GEOLOGY FOR BEGINNERS

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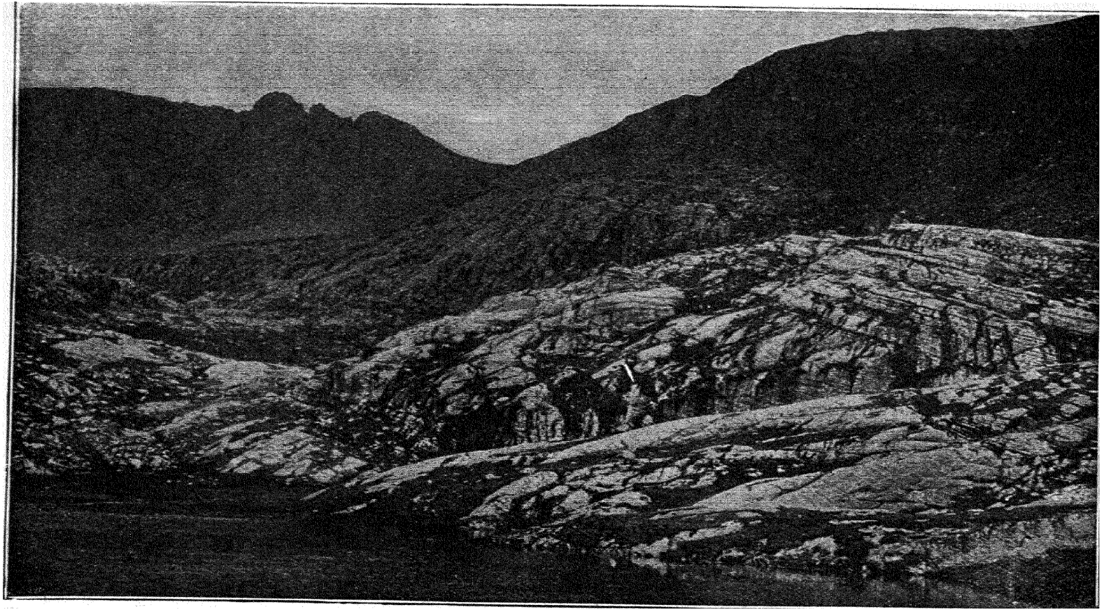
distant pinnacles of Crib Goch are chipped by frost action. (From a photograph by Mr. G. T. Atchison: copyright.)

Cwm Glas, Snowdon. The rocks in the foreground are smoothed and polished by glaciation so that they show the bedding well. The distant pinnacles of Crib Goch are chipped by frost action. (From a photograph by Mr. G. T. Atchison: copyright.)



GEOLOGY

FOR BEGINNERS

BY

W. W. WATTS, Sc.D., M.Sc., LL.D., F.R.S.
HONORARY FELLOW OF SIDNEY SUSSEX COLLEGE, CAMBRIDGE
EMERITUS-PROFESSOR OF GEOLOGY AT THE IMPERIAL COLLEGE OF
SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON

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PREFACE

In this work the writer has attempted to supply a small book on Geology which, while short and elementary in treatment, is accurate and fairly up to date. Further, it is well that sections and diagrams should be supplemented by photographs of hand-specimens and microscopic slides of rocks, and of the natural exposures where rocks are to be seen in the field. The author has kept both these aims in view while planning his work.

If he shall have succeeded in either aim the credit is due to those friends who have most generously allowed him to make use of their photographs and other illustrations, or who have looked over his proof-sheets. If he has failed, the blame must rest with him for not making better use of his privileges.

Care has been taken to make the book suitable for school work and for the examinations of the Oxford and Cambridge Schools' Examination Board. With this object in view there have been placed at the end of the chapters all the Questions set in the Science and Art Examination during twenty years, and those of the Oxford and Cambridge Board for ten years. The former are dated, except where a question has been divided for insertion in several chapters, when its origin is indicated by the figure XII.; the latter are simply marked O and C.

A few experiments are suggested here and there, and it would be well for the teacher to look a chapter ahead in order to get the simple materials requisite for the performance of them, or, in some cases, to start the experiment, and so save the time of his class.

It will be found useful to refer frequently to the index, in which, where necessary, the first entry gives the derivation, definition, or illustration of the word.

The range of most of the genera figured is given under the figures, unless the genus, or species if named, is confined to the System under which it is mentioned.

Most of the line drawings have been left clear, so that they can be coloured with crayons. This will make many of them more useful, *e.g.* Figs. 109, 121, and 127.

Much use is made of microscopic slides, as there seems to be no reason why young students should not learn to use a simple microscope as well as a hammer and acid bottle.

Naturally in writing this book no other elementary work of the class has been consulted, but no one who has ever read the late Professor Green's classic work on Physical Geology can help being attracted by the lucidity of his style and influenced by the charm of his methods. The writer owes an especial debt for the advice and assistance given him when acting as Professor Green's deputy on two occasions several years ago. The principal methods pursued in two or three of the earlier chapters, and the general practical aim of the book as a whole, are due directly to Professor Green's influence.

The writer wishes to express his thanks to Professor Lapworth for looking over the proof of the chapters on the Palæozoic Rocks, and to his old colleagues Mr. E. T. Newton, Mr. H. B. Woodward, and Mr. Clement Reid for revising the chapters on the Fossils, the Jurassic Rocks, and the Tertiary Rocks respectively. He also desires to thank Mr. G. W. Lamplugh for much friendly help, and Mr. A. S. Reid and Mr. F. Raw for reading the proofs of the whole work.

For several illustrations the writer is indebted to the late Sir Archibald Geikie, who kindly gave permission for the preparation of a few photographs from the admirable collection of rock-specimens belonging to His Majesty's Geological Survey in the Museum of Practical Geology. Fig. 102 is also borrowed, by permission, from Sir Archibald Geikie's *Elementary Lessons in Physical Geography.*

The writer has also had the good fortune to be allowed to make use of a large number of the illustrations prepared for Zittel's *Grundzuge der Palæontologie*, of which a translation has been published ; these are marked (Z.) Illustrations from De la Beche's *Geological Observer* are marked (B.)

Lastly, but very far from least, the writer wishes to express his heartiest thanks to a number of friends who have allowed him to process those photographs to which their names are appended. To the kindness of the following most of the illustrations of geological features and phenomena are due: Mr. R. Welch, Mr. Godfrey Bingley, Mr. C. A. Defieux, Mr. G. T. Atchison, Mr. A. S. Reid and Professor Waymouth Reid, Mr. H. L. P. Lowe, Mr. W. Lamond Howie, Mr. A. A. Armstrong, Mr. G. Hingley, Mr. R. M'F. Mure, Mr. A. E. Nichols, Mr. H. Preston, Mr. C. J. Watson, Mr. Griffith J. Williams, Miss M. K. Andrews, and Mrs. J. J. Cole. Fig. 206 is one of a set by Mr. Mure showing the fossil forest at Partick.

For kind help in suggestions and corrections towards the preparation of the later Editions the author wishes to thank Professors Boswell, Davies, and Fearnsides, Dr. C. A. Matley, the late W. J. Harrison, G. W. Lamplugh, and A. S. Reid, and numerous teachers, students, and reviewers.

A new chapter, XXIV., has been added in the sixth edition. Although placed for convenience at the end of the book it should be read after Chapter XVII., as it gives in outline the historical geology of Britain. It will be found useful to recur to it after reading Chapter XXI., as it provides a thread of connexion between the apparently isolated facts in Chapters XVIII. to XXI., and gives the relations between them and the growing geography of Britain.

The teacher should endeavour to get together a few photographs illustrating geological phenomena.

W. W. WATTS.

SUTTON, SURREY,
January 1935.

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GEOLOGY FOR BEGINNERS

CHAPTER I

INTRODUCTION

Definition.—The science of the earth is what is implied by the term geology,[1] but no single science is comprehensive enough to embrace the entire study of the earth. We can only hope to deal with such parts of it as are accessible to our observation, or to our study by reasoning. We may define the *earth's crust* as so much of the outer part of the earth as we can see in quarries, cuttings, mines, or borings, or reason about by means of conclusions drawn from our observations. It is the business of geology to ascertain what this crust is made of, and to employ the conclusions of chemists and mineralogists as to its composition; to observe the arrangement of these constituents and their relation to one another; then to go a step farther and endeavour to ascertain how each part of it was made and how it came to be where it is. If this can be done, a history of those parts of the earth can be written, and it is with this past history we have to deal. Geography tells us about the outlines and relief of the earth's surface at the present day; it is for geology to ascertain whether these have always been the same or different in past times. Botany and zoology tell us about the plants and animals now found on the earth; geology tells us whether they have always existed, or whether the earth has ever supported kinds of animals and plants different from those now living on it. Physics tells us about forces now at work on the earth's surface, of climates, tides, currents, and rivers; geology

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[1] Greek *ge* = the earth, and *logos* = science.

tells whether there has been any change in these forces in the past. Pursuing these studies we are brought into contact with constituents of the earth's crust which are of value in the arts and industries, and it is our business to learn about them, where they are found, and how they were formed, and if possible to discover where similar things may be found elsewhere.

Interpretation of Facts.—In some places we find old sea-beaches many feet above, and beyond reach of the waves (see Fig. 62), and sea-shells preserved in hard rock far inland; the sea must have been once at a higher or the land at a lower level than now. Traces of old forests are sometimes found to be submerged beneath the sea (see Fig. 63), and seams of coal, in which the shapes of old trees may be found, have been worked under the sea; forests once grew and were buried up where the sea now is. Remains of fish which once lived in great lakes may be found where there are now hills and plains, indicating vast changes in geography. Lava, poured out from volcanoes, is found in districts which are now quiet and restful, where the memory of man cannot recall the existence of volcanic mountains, still less their former activity. Bones, teeth, and scales of curious reptiles, entirely unlike anything known at the present day, may be found embedded in other rocks (see Figs. 240, 241, 255); so the character of the animal population must at some past time have been very different from what it is at present.

Geology as History.—Thus geology bids fair to show us that the earth has gone through vast changes in its geography, its inhabitants, and its physical condition. We must try to learn whether this has occurred in an orderly and regular fashion, due to the unbroken sequence of cause and effect, like the events of human history, or whether it has been tumultuous. and chaotic, and catastrophic. We shall find that a tolerably complete history of the changes of the earth and its inhabitants from the most remote times is written in the rocks, and this will reveal to us that the earth's changes have been of a most extraordinary but of a regular and orderly character. And we shall find that its history is by no means ended yet, but is being lived and written at the present day.

So it is essential to start with some knowledge of geography, and we must be prepared to learn some little chemistry, physics, zoology, and botany, as we go along, because it is only by knowing the present condition of the earth and the changes which go on in it now, that we shall be able to interpret the result of such conditions and changes in the past.

The Earth Crust and Rocks.—The earth has a solid rock framework beneath the soil, which is to be seen in railway and road cuttings, in quarries and excavations of all sorts, and in mines, wells, and borings. But in this way we cannot see very deep down—at the most a little over a mile, and that only in exceptional places. These rocks must be the present subject of our study, and for convenience we will abandon the idea that rocks are necessarily hard and resisting; we will call all constituents of the earth's crust, whether hard granite and sandstone, or soft clay, or gravel, *rock*. Each of these rocks will be found to be made up of individual substances which are called minerals, and each mineral is a definite chemical compound. A rock is therefore a complex thing, and may contain many substances, but these are grouped together into a comparatively small number of bodies called minerals.

Growth of Rocks.—On examining any of these rocks we meet with characters which suggest that they have not always been as we see them, but that they have been made at some time or other, and so we reach the conclusion that the earth's crust itself has been built up bit by bit, and must have a history of its own. Fossils, too, found in many rocks, are so like animals and plants (see Figs. 207, 268) that we are bound to believe they were once alive; if so, they must have become embedded while the rocks were being made and before they were hardened; thus they indicate that the history of the rocks will also reveal the history of the forms of plants and animals found in them.

Observation at Depths.—But we can only deal directly with the top of the crust. How is it possible to reach deep down into it when mines only take us down a mile or so? which is very little in an earth 8000 miles through. We can reason sometimes from the surface rocks to what would be found deep down, as the following example will show (Fig. 1). A bed of coal is seen at the surface at *a*, and a precisely similar seam at *b*. A shaft sunk down from *c* also penetrates a similar bed of coal at *d*. We are bound to conclude that it is the same seam as that met with at the surface at *a* and *b*, as the shaft penetrated through a series of rocks above the coal just like those met with at the surface at *e* and *f;* indeed some coal-seams have been actually worked out all the way from *d* to *a*. But if each of the beds of rock from *c* to *a*, and from *c* to *b*, curves down into the earth's crust, as depicted by the dotted lines, it is only reasonable to suppose that the rocks from *a* to *h* will also curve under, as they are found to come out from *b* to *g*, including the second seam of coal *g*. Thus we may infer the character of the earth's crust to a great depth by supposing the rocks to be plates bent into curves like those shown in Fig. 1 ; and that this is likely to be the case is further supported by finding the seam *g* at *i*, and the seam *b* at *k*, with corresponding rocks between and above them. So it might be worth while to continue the shaft *c* downwards, in the hope of meeting the second seam *gh* at *l*. This has been put to the test again and again, and so often with success, as to enable us to argue with tolerable certainty as to the nature of the earth's crust at great depths. This is not quite all, for it is equally logical to infer that the rocks were once continuous from *b* to *k*, and from *g* to *i*, and thus we may restore the position of the rocks not only beneath the ground but also above it, and prove that great quantities of rock have been in some way destroyed or removed.

