. Marnes d'Aresche .	26
		7. Marnes de Pinperdu	48
		6. Schistes de Boll .	7
	II. Lias moyen.	5. Marnes de Cernans .	20
		4. Marnes Souabiennes	43
		3. Marnes de Balingen .	34
	I. Lias inferieur.	2. Calcaires de Blégny .	15
		1. Couches de Schambelen	5

Of these subdivisions M. Marcou supposes his Calcaires de Salins to be contemporaneous with our Purbeck beds; his Marnes de Bauné with the Kimmeridge clay; his Calcaires de la Citadelle (Besançon) with the Forest marble; his Calcaire de la porte de Tarragnoz with the Great Oolite; his Schistes de Boll with the Upper Lias; and his Marnes de Cernanes and Souabiennes with the Marlstone; the rest agreeing with the intermediate divisions, except his Couche d'Argovie, which he believes not to be represented in England.

It was interesting to myself to have the thicknesses given, which I have given in English feet instead of French metres, since, not having yet visited the Jura, I had formed the erroneous notion that the groups might be as superior in thickness to our own as the Jura range is loftier than the Cotteswolds; while in reality it appears that the reverse is the truth, the total thickness given by M. Marcou being 1005 feet, while that of our own series is stated at 3370 feet.

The statement of the thickness, too, is very useful to the student visiting a district for the first time, since it tells him what sort of a group he is to look for, and what kind of a feature it will probably make in the country.

M. Marcou gives the following as the characteristic fossils of his several subdivisions, beginning with the lowest, and again subdividing some of them as indicated below :—

1. Cardinia concinna, securiformis; Lima gigantea. Ammonites planorbis, angulatus.

2 *a*. Spirifer Walcotti, Munsteri. Gryphæa arcuata; Pinna Hartmanni; Pleuromya striatula; Pleurotomaria anglica. Ammonites Bucklandi, Kridion; Nautilus intermedius.

2 *b*. Pentacrinus tuberculatus.

3 *a*. Rhynconella rimosa. Pholadomya Voltzii, reticulata. Ammonites bifer, oxynotus, planicosta, Turneri.

3 *b*. Terebratula numismalis. Mactromya liasina. Ammonites raricostatus.

4 *a*. Ammonites Davæi, fimbriatus.

4 *b*. Ammonites margaritatus.

5. Plicatula spinosa; Pecten equivalvis; Pholadomya foliacea. Ammonites spinatus.

6. Posidonia Bronnii.

7 *a*. Pecten paradoxus. Ammonites complanatus, discoides, mucronatus, Raquinianus, serpentinus; Belemnites digitalis.

7 *b*. Ammonites Calypso, Dudressieri, Germaini, radians, sternalis, Thouarsensis; Belemnites unisulcatus.

7 *c*. Cyathophyllum mactra. Leda rostralis. Turbo subduplicatus, Sedgwickii. Ammonites binus, insignis, jurensis; Belemnites compressus.

8. Terebratula Moorei. Turbo capitaneus. Ammonites Aalensis, bifrons.

9. Rhynconella subtetrahedra; Terebratula globata, perovalis. Lima proboscidea; Pholadomya media, Zietenii; Pleuromya tenuistria. Ammonites Murchisonæ, subradiatus; Nautilus clausus. Cidaris glandifera, horrida; Hyboclypus Marcou, canaliculatus.

10. Not yet certainly known.

11 *a*. (Coral beds). Comoseris vermicularis; Isastræa Conybeari, serialis; Montlivaltia trochoides; Thecosmilia gregaria.

11 *b*. (Calcaires blanchâtres). Mactromya mactroides; Pholadomya Murchisonii. Nerinæa jurensis. Belemnites giganteus.

12. Rhynconella concinna. Ostræa acuminata; Homomya gibbosa; Pholadomya buccardium; Pleuromya Alduini. Acrosalenia complanata; Clypeus Solodurinus, patella; Holectypus depressus.

13. } Not yet perfectly known.
14. }

15 *a*. Fossils broken and indeterminable.

15 *b*. Rhynconella varians. Nucleolites latiporus, Thurmanni.

15 *c*. Fossils broken and indeterminable.