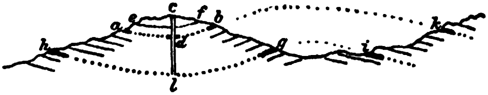

FIG. 1.—To show how the composition of rocks at a considerable depth may be ascertained from observations at the surface. *a*, *b*, *g*, *h*, *i*, *k*, seams of coal

The Earth's Interior.—As to the state of things below this we can form some ideas. As we descend in mines we find the rocks getting hotter, and on an average the temperature increases one degree (Fahrenheit) for every 60 feet of descent. If the temperature goes on increasing at the same rate, at 10,000 feet it would be high enough to boil water and, still deeper, even to melt rocks. When springs come up from a great depth they are found to be hot, and sometimes they issue as steam instead of water; while from certain parts of the earth's crust molten lava and red-hot stones are thrown out by volcanoes. So the interior of the earth is probably intensely hot.

Former Condition of the Earth.—This heat is gradually making its way out of the earth and escaping. If it has been escaping for a long time, the earth must once have been much hotter; and in imagination we may go beyond the reach of geological history so far as it has been at present read, back to a time when our earth glowed as a molten mass like the sun at the present day. If the earth has been gradually cooling down in this fashion, we have a means of explaining many of the remarkable phenomena we shall meet with in the subsequent chapters.

Plan of Work.—We will go to work in the following way. First, taking the more common rocks, we will pull them to pieces, and learn all we can about them, so as to know what to look for when we try to find out the method by which they may have been formed. We will next go to places where changes are taking place on the earth at the present day, where rivers are carving out their valleys, or the sea tearing its cliffs to pieces, and depositing the relics on the sea-bed; we will compare these deposits with our rocks, and find out the points of agreement or difference, and then we will see how the differences can be accounted for.

Again, we can study the matter poured out from active volcanoes in order to see if there are any similar substances to be found on the earth's crust. And we will see what some of the chief animals and plants now living are like, and then collect fossils from the rocks and compare them with those which live now, and make out their points of resemblance and difference.

If we get satisfactory comparisons in these ways we will go farther and arrange our facts in order; find out how the rocks succeed one another; and what points in the history of life or geography each one yields. In doing this we shall realise that the present surface of the earth, its landscape and scenery, has also a history of its own; and we shall see how mountains, valleys, lakes, and other features have been formed, and how they have acquired their present shape and character. Thus the history will be one of geography, of landscape, and of life; and we shall find that the earth has passed through the most wonderful chapters of life and growth and change before reaching its present stage.

RECAPITULATION

In this chapter we have learnt that Geology is the science which deals with the *earth's crust*; its *composition*, the *arrangement* of its constituent rocks, the *fossil* contents of the rocks, the *order* in which they are arranged, and, finally, the *history* which the records contained in the rocks may be made to yield if only we can learn the language in which it is written.

We very soon get evidence that the rocks have come into existence by the operation of such *natural causes* as we can study at work on the earth at the *present* day. Thus the earth's crust has been built up bit by bit, and each bit is the direct outcome of the *geographical conditions* which prevailed there at a certain period of the earth's history.

Geology teaches us about these ancient phases of geography; what the earth and its surface were like at particular periods of its history; how these geographical phases succeeded one another; and with what kind of a population of animals or plants each phase was associated.

By a simple process of reasoning we are often able to ascertain the structure of the crust at very considerable depths, and so to reach conclusions of great scientific and economical value with regard to the deeper parts of the earth's crust.

QUESTIONS ON CHAPTER I

1. What is understood in geology by the term rock? (1879.)

2. Define the "Crust of the Earth." Mention the chief substances of which it is composed. (1880.)

3. Prove that the geography of the earth has not always been as it is at present.

4. What is the meaning and derivation of the word geology?

5. How can the composition of the earth's crust deep down be often determined?

6. What is the nature of the earth's interior?

7. What was probably the former condition of the earth?

CHAPTER II

STUDY OF A PIECE OF STONE AT HOME

Granite and Conglomerate.—Obtain a piece of granite[1] and a piece of conglomerate and examine them carefully. The conglomerate is the easier to understand, so we will begin with that. It should be first broken across so as to get a clean fracture, but the best of the weathered surfaces should be preserved, as it often shows features which can hardly be seen on a fresh fracture.

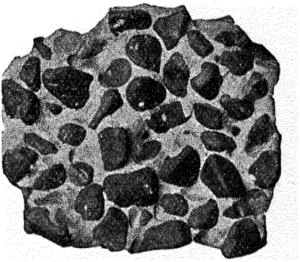

FIG. 2.—Conglomerate made of black flint-pebbles. From a specimen belonging to H.M. Geological Survey (⅙ natural size).

Pebbles.—It will be at once seen that the rock consists of a number of bits of other rocks, often of several sorts, differing from one another in colour, hardness, and shape. It looks like a plum-pudding with stones stuck in it for plums, and indeed it is often spoken of as pudding-stone (Fig. 2). In many conglomerates these pieces of stone can be got out with a hammer, or by scraping away the stuff between them. If this is done, it will be seen that they are rounded, and of a roughly oval shape. Indeed they are quite like the pebbles which may be picked up in a brook or on the sea-shore, and it is because the rock consists of a collection of different bits of rocks gathered together into one place that it is called a conglomerate (Lat. *con*, together; *glomerare*, to

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[1] Latin *granum* = a grain.

gather into heaps). Strike one with a hammer and it will break up like a bit of stone, or like a beach pebble.

Matrix.—Now look at the stuff which binds the pebbles together, using a lens for the purpose if you cannot see it well without. It will be seen to be a miniature conglomerate, made also of rounded bits of rock, just like the large pebbles in shape and appearance, but of smaller size. If you have chosen a bit of soft conglomerate you can break up this *matrix* in your fingers, or with gentle blows of a hammer on a steel plate, using no more force than is just necessary to separate grain from grain.

Pour water over the powder in a cup, wash it round and round, and then pour off the muddy water. Wash again and again in this way until the water runs off clear, to get rid of mud and fine sand, and then examine the residue with a microscope. If the matrix does not powder up satisfactorily in this way, put it into some dilute hydrochloric acid and warm it slightly. It will probably fall to pieces and can then be washed with water and treated as before. If this method fails, you had better try another specimen of conglomerate.

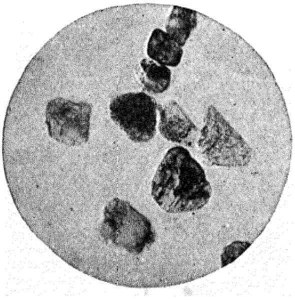

FIG. 3.—Grains of wave-worn sand ($\frac{12}{1}$).

Sand-grains.—A little of the washed residue should now be taken, spread while wet on a glass slide, and examined with the microscope, using a low power (1 inch or 3 inch, preferably the latter). The tiny pebbles shown in Fig. 3, which will now be seen, are clearly miniature copies of the large ones. They are usually well rounded, but most of them are clear and colourless like bits of glass. In addition, other kinds of grains will probably be present, some clear and transparent but of various colours, brown, green, or yellow, others turbid and cloudy. The chief difference between these grains and larger pebbles is that each consists of a single, simple substance, whereas the larger pebbles are bits of rock, and thus are generally composite and made of several substances united together. It is likely that smaller and smaller grains will be present, these being rougher in outline and less rounded than the larger ones.

Origin of Conglomerate.—Thus we learn that a conglomerate is a collection of *pebbles* packed together in stuff, conveniently called the *matrix*, which holds them together, and is itself a collection of minute pebbles. Searching about for anything which is at all like a conglomerate in appearance, we may come across some workmen making concrete. They take pebbles and sand from a river bed, a sea-beach, or a gravel pit, mix them up with slaked lime or cement, and water, and then leave the mass to set. The lime and sand set into a solid mass, very like the matrix of the conglomerate, and bind the pebbles together into an artificial conglomerate (Fig. 4). We might therefore be inclined to guess that a conglomerate has been made by nature in a similar way; by taking pebbles and sand from a sea-shore, mixing them together, and then binding them fast by something which acts like the lime in the concrete.

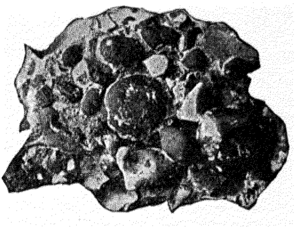

FIG. 4.—A piece of concrete, ½.

Granite. — Now take a piece of granite like that shown in Fig. 5. Its composition is not quite so obvious at first sight, and it is a good thing to have a piece with one polished face, and the rest cleanly fractured. In most granites will be seen large pieces of white or pink stuff (P); these you may at first be tempted to call pebbles. On looking more closely these are seen to be of

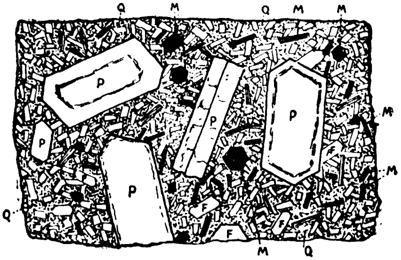

FIG. 5.—A slab of Dartmoor granite. P=porphyritic crystals of felspar; F=smaller crystals of felspar; M=hexagonal crystals of mica; Q=crystalline quartz (⅓ natural size).

an oblong shape, not rounded, and their sides are parallel. If their ends are carefully examined one, or sometimes both, will be seen to end in a sort of roof. They are, therefore, not pebbles, but they have a definite shape of their own (see Fig. 6). Now strike one of them gently with a hammer, or, better still, examine it carefully with a lens where it has been broken in fracturing the rock. It has not broken irregularly as glass would, but it shows little glittering parallel faces, each one of which is quite flat. That is to say, there is a kind of grain running through it, and it breaks more easily along these faces than elsewhere, just as wood splits best along the grain.

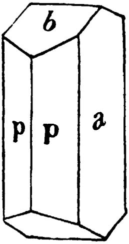

FIG. 6.—Crystal of orthoclase felspar. *a* = pinacoid face; *p* = prism faces; *b* = basal face.

Crystals.—We can, however, compare this stuff better with something else than with wood. Take a bit of sugar-candy and look at it carefully. You will see that it too is made up of bits which have flat sides and ends. The different bits are somewhat like one another in shape. Where it is broken you will see many little glittering faces on looking at it with a lens. Now, sugar-candy is simply pure sugar in what is called the crystallised form. Each shape that you see is a crystal,[1] and each crystal has a way of breaking which is like that of the other sugar crystals.

Felspar.—The pink bodies in the granite are also crystals, because they have a definite shape of their own, and also a peculiar kind of grain inside them which is manifested when you try to break them. But there is one great difference between the pink or white crystals in granite and those of sugar. The latter dissolve in the mouth or when placed in a vessel of water, the former never do so. This property is called solubility, and we can tell that the sugar is still present in the water by its sweet taste. In order to have a convenient name to use we will call the pink, oblong, shining-faced crystals in the granite, crystals of felspar.[2]

Mica.—Next look at the *matrix* in which the big crystals are embedded. First you will probably notice white or pink

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[1] Gr. *krystallos* = ice.

[2] German *feldspat* = rock-spar.

felspar crystals, in character like the big ones, but smaller in size (Fig. 5, F). Neglect these for awhile. Then on holding the bit of granite up to the light you will see very bright shining surfaces (Fig. 5, M). These are either silvery white in colour or else black, with perhaps a slightly bronzy look. Look at a number of these, one after another, and you are pretty sure at last to find one which is six-sided in shape like Fig. 7. Having found one you will probably see others, and will realise that there is a general tendency for this substance to take this shape. Apply the point of a knife very carefully below one of them, and you will be able to split off a little six-sided plate, and will then see another shining beneath it. This again may be split off, and so on, so far as it is practicable. This substance is evidently a little six-sided column built of plates, one above another, like that shown in Fig. 7. It too is clearly a crystal, but it has a different shape from the felspar; it also splits up more readily, and in a different direction. If you could get it out of the granite whole it would look like Fig. 7, a squat hexagonal column, with the "grain" parallel to its base, so that it splits up in that direction. Here we have a second crystal, with a shape and structure of its own; something again quite different in every way from the rounded rock pebbles in the conglomerate. These crystals, whether black or white, may be called *mica*.[1]

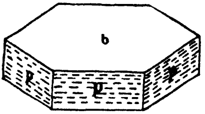

Fig. 7.—A crystal of mica. *p*=prism face; *b*=basal face.

Quartz.—To find out what acts as matrix to the crystals of felspar and mica and binds them together, we need rather closer examination still, and if possible on a polished surface of granite. Study with the lens will show you that there is a substance looking like glass which fills up all the interstices, as if the crystals had been placed in molten glass which had afterwards solidified around and among them (Fig. 5, Q). This is not easy to make out in powdered granite, though it can always be seen with a strong lens on a fractured or polished surface of it. It is better, however, to have a thin, transparent slide cut so that you can study it with a microscope (1 inch or 2 inch power) (Fig. 8). You will then be able to

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[1] Lat. *mico*=I glisten.

see the slightly turbid felspar with its crystalline outlines, the brown mica, the water-like third substance (Q), quartz, filling the spaces between, as shown in Fig. 8. For the time being we may call this third substance *quartz*, and we shall learn something more about it later on.

FIG. 8.—Microscopic section of granite. Q=quartz; felspar is cloudy, and mica dark (magnified about 6 times).

Contrasts.—Now contrast what you know about granite with what you know about conglomerate. In conglomerate you have bits of broken rock rounded into pebbles. The pebbles may be bits of granite or any other rock, and they must have been broken off other blocks of rock and then rounded into pebbles. On the other hand, in granite you have two kinds of crystals with their edges sharp and unharmed. They can never have been broken or damaged before being embedded in their matrix. The pebbles of a conglomerate, like those of a sea-beach, may have been broken from cliffs and pounded up by the waves till they were rounded. The crystals in the granite are more likely to have grown where they are found, in the same kind of way as crystals can be artificially formed. Crystals of sugar-candy are made by dissolving sugar in water and letting the water slowly evaporate or disappear as vapour or steam, when the sugar is left behind in crystals. This suggests to us that the crystals in granite may have formed from some kind of solution like this. Whether that is the case or not, the presence of crystals not damaged or broken indicates that they have *grown as crystals* at the spot where they are found, while the pebbles of the conglomerate show unmistakably that some other rock must have existed first, and that it was *broken to bits* and made into pebbles which were afterwards fastened together.

Granite seems to have been formed by one single process—*crystallisation;* conglomerate by a twofold process—rocks must first have been *formed*, and, secondly, *broken* to pieces and their fragments fastened together. For this reason it will be well to call granite a *crystalline* rock, and conglomerate a *fragmental* or *clastic*[1] or *derivative* rock, because it is made of fragments broken and derived from other rocks.

Dolerite.—This distinction between the two rocks is a very important one, and many other rocks belonging to each of the two divisions can be found. Take a bit of dolerite[2] for example (Fig. 9). It is finer-grained than granite, so that it is not easy to make out its crystals, but in a microscopic slide of it you will see (1) irregular, dark-bordered, cracked, and pointed crystals of *olivine* (O); (2) long, lath-like crystals of *felspar*, which are quite clear and transparent; (3) opaque, squarish, or diamond-shaped pieces, or crystals, of a black substance known as *magnetite;* and (4) another kind of crystal, called *augite*, which is clear and transparent, and acts as a matrix to bind the others together. It is at first difficult to distinguish between the felspar and the augite, so that microscopes for studying rocks are adapted with an instrument called a polariscope. The effect of the use of this instrument is, in a thin slide, to bring out the augite in brilliant colours while the felspar appears in drab and grey tints. The felspar crystals will now be seen embedded in augite as shown in Fig. 9.

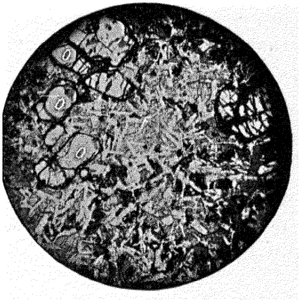

FIG. 9.—Microscopic section of ophitic dolerite. O = olivine; felspar, light needles; augite, half-tone; magnetite, black (magnified about 6 diameters, $\frac{6}{1}$).

Crystalline Substances.—In dealing with most of these crystals we have recognised that they have a definite shape of their own, and when that shape is present we can easily determine that a substance is a crystal. But if the crystal is broken, or for any other reason not perfect in shape, we can still find out by proper means that it is a part of a crystal. To do this most conveniently we must use a *polariscope.* The two parts of the polariscope are crossed in such a way that no light comes through the microscope; in other words,

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[1] Gr. *clasis* = breaking.

[2] Gr. *doleros* = deceptive.

the field of it is dark. If a broken bit of a crystal is now placed on the stage and rotated it will be found that it appears light in certain positions and dark in others. This property belongs exclusively to bits of crystals and not to other things. It is true that certain crystals lack the power to do this, but such crystals need not trouble us at present. It is owing to the fact that the minute particles of which a crystal consists are arranged or built together according to a definite plan that they acquire this peculiarity, and the outside shape of the crystal is merely a result of this definite building plan ; just as the shape and style of a house is the consequence of the plan adopted in putting the bricks or stones together in its different parts. And from the inspection of the ruins of a fallen building it is often possible to gain a very clear idea what the style and character of the building originally were ; to say what was the class of the masonry, the thickness of the walls, and the style of its architecture. So the polariscope not only enables us to recognise a fragment as part of a crystal, but also to say what kind of a crystal the original was and what shape it had.

Now, going back to our study of granite, we shall find that its matrix, which we have called quartz, is crystalline in *structure*[1] though not in shape. It has endeavoured to build itself into crystals, but has not succeeded in acquiring its crystalline shape. Elsewhere we can find this substance in the form of crystals, and when we do so their shape is that given in Fig. 10, six-sided columns like the mica, but roofed over with a six-sided pyramid at one or both ends. It does not possess the property of cleavage, which causes the mica to split so easily, and felspar much less easily, into thin plates. It has not succeeded in attaining its proper shape in granite, because the mica and felspar had crystallised first, and the quartz coming last could only squeeze into the irregular spaces between the other crystals. The same is the case with the augite of the dolerite.

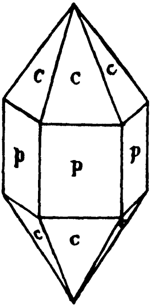

FIG. 10.—Crystal of quartz. *p* = prism faces ; *c* = pyramid faces.

Sandstone.—Sandstone furnishes us with a second example

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[1] Lat. *struo* = I build.

of a fragmental rock. A soft sandstone can be broken up like conglomerate, but it contains no big pebbles. It is rather like the *matrix* of the conglomerate. It should be gently powdered and washed with water in the same way; if deeply coloured it must be warmed in dilute hydrochloric acid. The grains obtained will be found to be rounded, glassy, and clear. A microscopic slide of sandstone (Fig. 11) shows these grains embedded in a still finer-grained matrix. Looking at the grains with a microscope it will be seen that they are in character very like the quartz matrix of granite. Further, the polariscope shows that they are *crystalline* in structure. They are, in fact, bits of broken quartz crystal, and if we could break up quartz crystals and give the fragments a round shape we could imitate a sandstone in the same way as concrete imitates conglomerate. We need not, however, break up actual crystals of quartz; the irregular grains of quartz in granite would do just as well, because they are crystalline in structure; and if we could destroy the felspar and mica in that rock and then pound up and round the quartz we should have what we require. Something of this sort is done in nature, for along the sea-shore we find abundance of sand which, when washed, if necessary with acid, and examined under the microscope, is quite undistinguishable from that in sandstone. In both sandstone and sea-sand we frequently see sparkling spangles of mica which, like the quartz, may have been derived from the smashing up of granite.

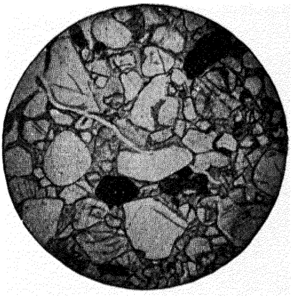

FIG. 11.—Microscopic section of sandstone from Spilsby, Lincolnshire (about 6 diameters, $\frac{6}{1}$).

Crystalline and Fragmental Rocks.—Dolerite then is a crystalline rock like granite, made of crystals and crystalline substances which have formed on the spot. Sandstone is a clastic rock like conglomerate but on a smaller scale. It too might have been made of fragments broken from other rocks. There is, however, this difference, that conglomerate is made of fragments of *rock*, pebbles which are recognisable as bits of granite, slate, limestone, sandstone, or other rocks, while sandstone is made of bits broken out from the crystals or crystalline particles, which are found to make up the bulk of other rocks. When a piece of granite is broken into large fragments each one will be composite, a bit of granite. But if one fragment be broken finer and finer it will at last part into its separate ingredients, quartz, felspar, and mica. Thus the grains in sandstone may represent the breaking up of pebbles into their ultimate particles.

The perfect or imperfect crystals found in nature, like quartz, felspar, mica, and augite are called *minerals*, and each kind has a definite composition of its own as well as a definite external shape and internal structure. Each mineral is a definite chemical compound, containing usually two or more of the seventy or so simple substances or elements which the chemist tells us the whole earth is made of. Quartz consists of two elements, silicon and oxygen, united into a chemical compound known as silica ; calcite, which occurs in limestone, of three elements, calcium, carbon, and oxygen, united to form a compound known as carbonate of lime ; mica of four elements, silicon and oxygen, combined with the metals aluminium and potassium ; and felspar also of at least four, silicon and oxygen, combined with aluminium and either potassium, sodium, or calcium.

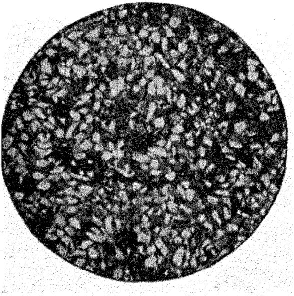

FIG. 12.—Microscopic section of shale, Skye (about 12 diameters, $\frac{12}{1}$). The elongated particles of mica, etc., are arranged anyhow.

Clay and Shale.[1]—There are two more kinds of fragmental rock which must have a little attention—clays and limestones. Clays are soft, dull-looking rocks which can generally be washed into particles by water. A powder is generally left, which in some cases can be moulded like pottery clay. The powder should be warmed in dilute hydrochloric acid and washed again in water (it will take some time to settle), and a pure

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[1] Ger. *schalen* = to peel off.

white clay like that fine sort used for china-making will be left behind. A microscopic slide shows that the clay contains extremely fine particles of quartz embedded in a semi-opaque, granular substance, like that which forms the matrix of many sandstones (Fig. 12); this is what washes away from the sandstone when it is pounded and washed in water. Clay and shale are finer-grained fragmental rocks, made of very fine quartz grit with muddy matter or impure china-clay. The better and finer the clay the less the amount of grit in it. In nature we find similar clay on the sea-bed or at the mouths of rivers, and it is being deposited from water just as pebbles and sand are.

FIG. 13.—A piece of weathered crinoidal limestone, Flintshire, from the collection of H.M. Geological Survey (about ⅓ natural size).

FIG. 14.—Microscopic section of limestone containing foraminifera; from India (magnified about 8/1).

Limestone.—Limestone is usually a harder rock, and some kinds seem to be crystalline like granite. A weathered example generally shows bits of shells or sea-lilies, or other things not unlike those to be found in the sea, sticking out of it (see Fig. 13). When warmed in hydrochloric acid it is almost completely dissolved, leaving behind only a little sand or mud. If a microscopic slide of it be examined, traces of dead animals are common in it. In a section of chalk, tiny shells made of a number of little globes stuck together can be seen (Fig. 244). In other limestones, traces of shells, bits of coral, and other organisms which will not yet be recognised (Fig. 14), are seen in abundance; of them, and small fragments broken from them, the bulk of the limestone is composed. Limestone is therefore a clastic rock, not made of fragments broken from other rocks, but in the majority of instances of fragments of animals such as live on the sea-bed. A bit of shell will be found to dissolve as completely in hydrochloric acid as the limestone does, so that the composition of the limestone is not the same as that of sands and clays, but it is what we should expect if the rock were made out of the remains of marine animals.

RECAPITULATION

In this chapter we have learnt that there are two great classes of rocks: Those like conglomerate, sandstone, clay, and shale, which are made out of bits *broken* from some rock which existed before; these are the *clastic* or *derivative* rocks: And those which, like granite and dolerite, are made up of *unbroken* crystals which must have grown where they are found, as their edges are quite undamaged and unbroken; these are the *crystalline* rocks.

The *clastic* rocks may be made of fragments of any kind of rock or of any kind of mineral, but the mineral fragments are generally broken and rounded bits of *crystals*, such as quartz, felspar, mica, etc. The *crystalline* rocks may be made of few or many minerals which are all perfect crystals, or else they have a crystalline *structure*, and have only been prevented by lack of room from acquiring their proper crystalline *shape*. Common minerals in such rocks are quartz, felspar, mica, augite, olivine, and magnetite.

Crystals are recognised by their shape, cleavage, and action on polarised light, tests which depend on the fact that the inner building of the crystal corresponds with the external shape.

Limestone differs from the other clastic rocks in that it is made of bits broken from the hard parts of animals or plants.

QUESTIONS ON CHAPTER II

1. Describe carefully the different constituents of a conglomerate and a sandstone. How may these rocks be analysed?

2. What are sand-grains? Compare them with the grains of a sandstone.

3. Describe the appearance, shape, and condition of the three chief constituents of granite.

4. Compare and contrast granite with conglomerate.

5. What is the difference between a mineral and a rock? Give some examples of each. (1877.)

6. Compare and contrast dolerite with sandstone.

7. What are crystalline substances? Give examples.

8. Point out the chief differences between clastic and crystalline rocks. To what are these differences likely to be due?

9. Describe shale and limestone.

CHAPTER III

STUDY OF ROCKS OUT OF DOORS

A Quarry and its Structures.—We must now go out of doors and look at the rocks like those we have been studying indoors. The rock specimens came from some quarry, cutting, or other opening into the earth's crust where the rock under the soil was to be seen. Fig. 15 gives some idea of the kind of thing which can generally be seen in a cliff, or in a quarry, in

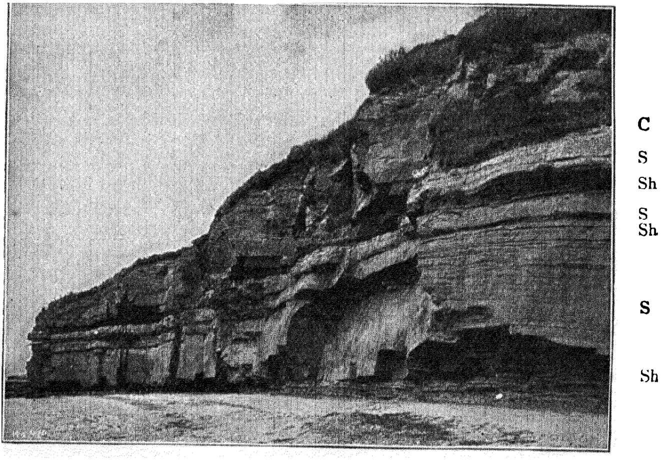

FIG. 15.—Cliff beneath Ardross Castle, Fifeshire. Carboniferous sandstones S, shales Sh., coal C; to show bedding, lamination, and undercutting by the sea. (After a photograph by Mr. A. S. Reid: copyright.)

a clastic rock. The most obvious feature is that the rock is traversed by straight cracks or planes of division, as though sawn through in several directions. Some of these cracks are seen to be parallel to others, so that they can be classified into separate sets, each set having one dominant direction (see Fig. 86, p. 114). On looking a little closer, we shall usually be struck by one set in particular, which may be quite horizontal, or else inclined at an angle to the horizon. The face of the quarry should now be more closely examined, and the rock will be seen to be banded parallel to this direction. One band will be a little coarser in grain than another (Fig. 15, S), or it will be slightly or even markedly different in colour. There may be a greater difference than this, for one band may consist of shale (Fig. 15, Sh.), another of sand, a third of conglomerate, and perhaps a fourth of coal (Fig. 15, C). It is unusual to find all these varieties in one pit, but two or more may frequently be seen.