16. Rhynconella tetrahedra. Pholadomya carinata; Pleuromya recurva; Trigonia monilifera. Ammonites anceps, athleta, coronatus, hecticus, lunula, macrocephalus; Nautilus hexagonus.

17. Rhynconella Thurmanni. Ammonites annularis, Arduennensis, Babeanus, canaliculatus, dentatus, Erato, Eucharis, Lamberti, Mariæ, oculatus, perarmatus, tortisulcatus; Belemnites hastatus. Pentacrinus pentagonalis. Sphænodus longidens.

18. Cnemidium Goldfussii; Spongites reticulatus, clathratus, lamellosus. Terebratula insignis. Goniomya sulcata; Gryphæa dilatata; Pecten fibrosus; Pholadomya cardissoides, exaltata, parcicostata. Ammonites biplex, polyplocus. Dysaster propinquus.

19 *a*. (Argile à Chailles). Gryphæa gigantea. Cidaris aspera, crucifera, meandrina, pustulifera; Ceriocrinus Milleri; Millerocrinus Beaumontii, Duboisianus; Pedina aspera.

19 *b*. (Coral beds). Isastræa explanata; Montlivaltia dispar; Stylina tubulifera; Thamnastræa arachnoides, concinna; Thecosmilia annularis. Ostræa rostellaris.

19 *c*. (Calcaire corallien). Fossils broken and indeterminable.

20 *a*. (Calcaire oolitique). Fossils broken and indeterminable.

20 *b*. (Calcaire à Nerinées). Nerinæa Bruntutana; Diceras arietina.

21 *a*. Natica dejanira, turbiniformis; Phasianella striata.

21 *b*. Ostræa sandalina; Astarte minima.

21 c. Rhynconella plicatella; Terebratula cardium. Mytilus pectinatus. Acrosalenia tuberculosa; Apiocrinus Meriani; Cidaris baculifera; Hemicidaris diademata.

22. Calamophyllia Stokesii. Trigonia picta, geographica. Acrocidaris formosa, *var.* minor.

23. Ostræa solitaria; Arcomya Helvetica; Ceromya excentrica; Corimya Studeri; Homomya compressa; Pholadomya myacina, protei; truncata; Pleuromya donacina. Natica globosa, hemisphærica; Pteroceras Oceani. Ammonites gigas; Nautilus giganteus. Hemicidaris Thurmanni. Pycnodus Hugii.

24. Nerinæa Elea. Clypeus acutus.

25. Exogyra virgula; Pholadomya multicostata; Trigonia concentrica. Nautilus Marcousanus. Acrosalenia aspera; Discoidea speciosa. Pycnodus Nicoleti.

26. Natica athleta, Marcousana; Nerinæa Erato, salinensis, subpyramidalis, trinodosa. Pygurus jurensis. Gyrodus jurensis; Sphærodus gigas.

I am glad to be able to put before the student so good an example of a typical locality well worked out, as the preceding account affords, and recommend to him as a study the comparison of the distribution of the fossils, and of the identity or diversity of species in the English Oolites and the Swiss Jura.

I am also pleased to see in the same work above quoted, that my somewhat hypothetical notions as to the use of the term Neocomian (p. 503), coincide in great measure with those of M. Marcou, based on ample knowledge of the whole case. M. Thurmann's name of Neocomian appears to be an excellent one for the Swiss district, and we want a corresponding one to designate the contemporaneous rocks of the British province. Marcou gives the following table:—

	Switzerland.	*England.*
UPPER NEOCOMIAN.	6. White limestones. 5. Limestones with green grains.	Lower Greensand (the bottom part of it).
MIDDLE NEOCOMIAN.	4. Marls of Hauterive. 3. Yellow Limestone.	Weald Clay and Hastings Sand.
LOWER NEOCOMIAN.	2. Limonite. 1. Blue marls unfossiliferous.	

It appears that No. 1, the blue unfossiliferous marls, are now known to contain a few small fresh-water and terrestrial species.

This increases the probability of its being contemporaneous with a part of the English Wealden, and that the rest of the Swiss Neocomian are the marine beds corresponding to our exceptional freshwater ones, and to part, at least, of the Lower Greensand.

Perhaps it may turn out that the series is not complete in either locality, and that we must either extend the term Neocomian so as to make it synonymous with Lower Cretaceous, as in p. 496, or invent some other term which shall include all the Neocomian and all the Lower Greensand, unless we prefer to remain satisfied with the phrase of Lower Cretaceous.

Nothoceras.—M. Barrande has lately established a new genus of Cephalopod under this designation. It is intermediate between Nautilus and Goniatite, and is of Upper Silurian age; one species, N. Bohemicum, being found in his stage E.—(*Bulletin de la Société Geol. de Fr.*, t. xiii. p. 372.)

INDEX TO THE FOSSILS.

ALL the genera mentioned in this work are here arranged alphabetically. The first reference, when the figures lie between 326 and 379, is to the abstract of Pictet and Bronn, and will point out the biological relations of the genus, as well as give a condensed statement of the geological age of its species, and their number. If there be no other reference, it is a genus either not recognised by British naturalists, or of which no species has yet occurred within the British area. The succeeding references will give the geological date of the genus, and enable the student to trace the geological history of its principal species.

If the first reference be not included within the numbers given above, the genus is most probably one not recognised by Pictet or Bronn, and is perhaps a new one named since the publication of their works.

The student will find it an instructive exercise to trace through the references under the principal genera, so as to become acquainted with the names of the species of the several periods; for their forms I can only refer him to a museum, or to a library containing Pictet's last edition of his *Palæontologie*, with the *Atlas*, the last edition of Bronn's *Lethæa Geognostica*, the work of Goldfuss, Sowerby's *Mineral Conchology*, and other more special works.

GENERAL INDEX.

Including the classes and orders, and some of the families of fossil animals and plants, but excluding the genera, which are given in the preceding index.

Comparative Anatomy & Physiology of the Vertebrate Animals by Richd Owen FRS 2 vols 8vo [illegible] ([illegible])

Advanced Text Book of Physical Geography. By D. Page [illegible] (1864)

ERRATA ET CORRIGENDA.

My excuse for the number of the following corrections, must be the circumstances under which the book has been written and the proof sheets corrected: at odd times, namely, in the intervals of other occupations, on wet days in country inns, in railway carriages, in remote parts of the country where I could not refer to the rest of what I had written and while so engaged in other matters that I could not recollect it. I only discovered many of those noticed while preparing the Indexes, and fear some others may still remain which have escaped my attention.—Author.

Page 21. Line 3, for postash, *read* potash.
29. Line 12, for second potash, *read* potassium.
125. Figure 2 has unfortunately been printed upside down.
307. Line 2 from bottom, for 4. Placoids, *read* 4. Cycloids.
308. Line 2 from bottom, for peutremites, *read* pentremites.
324. Lines 9 and 18, for species or genera, *read* individuals or species.
328. Lines 34 and 35, for Chæro, *read* Chœro, and in other places, in words compounded of χοιρος, a pig.
337. Line 5, for Cælopoma, *read* Cœlopoma, and *passim* for Cælo, *read* Cœlo, in all words compounded of κοιλος, hollow.
339. Line 7 from bottom, for Playtosomus, *read* Platysomus.
359. Line 5, for Catanostoma, *read* Catantostoma.
406. Among *Gasteropoda, dele* * Helminthochiton.
407. Line 9, *insert* * Agnostus.
407. Line 12, *insert* * Olenus.
411. Line 5, for Othis, *read* Orthis.
411. Among *Conchifera, insert* Cypricardia simplex.
411. Among *Gasteropoda, add* Turritella cancellata, and Phasianella gigas.
411. It is very doubtful whether the fossils referred to the genera Avicula, Cardiola, and Pterinæa, among the *Conchifera*, and to Pleurotomaria among the *Gasteropoda*, are rightly so referred, or if they are, whether the rocks containing them be really of Cambro-Silurian age. The localities of Doonquin and Ferriter's Cove, which in Morris' Catalogue are marked as L. S. (Lower Silurian), should unquestionably be U. S. (Upper Silurian), and those of Galway are probably of the same period.
412. Among *Polyzoa, insert* Graptolites priodon.
415. Among *Gasteropoda, insert* * Helminthochiton, and *dele* Macrocheilus.
423. Among *Conchifera, insert* Cypricardia solenoides, and Psammobia? rigida.
427. Among *Brachiopoda, insert* Producta.
427. Among *Conchifera, insert* Posidonomya.
430. Among *Gasteropoda, dele* Murex, as the M. harpula is a Macrocheilus.
432. Line 5, *transfer* Pleuracanthus punctatus to next line.
435. The American Devonians are taken from Professor H. D. Rogers's Memoir in *Johnston's Physical Atlas.*
435. Line 2 from bottom, *dele* Petraia.
437. Line 2 from bottom, for Trigonoceupum, *read* Trigonocarpum.
456. Line 17, for Petalodus, *read* Pœcilodus.
462. If the genera Vermilia, Rissoa, and Lima, really occur in the Carboniferous Period, their first appearance should be *transferred* to page 438.