Stratification.—Clastic rocks tend to occur in plates lying parallel to one another, like a pile of sandwiches, or of sheets of paper of different colours. These plates may be a few inches thick or a few feet (Fig. 15), even in some cases hundreds of feet, but fragmental rocks almost invariably have this arrangement. For this reason they are called *stratified* or *bedded* rocks (Lat. *stratum*, meaning strewn out), and the individual seams are called beds or *strata* (regular strata). If a bed of conglomerate is present, the greatest length of the pebbles will be found to be parallel to the direction in which the bed is lying. (See Figs. 18, 28, 50, 60, 61, 66, 86, 227, 287.)

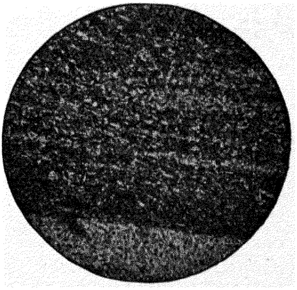

FIG. 16.—Section of laminated shale Breidden, Shropshire (about $\frac{6}{1}$).

Lamination. — In most sands and clays, and even in some pebbly rocks, each bed is made of thin leaves (see Fig. 15, Sh. and S), which are called *laminæ* (Lat. *lamina*, a plate), and are sometimes of extreme thinness, so that in shales as many as a hundred may be found in the thickness of an inch. If a specimen be broken off, it will probably split under the blade of a knife into these thin plates. Occasionally the laminæ do not differ perceptibly from one another in character, but they merely split readily apart (see Fig. 98). More usually, however, they differ slightly in depth of tint or in colour, in coarseness of grain, or in the materials of which the different layers are made up. This is very conspicuous on examining a section of a laminated rock under the microscope (Fig. 16). In other words, the laminæ are merely diminutive strata enclosed within the larger ones.

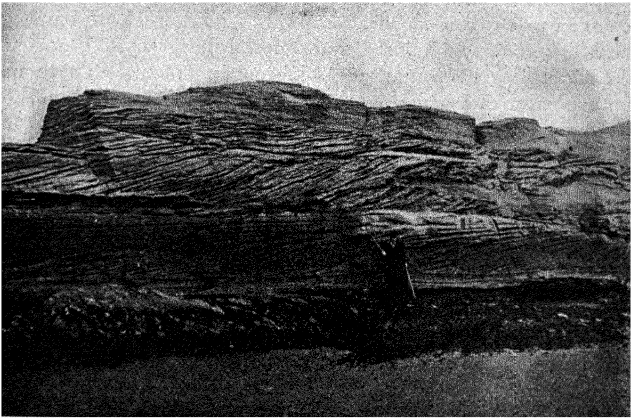

FIG. 17.—False-bedding in Triassic sandstone, Hilbre Island, Cheshire. (After a photograph by Mr. C. A. Defieux: copyright.)

Regular and Irregular Bedding.—Generally the laminæ run parallel to the larger strata, and the latter are bounded above and below by parallel faces (Fig. 15). The bedding is then said to be *regular* (see Fig. 86). When the strata are coarse-grained, especially in sandstones and conglomerates, *oblique lamination* occurs, and the individual laminæ though roughly parallel to one another are not parallel to the upper and lower surfaces of the larger bed in which they are contained, nor are they necessarily parallel to the laminæ in the next bed above or below. This is illustrated in Fig. 17. If this structure is not to be seen in the quarry, it may generally be found in any neighbouring gravel pit. When the lamination is oblique a rock is usually *false-bedded*, that is, the strata are not plates, but thin out in one or more directions, and are shaped like wedges or lenses. (See Fig. 17.)

Unstratified and Intrusive Rocks.—If quarries in a crystalline rock like granite or dolerite be available, they should be studied next. These rocks will also be found to be traversed by cracks, some of which may occur in parallel sets; but as a rule nothing whatever corresponding to lamination or stratification will be found. The crystalline rocks are *unstratified*. If the contact of crystalline and fragmental rocks can be seen, it should be attentively studied. The crystalline rock will be found to be in a mass, and it will thrust itself irregularly into the fragmental rock, as if it had been pushed or squirted into it. The diagram (Fig. 18) shows the occurrence of a

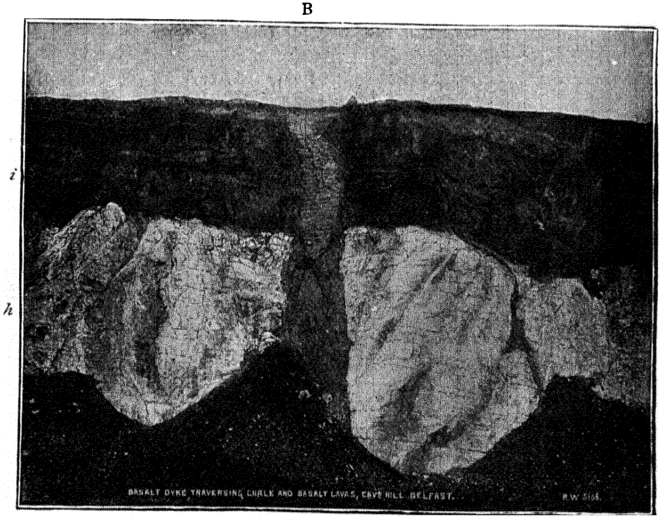

FIG. 18.—Cliff of chalk, with layers of flints (*h*), covered by lava-flows of basalt (*i*); both pierced by a dyke of dolerite (B), which is columnar in the upper portion. (After a photograph by Mr. R. Welch: copyright.)

mass of black dolerite (B) in contact with bedded white chalk. It has clearly pushed itself right through the chalk; it breaks across its layers, injects little tongues or veins into it, and is found to bake and harden the chalk where it comes into contact with it. Clearly the dolerite has come there after the chalk was formed as strata; in other words, it is *intrusive* into it. This is the general character of crystalline rocks. They are intrusive into the fragmental series, or into one another. (See also Figs. 111, 122, 123.)

Clastic rocks occur in regular or irregular strata; crystalline rocks in irregular unstratified masses often seen to be intrusive into clastic rocks after the latter were formed and consolidated.

Fossils.—On splitting fragmental rocks along the planes of lamination fossils[1] may often be found lying on the planes. These are generally present in limestones and clays, frequently in sandstones, but more rarely in conglomerates. The fossils may be shells, sea-lilies (Fig. 13), sea-urchins (see Fig. 142), bones or teeth of fish or other animals, bits of sea-mats and the like, or traces of leaves (see Fig. 207), bark (see Fig. 208), or stems of plants (see Fig. 210). Each of these is not altogether unlike something living at the present day, such as may be seen figured in books of natural history. Further, the bulk of them are animals that live in water—generally in the sea (Fig. 19); or plant remains, which may have been washed into the sea or a lake. Now these fossils may sometimes be found in successive laminæ one above another, and they indicate, not that the sea was there just once, but that it was there again and again, or rather that it stayed there for a long period, while generation after generation of animals lived and died. If sand or mud were being slowly deposited in a lake or the sea, the animals living in the water above, or those washed in

FIG. 19.—A piece of fossiliferous fissile limestone (about ⅓).

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[1] Lat. *fossus* = dug up.

by rivers, would drop to the bottom when dead, and be buried up by the sand or mud as it accumulated.

Unfossiliferous Rocks.—It may be instructive, though it will not enrich the collection, to search in the crystalline rocks for fossils. None whatever will be found, for, as they are unstratified, these rocks are also unfossiliferous, and we may search without finding a trace of an organism. This constitutes another important distinction between crystalline and fragmental rocks.

Summary.—It is now time to review some of the important facts we have gathered. We find that fragmental rocks, in the materials of which they are made, recall familiar objects of the sea-shore and the river-bed. We have conglomerates of beach- or river-pebbles, sandstones like the sea-shore sand or that of a river-bed, clays like the sea-beds, or that in the flood-plain, or at the mouth of a river, and limestones made entirely out of the relics of creatures such as live in the sea.

Again, we find these rocks in sheets like the present beds of pebbles, sand, mud, or ooze met with on the sea-floor ; and in each of these rocks we find fossils such as are to be seen on the sea-shore to-day, scarce amongst the pebbles, occasionally occurring in the sandstones, and frequently seen in clays, as they are of common occurrence on those parts of the sea-bed where mud is nowadays being carried down. Further, we have limestone entirely made up of fossils and their fragments, as we have shell banks, beds of ooze, and piles of organisms on the sea-bed. The conclusion we must inevitably come to is that the chief types of fragmental rocks are likely to have been formed by the same agencies as are nowadays making pebble beaches, sand shores, mud flats, and sea-bottoms. The pebbles, sand, and mud, washed out from the land and deposited in great bodies of water like seas and lakes with organisms living in them, present to us materials like the conglomerates, sandstones, clays, and limestones, lying in flat sheets just as they are found in the solid earth crust. It only requires that they should be solidified and then lifted up above the water to make such sediments into the rocks of our quarries and cuttings.

When we turn to the crystalline rocks all is different. Crystals undisturbed and unbroken make up the bulk of these rocks. Their constituents cannot be water-borne, they contain no fossils, their arrangement has none of the characters of sediments. Their injection into other rocks suggests that they have come up in a fluid state from below, and their crystalline character links them with the lavas which flow from volcanoes. This material forces its way out from the inside of the earth in red-hot molten masses, which slowly solidify and crystallise as they do so. Some of the characters we can observe in them suggest those of the crystalline rocks. It is possible that crystalline rocks have come up red-hot and molten from inside the earth, and that as they cooled they developed the crystals of minerals we find in them. This will account for their freedom from fossils, the absence of stratification, and their massive and intrusive character.

Derivation of Clastic from Crystalline Rocks.—Further, the material of these crystalline rocks when broken up and ground down will provide the stuff required for making some, at least, of the types of fragmental rocks. These may be in large part of secondary origin, and derived by breaking up from crystalline rocks originally. We have next to see whether there is any such breaking up going on at the present day in nature, and whether it results in the formation of anything like the materials which build up fragmental rocks.

RECAPITULATION

On studying the different kinds of rocks in the *field*, in quarries, cliffs, cuttings, and the like, the distinction into two classes is found to be maintained. Clastic rocks are bedded or *stratified*, *laminated*, and *fossiliferous*. Crystalline rocks are unbedded (*unstratified*) and *unfossiliferous*, and they occur in *irregular masses*, which are often thrust intrusively into others, whether bedded or unstratified.

Stratification means that the rock is made of great sheets resting on one another, each one differing from its neighbour in colour, composition, or structure, or else divided from it by a parting plane. The rock often splits into thin leaves, *laminæ*, which may be parallel to the greater planes (*regular lamination*) or not (irregular lamination and *false-bedding*). The laminæ differ from one another like miniature strata, or they are due to a "grain" in the rock resulting from the occurrence of flattened constituents arranged parallel to each other.

The constituents of many clastic rocks have certainly been derived, directly or indirectly, from crystalline rocks.

QUESTIONS ON CHAPTER III

1. Describe the structures found in a quarry of clastic rock and contrast them with those found in a quarry in crystalline rock.

2. What are stratification, lamination, and false-bedding? Draw diagrams to illustrate each.

3. What is commonly understood in geology by a stratum or bed? (1882.)

4. What are fossils? In what class of rocks do they occur?

5. What evidence is there that clastic rocks may have been derived from crystalline rocks?

6. Tabulate the chief differences and resemblances between clastic and crystalline rocks.

CHAPTER IV

WEAR AND TEAR OF ROCKS BY THE WEATHER AND SPRINGS

Wear and Tear.—In the last two chapters it was shown that the material of which sandstone is made might be derived from granite if the rock could be broken up, some of its constituent particles smashed and rounded, put together, and then fastened into a hard stone: we have now to see if this can be done by any natural agencies. If we were to visit a granite district like the Cheviots, Mount Sorrel in Leicestershire, or Hey Tor

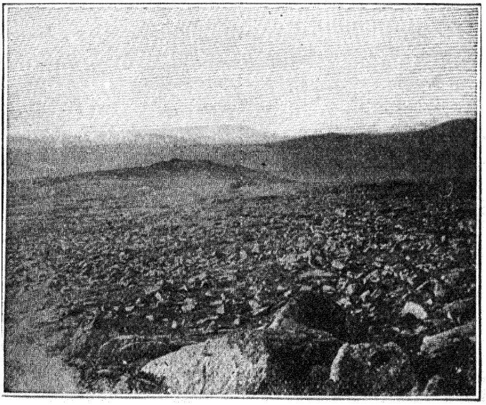

FIG. 20.—Granite blocks from a crag strewing a hillside, Heytor, Devon.
(From a photograph by the late J. J. Cole: copyright.)

in Devon (see Fig. 20), we should find the granite broken up into separate blocks, and the sides of the hills strewn with them, while in the beds of the streams we should see rounded lumps and pebbles of the same rock.

Disintegration.—Again in some granite districts, like Dartmoor, we should find the surface of the hard granite so much softened that it could be dug out with a spade, while the streams are milky in aspect from the amount of fine clay which they carry from the granite. At the same time, near the bottom of a stream we should find the water pushing along sand-grains which, on examination, would look like bits of the quartz from the granite, and this indeed they are. Thus granite is found to be undergoing a twofold process, being broken up into separate recognisable particles, and being softened into something very like clay.

Transportation.—Streams when in flood carry along with them not only mud and sand from granite, but from all other rocks, and if you take a glass of water from one you can easily satisfy yourself that this is the case. Wash the water round and round, and then pour it off rapidly into a second tumbler: a little sandy sediment will remain in the first glass. Next let the water in the second tumbler stand for a few hours; the water will gradually clear, and at last a considerable deposit will be found at the bottom; if the water be cautiously poured off, this will harden and dry like mud.

If you listen to a stream in flood you will hear that pebbles are rattling against the bottom as they are swept along in the water; this is more easily realised at the sea-side, where every wave that breaks on the shore may be seen to pick up pebbles from the beach and to hurl them forward and drag them back again.

Deposition.—Once more, if you follow a stream down towards the sea you will find its banks made of gravel, shingle, and pebbles, just like those in the shallows and reaches of the river itself; these have been deposited by the river at one time (see Fig. 54). At the mouth of the river, or along the sea-shore, banks of gravel and flats of mud can be seen, and if you pick up a handful of the sand and examine it carefully you will see that it is quite like that in a bit of sandstone, if you can imagine it to be softened and its cement removed (see

Fig. 50). Indeed, one of the experiments in the second chapter has shown how sandstone can be again reduced to the same state as the sand of these banks. In the same way the material of the clay flats is quite like softened clay rocks or shales.

Thus it is clear that we must look to the places where rocks like granite are being broken up by the weather, and follow them down towards the sea if we wish to see how hard crystalline rocks can be made into something approaching to clay rocks and sandstones. We will therefore endeavour to find out what happens where granites, or indeed any other rocks, are being *denuded*,[1] that is, acted upon by the weather, streams, and the sea, and we shall see that this will lead us to a complete understanding of the origin of the great group of fragmental or clastic rocks. *Denudation* takes place either above sea-level, when it is called *subaërial*, or below it, when it is called *submarine*.

The Work of the Weather

Frost.—Wherever a rock is exposed to weather in temperate or arctic climates, the bare scars and cliffs are more or less buried in sharp-edged chips, split off the parent mass of bare rock; these heaps are called *screes* or taluses (Fig. 21). After a spell of frost new chips are always to be found, and the nature of the rock and an examination of its structure show that the chips have been split off the cliff above by frost. Most rocks are cut up by small fissures (joints as they are called), often too small to be seen, but not too small for water to penetrate into (see Fig. 25). Now it is well known that in freezing, water

FIG. 21.—Scree of edged fragments of rock falling from the Nüschenstock in Switzerland.

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[1] Lat. *de* = down, *nudus* = bare.

expands in volume so much that nine cubic inches of water turn into about ten of ice. The force developed by this expansion is so powerful that it is practically irresistible, and strong steel bombs, filled to the brim with water and closed with a screw-stopper, may be burst when the water freezes in a cold winter night. The same force comes into play when the water is in rock-crevices ; their sides are forced apart, and the joints extended farther and deeper. Another and another frost carries the work still deeper, just like driving a steel wedge into the fissure, until at last the rock is broken along the line, and a piece wedged off, which falls away and is added to the scree below. This work goes steadily on every winter in temperate latitudes, and at every frost in high latitudes and altitudes, so that screes are always being added to.

The Downhill Path.—On walking up a scree you will find that the rocks, being just at the angle of rest, are always in an unstable position and give way under your feet, rattling down the hillside, and sometimes carrying the unwary climber away with them. For this reason climbers are not averse to descending screes, though they much dislike ascending them. Without the intervention of a climber, however, the weight of new rock-fragments always being added to the top of the screes puts them into continual movement, and they are always slowly travelling down the hillsides, and their component fragments slip down and down the slope until they reach the bottom, and at last fall into the stream there. Their future course will be traced later on.

Disintegration.—But we have not yet quite fully realised the action of frost. Many rocks are porous or spongy, and absorb a certain amount of water into the spaces between their grains, into the cement, or into any decomposed and porous minerals contained in the rock. This water freezes in like manner, and has the effect of pushing apart the constituent fragments or crystals. When the ice thaws there is nothing to force these back again, and the rock remains in a loose condition, with its constitution undermined by the forcing apart of its particles. Such rocks are found to be friable and *disintegrated*[1] at their surface, and will even crumble when rubbed with the finger.

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[1] Lat. *dis*=asunder, *integer*=a whole.

This outer crust of particles scales off from time to time, and contributes to the screes and any other material accumulating on the slopes, which, in its turn, will all find its way down to the streams, and thence be carried away as grit and mud. Granite used for building in Canada must be protected with waterproof varnish to stop disintegration by frost, and even in our own climate, where frosts are so much less severe, porous rocks do not stand well in buildings in wintry weather.

The decay and slipping of railway- and road-cuttings and embankments, the splitting of bricks, waterpipes, and water-bottles, the disintegration of roads and garden paths, the splitting of paving stones and breaking up of walls, are all familiar examples of the work of the frost-wedge; while the sharp edges of cliffs and the peaked outline of mountain summits and ridges are the forms left behind in outstanding rocks, whose fragments are being chipped away by its action.

Gravitation.—Directly a piece of rock is loosened by frost, gravitation comes into play, and drags the loosened fragments down to a lower level. Every bit of loosened rock situated on a slope has a tendency to find its way down to a lower level. The smaller fragments drop into the interstices between the larger ones and make their way down the hill. The whole scree itself is in an unstable position, and any additional loading above by the dropping of new fragments, or any removal of support by washing away fragments below (in a way which will be shortly explained), will set the whole into slow motion, and all the fragments will travel gradually downwards to a lower level, and eventually reach the valley-bottom.

Heat and Cold.—The work of disintegration is not confined to regions of frost and thaw. In hot countries especially, but to some extent everywhere, the mere alternation of heat and cold has a somewhat similar effect. All rock constituents expand when heated and contract when cooled, and the amount of expansion and contraction in different minerals varies considerably. Thus, to take an example, a rock composed of quartz, felspar, and mica, or one of sand-grains and cement, will have each of its constituents expanding and contracting at a different rate, so that they will tend to tear one another apart. The outside of such rocks becomes converted into a loose disintegrated crust, which easily breaks down and begins its downhill journey. The alternate wetting and drying of a rock by rain and sunshine has a similar but rather less effect.

Wind.—Wind is the next agent to step in and deal with disintegrated rock. It is but rarely that the wind alone can move large stones, but any loose material like dust and sand is easily picked up and swept along by it. This we were once familiar with on dusty roads, and the same thing may be seen in broad stretches of sand left by the tide. The sand is blown about, and aggregates into the heaps known as sand-hills or sand-dunes. In these the sand is laid down in layers, and a section of a sand-dune, like that shown in Fig. 22, is often well stratified. Wind sometimes produces a ripple-mark in the sand (see Fig. 50, p. 76), and the laminæ in dunes frequently show rippling. The wind easily acts on the disintegrated crust of rocks, whether due to frost or to alternations of high and low temperature, blows it away, and deposits it eventually at a somewhat lower level than it started from, thus aiding in the *degradation*[1] of solid rocks, the bringing of their constituents to a lower level. In dry, hot deserts, like those of the Sahara or

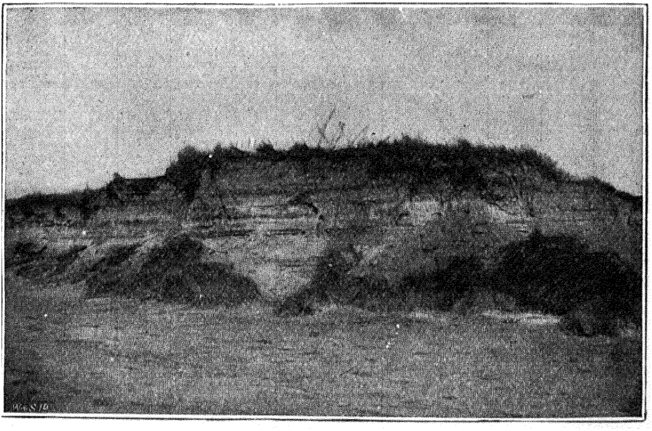

FIG. 22.—Sand-dune at Leasowe, Cheshire; to show bedding.
(After a photograph by Mr. C. A. Defieux: copyright.)

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[1] Lat. *de*=down, *gradus*=a step.

the Great Basin of North America, sand-storms are well known and dreaded, owing to the amount of sand swept along by the wind. The result is seen on the desert borders of Egypt, where outstanding stones, monoliths, and temples have been polished and worn by the sand blown against them. Cleopatra's Needle, when it came to this country, was well polished only on the side which had not been embedded in the sand of the desert. The sand-grains themselves suffer by the process, and get all their sharp edges knocked off, becoming worn, smaller, and beautifully rounded in consequence. They are not buoyed up much in the air, and feel the full brunt of friction and impact, so that grains even as small as $\frac{1}{100}$ inch in diameter become rounded by wind (Fig. 23).

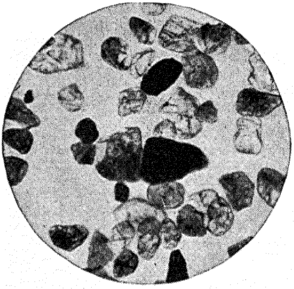

FIG. 23.—Grains of wind-worn sand (magnified about 10 diameters, $\frac{10}{1}$).

This natural process is imitated artificially in the sand-blast; in this sand is blown by a jet of steam against the surface of glass, which can be ground by this means into any desired pattern; the sand has to be renewed from time to time, for it becomes less angular and loses its cutting edges in the process, just as it does in nature.

Rain.—Next we have to consider the action of rain. Rain and hail form, as it were, an arming for the wind as it beats against disintegrated rock, and help not only to batter it to pieces, but by lubricating it and making it more slippery enable it to pass downwards more easily. Gently washing over the surface of loose rock and soil, rain drives it slowly to a lower level, or at any rate enables each individual particle of it to settle down in a direction which is almost invariably downhill. This is the *mechanical* action of rain, and its action on deep masses of soft rock is seen in the production of *earth-pillars*. Any hard mass of stone in the soft material acts as an umbrella, and while the bulk of the softer material is swept away, the portions so protected remain for a time, and thus stand out, above the parts which are washed away, in the form of pillars, each capped by a stone (Fig. 24). After a while the rain, drifted by the wind, cuts under the stone in one direction or other, weakens the pillar, and brings its capital down, to become in turn the capital of a second pillar, while the first, deprived of its umbrella, is gradually washed away by each successive shower.

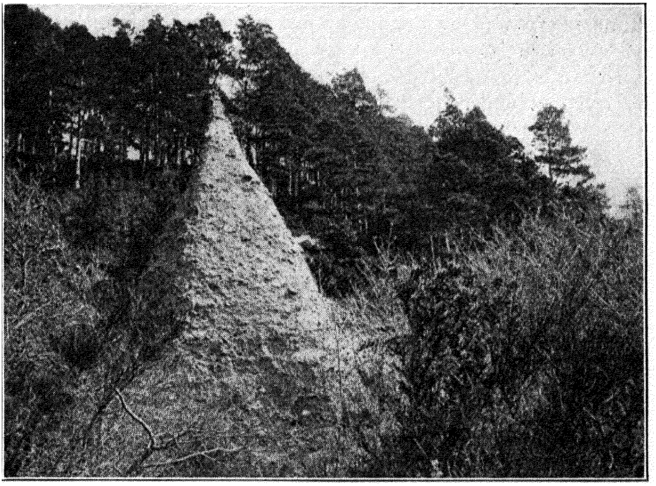

FIG. 24.—"Earth-pillars" of Old Red Sandstone conglomerate, Fochabers, Elgin. These have been washed out of a mass of conglomerate, which once filled the valley, by rain. (From a photograph by Mr. W. Lamond Howie : copyright.)

Chemical Action.—The mechanical action of rain is however small compared with its chemical action, which is of vast importance and far-reaching in its effects. If water is poured upon salt the effect is to wash it away gradually. The water which has passed over the salt is not turbid as if it had washed over clay, but quite clear, and it is only by the taste that we know it has taken some of the salt up into itself, or dissolved it. Water is capable of dissolving many of the things occurring in the earth's crust in the same way; indeed most substances soluble in plain water have already been washed out of those parts of the earth's crust to which rain ever reaches, and have found rest in the sea. Beds of rock-salt are found, however, in parts of Britain (Worcestershire and Cheshire), and when rain-water gains access to them it comes back to the surface as a brine spring, laden with salt in solution, and tasting like sea-water.

Rain-water as it falls is, however, never pure; it is still "soft" water although it has taken up many things from the atmosphere, and in particular has dissolved a large quantity of the two atmospheric gases, carbonic acid and oxygen. *Carbonic acid* dissolved in water turns it into a powerful solvent, making it behave like a weak acid, just as lemon juice or vinegar would do.

Disintegration.—Limestone, chiefly made up of that compound of calcium, carbon, and oxygen, which chemists call carbonate of lime, is only slightly soluble in pure water, but is taken up readily by that which is acidified with carbonic acid. All springs in chalk and limestone districts (Surrey, Derbyshire, Somerset) hold in solution much carbonate of lime, and the water is "hard" in consequence. Limestones are rarely quite pure; they usually contain sand-grains or mud mixed with the carbonate of lime, and when the latter is dissolved the former are left behind, as they are insoluble, forming masses of sand, or clay, or the disintegrated rock known as rotten-stone. Many sandstones have a cement of carbonate of lime, and the solution of the cement by carbonated rain-water reduces the rock again to a mere heap of unconsolidated sand. Carbonates of iron and of magnesia are similarly dissolved, and thus a large series of rocks is more or less affected by rain-water.