ERRATA ET CORRIGENDA.

465. Line 19, for Arthisina, *read* Orthisina.
468. Line 7 from bottom, Capitosaurus should be in the larger type used for the genera.
470. Line 17, *dele* the comma after others.
471. Line 5 from bottom, *read* "700 feet with, or 500 without, the salt."
473. Among *Polyzoa*, for Apseudina, *read* Apsendesia.
474. Among *Gasteropoda*, *insert* Murex.
494. Line 2 from bottom, for Siphonodictyum, *read* Siphodictyum.
495. Among *Conchifera*, *insert* Crassatella, Gastrochæna.
500. Line 6, *dele* Cyprina angulata.
505. Line 16, for Rotulina, *read* Rotalina.
510, 512. Among *Echinodermata*, for Oriaster, *read* Oreaster.
517. Among *Conchifera*, *insert* Saxicava.
528. Omitted, *Cirripedia:* Balanus unguiformis.
533. Add to the Characteristic Fossils of the Bembridge Limestone—
Reptiles: Trionyx incrassatus.
Mammalia: Anoplotherium commune, secundarium; Chœropotamus Cuvieri; Dichobune cervinum; Palæotherium crassum, curtum, magnum, medium, minus.
546. Line 25, for Mytellus, *read* Mytilus.
568. *Passim* for Baunè, *read* Bannè.

Since the preceding was in type, the receipt of No. 52 of the Geological Journal has enabled me to make the following corrections from Dr. Falconer's paper.

Page 329. ORDER 6.—*Proboscidea:* Elephas M Pl and Ps 13 (*subgenera*—Stegodon M 3, M and Pl 1; Loxodon * M 1, Pl 2; Euelephas † M 1, Pl 2 or 3, Ps 2); Mastodon M Pl and Ps 13 (*subgenera*—Trilophodon u M 3, Pl 1 or 2, Ps 1 or 2; Tetralophodon M 3, u M 1, Pl 1 or 2); Deinotherium M 2.

539. Dr. Falconer mentions the following fossil Proboscidea as belonging to the Miocene period, and found in France and Germany. Mastodon (*subgenus* — Trilophodon), tapiroides, augustidens, Pyrenaicus (*subgenus* — Tetralophodon), longirostris; and the following as found in India (*subgenus* — Tetralophodon), latidens, Perimensis, Sivalensis; and the following Elephants as found in India (*subgenus* — Stegodon), Cliftii, bombifrons, ? Ganesa, insignis (*subgenus*—Loxodon), planifrons (*subgenus* — Euelephas), Hysudricus. He also speaks of the Deinotherium as a true Proboscidean, and says there is only one species, D. giganteum, in Europe, and one in India, D. Indicum, from Perim Island, and Attock in the Punjaub, both of Miocene age.

544. To the Mammalia found in the Red Crag, add Mastodon (Tetralophodon) Arverneusis, and Elephas (Loxodon) meridionalis and ? priscus and (Euelephas) antiquus, these species being also found in the so-called Norwich or Mamaliferous Crag, which, on this, and other accounts, is believed to be merely a part of the Red Crag.

546 and 547. To the Pliocene fossils of France and Italy, add Mastodon (Trilophodon), Borsoni.

549. Line 3, for primigenius, *read* antiquus; and line 4, for angustidens, *read* Arvernensis; and line 4 from bottom, *dele* antiquus and priscus.

* The existing African elephant belongs to the subgenus Loxodon. It was the one formerly tamed under the Romans.

† The existing Asiatic elephant belongs to the subgenus Euelephas. Neither of the two living species are included in the numbers of fossil species mentioned above.