Decomposition.—But acidified water can do more than effect simple solution; it can bring about the decomposition of minerals into simpler compounds, some of which are readily soluble. Indeed there are few minerals which are not attacked thus, felspar, augite, hornblende, and mica, all suffering in this way, and it is well known that granite often has its felspar softened and changed when exposed to rain for a long period.

What takes place is somewhat as follows:—The felspar of granite is a compound of two substances known respectively as silicate of potash and silicate of alumina. The first of these is a compound of potash and silica, the second of alumina and silica. The effect of carbonated water is to break down the link between the two compounds and decompose one of them, the silicate of potash, converting it into carbonate of potash, which is soluble in water, and is carried away by it in solution; the silica formerly united with the potash being left behind. The change may be represented thus—

Potash and Silica	Carbonic Acid	=	Potash and Carbonic Acid (Carbonate of Potash)
			Silica
Alumina and Silica (Felspar)	Water		Alumina, Silica, and Water (Hydrated Silicate of Alumina) (Kaolin or China-clay)

Thus in the end there is little left of the hard crystal of felspar except a mass of silicate of alumina united with water (hydrated), which occupies about the same space as the original felspar. This is only another name for pure clay, *kaolin*, or china-clay, and thus the place of the felspar in granite is taken by a substitute of clay. The result is easy to see. If the mortar between the bricks of a house were to become soft, the walls would soon crumble down and the house would fall. Precisely the same happens with the granite. Bound up into a solid mass by hard, resisting felspar, the rock is intensely durable, but with its binding felspar converted into clay it readily washes away. Every passing shower removes some of the china-clay, leaving behind a spongy mass of quartz and mica, on which storms and frost can act with great ease, crumbling the rock down and washing the hard constituents away. We shall follow their future career a little later on.

Not only granites, but rocks which contain pebbles of granite and pebbles or grains of any other felspar-bearing rock, will be similarly attacked. There are other rocks which contain a felspar rather different in composition from the one just described. The felspar of dolerite, for instance, is chiefly made of two silicates—silicate of lime and silicate of alumina. Carbonated rain-water acts on it in an analogous way, in that the silicate of alumina is left behind as clay. The silicate of lime is converted into carbonate, and washed away in solution by other rain-water bearing carbonic acid.

Salts in Solution.—The water that runs off the chief kinds of crystalline rocks obtains in this manner carbonates of potash, soda, and lime in solution, and these substances are invariably found to be present in stream, river, and sea water. Silica is also obtained from felspars, as shown above in the case of granite. By similar means and from other minerals salts of iron and magnesia are obtained. They are generally present in natural water. We also see from these examples the means by which a crystalline rock is made to break up into its constituent mineral particles, and why the finer grains in sandstones are usually not bits of mixed rocks, but broken bits of individual minerals.

Action of Springs

Solution.—Rain-water which is so active at the surface loses little of its power when it makes its way underground. If rocks are penetrated by cracks, or if they are open in texture, they are called *pervious*,[1] or *porous*, and rain-water slowly sinks downwards through them. When the water meets a rock which has not these qualities, an *impermeable*[2] layer or mass, it runs downward along the junction, and if its journey along the band of rock brings it to the surface again, it issues as a spring.[3] The water of such springs is always found to be laden with matter derived from the rocks traversed. Spring waters in limestone districts are "hard" and charged with carbonate of lime; where there is much iron in the rocks, with carbonate of iron; and in regions of crystalline rocks, with carbonates of potash, soda, and lime, usually accompanied by silica. These have been *dissolved* by the water from the sides of the cracks it traverses, or from the body of the rock which it permeates. In limestone districts, like Western Ireland and about Ingleborough and in Derbyshire, the cracks become widened out into deep fissures (Fig. 25), so much so that all the rain and streams in such a district are swallowed up by them (see Fig. 301), and travel along in underground caves, issuing as rivers lower down. Where water percolates through the mass of the rock the same work is done as at the surface,

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[1] Lat. *per* = through, *via* = a way.

[2] Lat. *per-meo* = to pass through.

[3] See page 326.

minerals are changed and partly dissolved, and the rock throughout becomes converted into a loose, friable mass. This is the reason that the action of the weather extends so deep down into a mass of granite as in Devon and in Cornwall; and why great masses of sandstone sometimes have their cement, carbonate of lime, entirely removed, and become reconverted into loose sand.

FIG. 25.—"Grikes" or joints in limestone widened by solution, Hampsfell, near Grange, Lancashire. (From a photograph by Mr. G. Bingley: copyright.)

Deposit.—Under certain circumstances, however, the action of springs is different; coming to the surface it is common for springs in limestone districts to *deposit* some of their carbonate of lime. This is because the carbonic acid is able to escape into the air, and the carbonate of lime is no longer soluble in water deprived of acid. Petrifying springs, which deposit carbonate of lime on twigs, birds' nests, and other objects placed in them, are examples of this action.

Where springs have formed large open fissures, or caves, by underground solution, a similar action takes place, and the dripping of water through fissures gradually builds up hanging stalactites of carbonate of lime. As each drop of water hangs for a moment on the roof of the cave, a little of its carbonic acid escapes, and a small quantity of its carbonate of lime is rendered insoluble and deposited as a tiny ring. Drop after drop follows, and gradually the ring is converted into a tube which is lengthened and strengthened until an icicle-like stalactite results. The residual water splashes on to the floor of the cave, and deposits more carbonate of lime there as a stalagmite, which grows higher and higher until it reaches the stalactite and joins it to form a pillar. This is shown in Fig. 26.

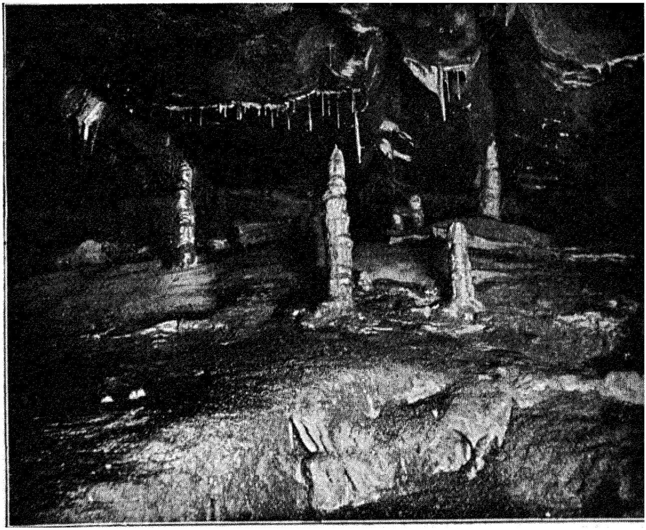

FIG. 26.—Stalactites and stalagmites in Clapham Cave, Yorkshire. (From a photograph by Mr. G. Fowler, published in Simmons's *Physiography for Beginners*, by Macmillan and Co.)

Petrifying Springs.—Many calcareous springs, on reaching the surface of the ground, deposit large quantities of carbonate of lime, making great deposits of what is called *tufa*, if light and spongy, *travertine*, if compact and sufficiently stony to be useful as a building stone. If the evaporation of water, or the escape of its gases, reducing its solvent power, takes place underground instead of above it, the deposit will be found as a lining to the cracks traversed, forming veins of spar (see page 332); or it may take place while permeating the mass of a porous rock, and then the crystalline deposit will form between the grains of the rock and bind it together into a solid mass (see page 89). Some of the sandstones that we examined in Chapter II. have a cement which has been made in this way.

RECAPITULATION

In many places rocks, both crystalline and clastic, can be seen undergoing *destruction* and change. Their minerals become *softened* and altered, they are *broken* into fragments, the fragments are *rounded* and worn, and these fragments, which are pebbles, sand-grains, and mud, are *laid down* in sea-beds and on the flanks of rivers.

This process is known as *denudation*, and the agents to which it is due belong to two main classes—*subaerial*, those working above sea-level, and *submarine*, those working below it.

The weather is one of the principal agencies occupied in this work. *Frost* and the alternation of *heat* and *cold* fracture rocks along their joints and between their grains, reducing them to piles of fragments on which *gravitation* comes into play, dragging them to a lower level. *Wind* and *rain* aid, the former wearing the smaller fragments away, the latter carrying them downhill.

But the chief action of rain is as a *chemical agent* dissolving and decomposing rocks and minerals by the action of the acids, chiefly *carbonic acid*, which it always contains. Most minerals give way under this action, and especially the *felspars* in granite, which are reduced to a soft mass of china-clay by the operation.

Spring-water carries this work deep down into the earth, bringing up dissolved matter and often depositing some of it at the surface.

QUESTIONS ON CHAPTER IV

1. Give instances to show that rocks are now undergoing change.
2. What becomes of the relics of these changed rocks?
3. What do you understand by the term denudation? (O and C.)
4. Give evidence of the action of subaerial denudation. (O and C.)
5. By what agencies is the weathering or disintegration of rocks effected? (1881.)
6. Explain the action of frost as a denuding agent.
7. Why are mountain-peaks steep, and why do screes occur on the slopes?

8. What is the effect of the alternation of heat and cold on crystalline rocks?

9. Describe blown sand. How would you recognise grains of such sand in sandstone? (1893.)

10. What are "earth-pillars," and how are they formed?

11. Show clearly the action of carbonated rain-water on a granite. What becomes of each of the products of disintegration?

12. What are "stalactites" and "stalagmites"? How have they been formed? (1881.)

13. Why are caverns common in many limestone districts? (1877.)

CHAPTER V

WEAR AND TEAR BY RIVERS AND GLACIERS

Streams and Rivers

Rills.—We must now follow the course of the rain-water which flows over the surface of the ground in rills, streams, or rivers. The rain-water which falls on a lane during a heavy shower should be watched : The water flows steadily downhill, increasing in volume from the fresh rain as it goes, until it has gathered strength and volume enough to form a distinct rill, which, in its turn, flows on, being joined by other rills, and getting larger and larger until a small stream is made. The rushing water will gather up sticks and straws, fine mud, and even coarse sand, washing them along in its course, and by sweeping them away it hollows out its course a little. The water from a second shower will be likely to follow the same course, carrying still more sand and mud, and further deepening its channel, and, if such a thing were allowed by the road-menders, a little valley-system would in course of time be started by the carrying away of the loose, disintegrated dust and mud of the road. In nature exactly the same thing occurs ; rills join one another to form a stream, other tributary streams add their quota, springs pour in their water, and eventually the union of all the streams forms a large torrent or a river, the water of which will carry two classes of substances—the matter dissolved by rain and springs, and the mud, sand, and even pebbles washed in by the water as it rushes over disintegrated rock.

Transport.—In Cornwall, where the granite has been disintegrated by rain and springs, water is used for washing away the weakened granite. It is forced to flow over the loose material, and at once becomes milky by taking up the fine particles of loose clay into which the felspar has been converted. If its speed is great enough it breaks up the rest of the rock, now so much loosened ; and tiny pieces of quartz and mica will be carried away and deposited when the water is allowed to stand. In the works the milky fluid is passed through "pits," "drags," and "micas," to get rid of quartz and mica by settlement before passing into the later tanks, where the extremely fine white clay used in the manufacture of porcelain is alone deposited after long standing.

Streams in a granite district do precisely the same work. When flowing very slowly they merely take up fine clay, but as the velocity and volume increase, the rest of the disintegrated rock is broken up, and quartz and mica carried off. The carrying away of these things leaves the stream a hollow to run in, which is always being deepened by the same process. If a glass of water be taken from such a stream and allowed to stand for a few seconds, and then the milky-looking fluid be poured out into a second glass, it will be found that the heavier particles of quartz and mica will be deposited in the first glass, while the second will have to stand several hours before all the clay is deposited, and if the water is kept in slight motion it will never settle at all. This shows that the quartz and mica, being larger and heavier, are less easily carried, while the clay is much more easily carried, as it remains mixed up with the water so long. The latter state is spoken of as *suspension*, and almost all streams will be found to carry fine particles of mud in suspension. The mud is always tending to fall slowly downward, but it is always being forced up again by the motion of the water. If the stream is very slow the quartz is not carried in the same way; it is pushed or *rolled* along the bottom as the water moves. But most streams move quite fast enough to carry fine mud or broken quartz in *suspension*, and at such a rate they can also push and *roll* small pebbles along their bed. If the velocity of the stream reaches two miles an hour, fragments of stone as big as an egg can be rolled along the bottom. This velocity is exceeded by most streams, and by nearly all of them when in flood; and the floors of such streams are covered with a clean gravel made of pebbles rounded by rolling along.

Rolling and Carving.—Near its source a stream often flows down steep, bare, rocky slopes, with great velocity. The activity of frost is conspicuous here, and from crags and cliffs above the stream blocks of stone are constantly falling, or travelling down the screes, into it (see Fig. 21). Thus there is a plentiful supply of sharp-edged chips of rock, and the stream is generally powerful enough to sweep them along. Rolling over the bed of the valley they knock against each other and against the bed of the stream, tending to break away each other's edges, and to get gradually worn down into the familiar rounded pebbles which can be picked out of any stream. The fragments form the arming of the stream, and are used by it as graving tools to deepen and wear away the bottom of its valley. But like all tools they become blunted by use, and their angles and corners are worn away by concussion and friction. The bits broken off go to make smaller pebbles, sand-grains, and particles of mud, according to the composition

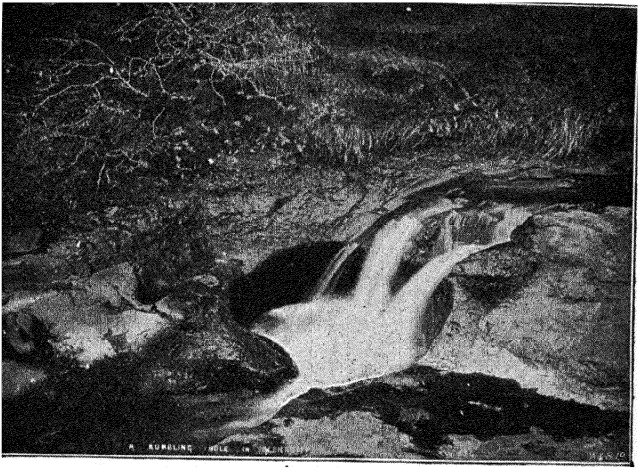

FIG. 27.—"Pot-hole" cut by stream in basalt, Glenariff, Antrim. (From a photograph by Mr. R. Welch: copyright.)

of the bit of rock which is broken down, and the pebbles themselves become rounder and smaller the farther we follow the stream down the valley.

Mud and sand carried in suspension do not suffer much from friction and impact, as they are cushioned round by water; but if the stream moves so slowly that they are rolled along the bed, they must suffer like the pebbles. As a matter of fact it is found that fragments of sand less than $\frac{1}{12}$ of an inch in diameter suffer very little, and are almost as sharp-edged when they reach the sea as when they started on their journey. If a stream comes from a district of disintegrated granite, the mica will mostly be carried in suspension, but the quartz, which is derived in irregular crystalline bits from the parent granite, is, at any rate in its larger pieces, broken up, worn and rounded, until it passes into the round bits of clear crystalline quartz which we call sand-grains.

One of the functions of a stream in denudation is therefore to make rock-fragments into pebbles, and the larger bits of minerals, especially quartz, into rounded sand-grains. In doing this it carves its course into a valley, either scoring directly downwards by means of the pebbles, or swirling them round and round in eddies, and so carving out "pot-holes" like that shown in Fig. 27.

Gravel.—It has been shown above that the material which a stream can carry depends largely upon its velocity. Now, as we trace it lower down the valley, its velocity varies from point to point, and even from side to side, but on the whole it tends to diminish, so that while at one part it may be able to carry all its load, at another it may be compelled to drop some of it. Thus we find banks of gravel and even sand here and there in the river's course, which block it up to some extent, and are only partially cleared away by floods, when the river is full of swiftly-flowing water. The heavier material is dropped first, then the finer, and lastly the sand and mud. Most rivers, however, are able during their floods to carry all the material furnished by their feeders, so that it all eventually makes its way to the sea. It is only that some of it is temporarily or locally deposited, and again picked up and moved on a stage farther down. Nor is this all; for another source of supply provides the rivers with new materials even when they reach flatter, soil-covered land. This action must now be studied.

Soil-Making

Subsoil.—The disintegrating action of frost, wind, and rain is by no means confined to high altitudes and to bare rock-surfaces, but it goes on, in and below the soil of flatter lands. Water gets into rock-crevices and between the grains of porous rocks, and on freezing splits and disintegrates them; it even breaks again and again fragments already detached by it. Carbonated rain-water sinks into the rock, and, removing the cement and soluble minerals, leaves it disintegrated. Thus the rocks become covered over with a layer of broken and disintegrated fragments which, as a rule, get smaller as we go farther away from the rock-floor. This layer is called the

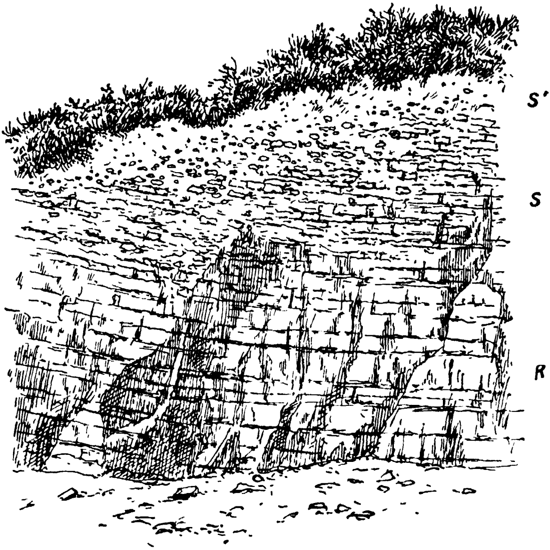

FIG. 28.—Conversion of rock (R) into subsoil (S) and soil (S'), near Welshpool. (Drawn from a photograph.)

subsoil (S); it may be seen between the soil (S′) and rock (R) in any quarry, and is illustrated by the diagram, Fig. 28.

Organisms.—The penetration by roots and rootlets of living vegetation, and the action of acids derived from dead vegetation, disintegrate the rock fragments still further, and furnish a still larger supply of small particles, which become mixed with leaves, twigs, and rootlets. This mixture forms the *soil*, in which earth-worms contribute still further work. They pass much of the soil through their bodies, extracting nutriment from the organic portion of it, and rejecting the rest in a comminuted state, so that it is readily acted upon by rain both chemically and mechanically.

Downhill Movement.—Now all soils on the sides of valleys are resting on a slope, and their finer particles are always tending to slip downhill. Old worm-burrows, the holes left by decaying roots and grass, those made by rabbits, ants, moles, or any other burrowing animals, when deserted will tend to collapse downhill; and, of the soil brought up and deposited by them, a larger portion of each heap will be washed by rain in a downhill than in an uphill direction. Indeed, movement of any sort in the soil will tend downhill, and the goal of it all will be the bottom of the valley, towards which it will creep steadily downward; there the stream is at work as a scavenger, clearing away all the fragments as they are fed into it.

Scavenging.—Although denudation is not so obvious in cultivated and soil-clad valley-slopes it is quite as active here as elsewhere, and a river is kept fully supplied with coarse and fine material, which it sweeps along, and uses to clear out and deepen its own bed. A river acting alone would make a steep-sided valley like a saw-cut (Fig. 29, *a b a*) through the rocks; but with weathering and soil-making going on on both sides of it, the abrupt slope is softened down and made more and more gentle (*c b c*, *d b d*), until it at last reaches so low

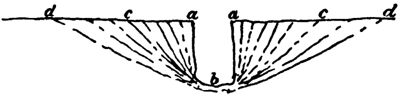

FIG. 29.—To show the successive stages in the opening out of a river gorge until a V-shaped valley is produced.

an angle that soil will no longer move down it. When this stage is reached the river is said to have reached its base-level; it is practically dead, and no further mechanical action can go on until, for some reason or other, the river begins to deepen its bed still further.

Dissolved Matter.—It must not be forgotten that in addition to pebbles, sand, and mud, carried mechanically by the stream, every river contains dissolved matter—salts of lime, potash, soda, etc.—which it partly receives from rain and springs, and partly acquires for itself by flowing over beds of limestone or rocks containing other soluble ingredients. We cannot see this in the water, but can demonstrate its presence by taking some of the water, filtering it, and boiling it away in a glass vessel or a clean kettle. A crust, generally white, will almost invariably be left behind when all the water has disappeared as steam.

Glaciers

Snow-fields and Glaciers.—A very important agent of erosion and transport is found in moving ice. The climate is cold both in high latitudes, and at high altitudes in lofty mountain ranges. In such regions the snow which falls in winter is too great in amount to be all cleared off by the sun's heat in the summer, and so some of it remains unmelted all the year round, and goes on accumulating year after year, forming what is called a snow-field or *névé*. The height above the sea at which this perpetual snow begins is greater in tropical than in temperate or Arctic regions. The snow-line in the Arctic regions comes down to the sea-level. In Norway it is 5000 feet; in the Alps 8000 feet; and in the great mountains of Kenia and Kilimanjaro, in Africa, it is as high as 16,000 feet above sea-level. The snow piled up above the snow-line must be drained off in some way, and as it does not all melt it escapes in the solid form. The snow at the bottom of the snow-fields becomes gradually converted into ice, partly by the pressure of the overlying snow and partly by the trickling down and freezing of water which has been melted by the sun at the surface. From the edge of the snow-masses long tongues of ice are pushed forward into the valleys. These are called *glaciers* or ice rivers. Their relation to the *névé* will be seen in the accompanying map (Fig. 30). They are formed of clear blue ice, often broken up into tumultuous masses, cliffs, and seracs, and containing on their surface lines and heaps of stones which are called moraines. A line of pegs driven into the ice across a glacier shows that it moves downwards very slowly—not sliding in a solid mass, but flowing as treacle or pitch would do, only much more slowly, swelling out where the channel is broad, contracting in narrows, filling deep holes, and breaking to pieces where the angle of its bed increases. The flow of a viscous substance may be studied by taking an oblong box and tilting it up at an angle of 15 or 20 degrees; melted cobbler's wax is poured into the lower end and allowed to solidify. The box is then placed with its bottom on a level table, and the wax will gradually flow down towards the other end, taking some days to complete its journey. The

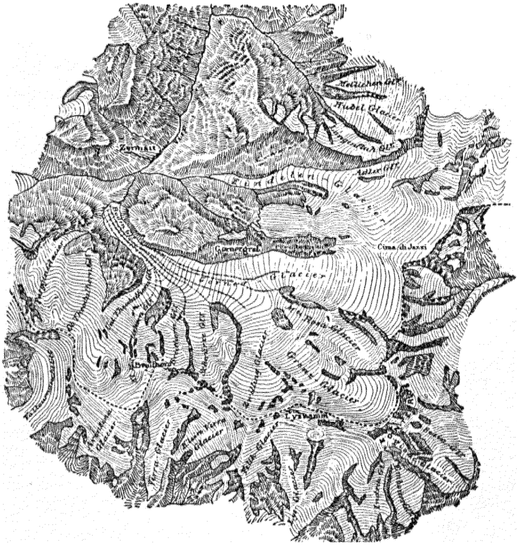

FIG. 30.—Map of the Findelen and Gorner Glaciers to show snow-fields, and medial moraines where two glaciers meet and flow side by side.

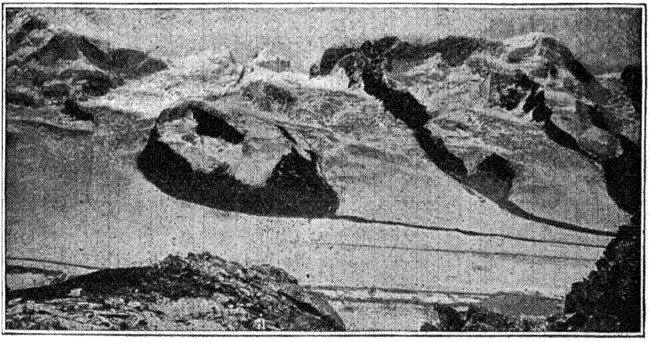

FIG. 31.—View of the Gorner Glacier from the Gorner Grat looking towards the Lyskamm, Zwillinge, and Breithorn. The Zwilling Glacier comes down at the left hand meeting the Schwärtze Glacier in the middle, and that meets the Breithorn Glacier to the extreme right of the picture. Medial moraines occur between each pair of glaciers. The same moraines can be seen on the preceding map.

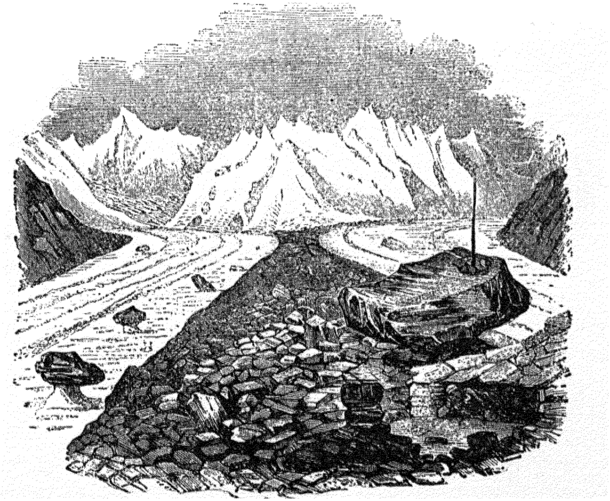

FIG. 32.—Medial moraine with "ice tables" of stone, each supported on a pillar of ice which has been protected from the sun's rays by the stone. (B.)

rate of movement in Alpine glaciers is very slow, being about one foot per day.

Moraines.—The sides of the rocky valleys filled by glaciers undergo the same disintegration by frost and rain as other valleys, and these rocks give rise to heaps and screes of broken fragments. Instead of falling into a stream, and sinking to the bottom to be ground to pebbles, these blocks tumble on to the *top* of the ice, and as the glacier moves on, the whole of its sides become fringed with a line of detritus which is called a *lateral moraine.* When two tributary glaciers meet they do not mix together like two streams, but flow on side by side, and the right-hand moraine of one joins the left-hand of the other to form a continuous line of moraine down the middle of the united streams. This is called a *medial moraine* (Figs. 31, 32). The stones thus carried down will not be worn or damaged, but will be as sharp and angular after their glacier journey as if they had never been moved from the scree under the cliff.

Many of these stones and blocks fall through fissures in the glacier (Fig. 33), and so make their way to the bottom, where they are frozen into the ice and ground against the rock-bed of the glaciers, with all the weight of the ice holding them down. They score their way into the rock beneath, grooving, scratching, or polishing it according to their size and hardness. Thus the bed is worn away, and the transported stones are

FIG. 33.—Crevasse on the Morteratsch Glacier, Piz Bernina in the background, lateral moraine between.

FIG. 34.—Ice-scratched stone, from Doncaster (about ⅓).

polished, striated, and grooved (Fig. 34), all their rough surfaces and some of their edges being ground off into fine sand or mud, which will be carried on by the ice itself, or by the streams which are continually flowing on, in, and under the ice. A vast amount of rock-flour or fine mud is thus prepared by the glacier which acts as a millstone.

Terminal Moraines.—When the glacier reaches a warmer region on its downward journey it receives more and more heat from the sun, and melts away, getting gradually thinner, until at last its end is reached, and we find it giving birth to a river, which flows away and carries with it a vast amount of mud and stones derived from the glacier.

FIG. 35.—End of the Morteratsch Glacier. To show débris falling off the front to form a terminal moraine.

At its end the glacier shoots down the material it has carried

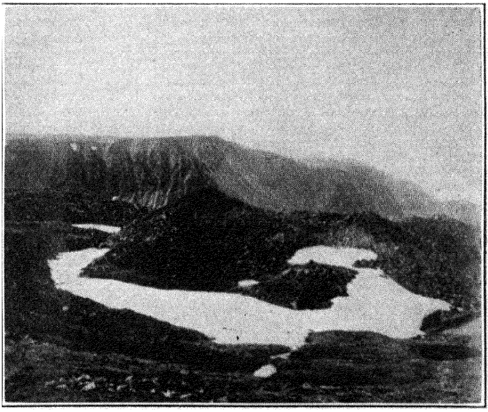

FIG. 36.—Old moraine, Cairngorm Range, Scotland. (From a photograph by Mr. W. Lamond Howie: copyright.)

on its surface, within its mass, and on its under side, into a great heap, like that seen in Fig. 35. This heap stretches right across the valley, and is called the terminal moraine. It consists of a mass of mud and clay, mixed with angular stones, some of which may have travelled many miles without receiving any damage by wear and tear, and a certain proportion of polished, scratched, and grooved stones, borne under the glacier and worn down there. This class of deposit is very characteristic of glacial action, and old moraines, like that shown in Fig. 36, are commonly found in mountain districts. The solid, moving ice cannot sort out its material into coarser and finer grades as a stream does, but throws it all down pell-mell in a mixed mass. This mixed material is not stratified or laminated as it would be if it had been deposited from transport by water (see page 71). Ice does not round its stones into pebbles, but wears, polishes, and scratches one or two sides of them, and the moraine rests on an easily recognised surface, which is smoothed and polished (see frontispiece), and then scratched and grooved in the direction in which the ice has moved (Fig. 37). Surfaces in the moraine

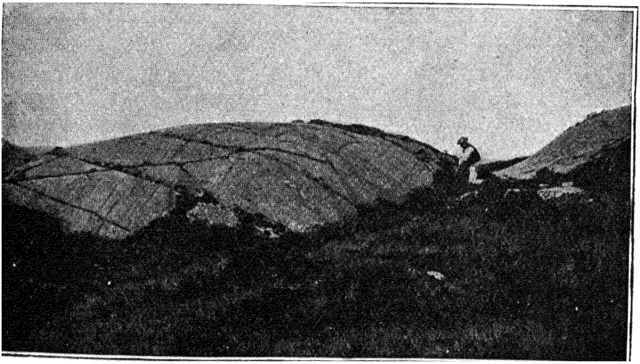

FIG. 37.—"*Roche moutonnée*,"[1] to show smoothing and striation by ice, Capel Curig, Carnarvonshire. The scratching shows that the ice must have moved away from the observer. (From a photograph by Messrs. Williamson and Wills, kindly lent by Mr. C. J. Watson: copyright.)

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[1] Looking like wigs made of frizzly wool (*moutonnée*).

itself are sometimes smoothed and striated. We can further recognise the action of ice in the large size of the transported fragments; sometimes blocks weighing hundreds of tons may be seen on a glacier, and equally large blocks are found about terminal moraines; they are called *boulders* or *erratics.* These and smaller blocks are often dropped in precarious positions when the ice melts, and as they are sometimes left perched on the flanks of a valley, they are spoken of as *perched blocks* (Fig. 38). Again, few traces of shells or any other organisms are found in glacial deposits.

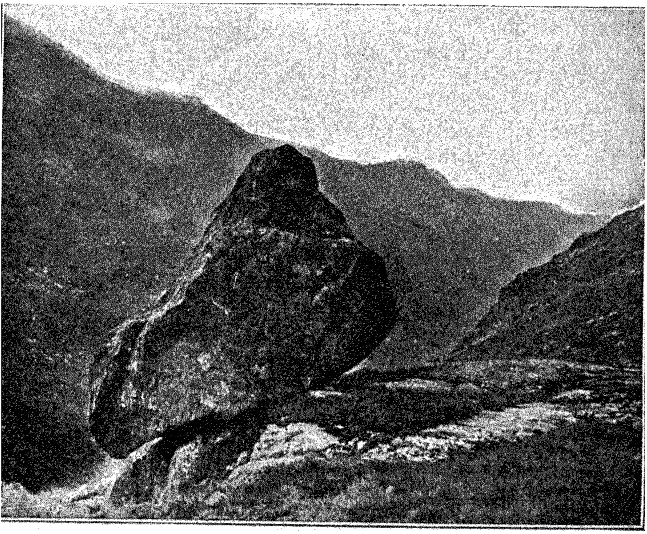

FIG. 38.—Perched block in the Pass of Llanberis. (From a photograph by Mr Godfrey Bingley: copyright.)

Ice-sheets.—In the Arctic and Antarctic regions large areas are covered completely, except on their higher peaks, with confluent glaciers or ice-sheets. These move more rapidly than valley glaciers, averaging about 30 to 50 feet per day, and they travel over the country in the direction of its general slope, often across the smaller hills and valleys, and even, in some cases, going up instead of down the latter. The large ice-masses which have been studied in Greenland exercise very great denuding effects, for their lower part is found to be loaded with stones and clay carried, as it were, in suspension in the ice. Such ice-sheets usually end in the sea, and there they break off into massive icebergs, which float away and carry their burden of detritus to be dropped over the sea-bed as the ice gradually melts. In this way large boulders may be carried very far from their origin and dropped amongst fine clays or other marine sediments. When a great iceberg strands on a submarine bank of clay or sand, so large a moving mass exercises great force before it is brought to rest, and this force is frequently found to have been employed in crushing and contorting the sand or clay. Contortion is a common feature in certain deposits of glacial origin. Further work of floating ice will be considered in the next chapter.

RECAPITULATION

When rain gathers into streams it becomes not only a disintegrating but a transporting agent on a large scale. Its chief work is to *carry downwards* the supply of rock fragments given to it by gravitation, frost, wind, rain, and springs, but it uses these materials to *carve out* and *deepen* its own bed into a *valley.* The gravel and sand are blunted and worn down in the process until they become like the *sand* and *pebbles* found in sandstones and conglomerates.

This work is not confined to bare surfaces of rock, but takes place under the covering of *soil* where disintegrating agents are in full play. The soil produced by them is always *on the move* down slopes, and eventually it is scavenged away by rivers and streams. The conjoint action of streams with soil-making agents widens out the steep river-sides and sullen gorges into open, smiling, cultivated river-valleys.

Glaciers in cold regions fulfil the same functions as rivers in warmer districts, but, instead of making rounded pebbles and sand, they carry *angular* or *smoothed* and *scratched boulders*, they *striate* and *polish* the rocks they move over, and instead of producing a laminated series of deposits they form an irregular *moraine* with a pell-mell arrangement of material.

QUESTIONS ON CHAPTER V

1. What is meant in geology by the term denudation? Explain briefly the general nature of the effects which are produced by it. (1877.)
2. How does river-water differ from rain-water? (1887.)

3. Trace the history of a fragment of stone from the time when it is broken off the parent rock until it falls into a river.

4. Explain the fact that certain rivers and streams have petrifying properties. (O and C.)

5. What are soils? Explain their origin. (1888.)

6. How is vegetable soil produced? (1884.)

7. What is a glacier? Describe its formation, motion, and work. (O and C.)

8. Explain how glaciers and icebergs are formed. What evidence is there of ice-action in Great Britain? (O and C.)

9. Name the chief natural surface agencies now altering the configuration of Great Britain, and explain their action. By what other surface agencies has the same area been modified in the past: what traces do we find of these? (O and C.)

CHAPTER VI

MARINE DENUDATION—RATE OF WORK

The Sea.

THE ultimate destination of all streams is the sea—a vast body of deep water, the bulk of which is still. The sea receives all the denuded matter brought down by rivers, and its shores are bordered by gravel beaches, sand banks, and mud flats, made of materials thus brought down. But the sea itself is a great engine of destruction, doing most of its work at its margin, although some is effected by currents along its bottom, where that is not too deep.

Weathering and Gravitation.—The mere fact that the sea cuts away the land in a way which will be immediately explained, so that its margins are often cliffs, brings into play a number of other agencies. Gravitation is at once felt when the cliffs are vertical or overhanging, or when the rocks rest in an unstable position, and fragments fall away from them. Rain rushes down the steep slopes and washes débris down. When the rocks are soft the rain mingles with them and forms mud-streams, such as may be seen in the Isle of Wight or the Norfolk coast, where the cliffs are made of clay and sand, flowing down the chines like glaciers of mud. The ends of these are easily attacked and washed away by the sea. Springs, again, frequently issue at the foot of cliffs, especially

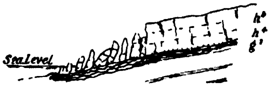

FIG. 39a.—Section of the landslip of Axmouth, Devon. g^1=Lias clay; h^4=Greensand; h^5=Chalk.

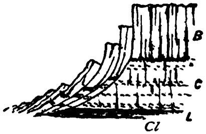

FIG. 39b.—Section of landslip on Antrim coast. B=Basalt; C=Chalk; Cl.=Clay.

where hard, permeable rocks rest on softer, impermeable[1] rocks. The springs and the waves sap away the softer rocks and render the hard ones above unstable, so that they tend to slide forward into the sea, forming landslips (Figs. 39*a*, 39*b*). This is well seen on the coast of Antrim and at Axmouth. The harder rock-bands break and crush as they move, and when the mass reaches the sea it is disintegrated and falls an easy prey to the waves.

Wave Work.—The sea has also great power over its coasts, because its surface is in constant movement by means of tides, waves, and currents, which chafe away the shores and erode its bed. Even during calm weather the waves which beat on the shore with each rise and fall of the tide effect much destruction; but this power is increased a thousandfold when the surface of the sea is lashed into fury by a raging hurricane. Storm-waves have been known to rise to a height of 40 or 50 feet, in deep water; when they break in shallow water they become much higher, and the foam, and even the pebbles, thrown by them are known to have reached heights of over 150 feet. The weight of such a mass of water as this, combined with the great velocity with which it rushes inland, often produces a pressure equal to about two tons on each square foot of exposed rock. Such waves act like a battering-ram or sledge-hammer on the cliffs, and tend to shatter them to pieces by dislodging great fragments.

Air Work.—But this force acts at a disadvantage, owing to the fact that it is applied to the *outside* of the rock, backed up as that is by all the mass behind. A quarryman does not usually work at such a disadvantage as this. Either he gets behind the face of the rock by driving wedges into the cracks, or else he drills a hole and puts a blasting charge in it; in both cases applying the power from the inside. The waves have a similar power in the use they make of air. Fissures and cracks in rocks are filled with air, usually at the ordinary atmospheric pressure; but when a wave rushes forward and beats on a rock, its pressure drives the water into any fissures there may be, and forces the air out on the landward side if there is an escape for it in that direction. This is the cause of the blow-holes common near cliffs, where the air is

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[1] Lat. *im* = not, *per* = through, *meo* = I pass.

alternately driven in and sucked out again by the waves. But if there be no escape for the air it is simply compressed until its pressure is equal to that of the wave outside. The two pressures for a moment balance one another; then, as the wave retreats, the outward pressure is suddenly removed, and there is nothing to balance the great interior pressure. The air expands suddenly, and if it cannot readily escape by the fissure through which it was driven in, it behaves like an explosive charge, and blows off pieces of rock along cracks or lines of weakness. The action is quite analogous to blasting, in which a great volume of gas is suddenly liberated inside a small space in the rock. The sudden expansion forces the sides of the rock apart and breaks it to pieces. The waves thus hollow out the rock about the level of the breakers, and break off blocks the shape of which (see Fig. 40) is ruled by the principal weakness-planes of the rock, whether joints, bedding, or dykes (see also Fig. 88).

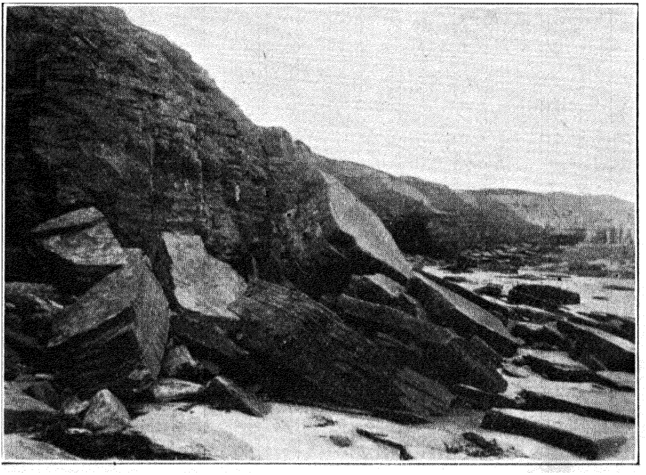

FIG. 40.—W. St. Mary's Island, on the Northumberland coast; showing denudation along joints and bedding. (From a photograph by Mr. G. Hingley: copyright.)

Shingle.—The power of the waves does not end here. On looking at the foot of cliffs when the tide is low, there will be seen, close under the cliff, great blocks of rock with sharp angles and edges, which have evidently only just been broken from the cliffs. Similar blocks occur a little nearer the edge of the sea, but they are rather smaller, and a little more rounded. Farther out again the blocks get smaller and smaller, and eventually they pass into shingle, at first coarse and then fine, graduating down into sand. These blocks have been broken from the cliffs by the weather, the weight of the waves, or the work of compressed air. The smaller ones are moved by every wave, the larger ones during storms—for it must be remembered that every stone loses about one-third of its weight when submerged in water, and is thus much more easily moved. As they are hurled against the cliffs they form a new and effective type of artillery, by which the cliffs are still further battered down, while they themselves become broken up and rounded by the process, until they are worn into pebbles like those of the shingle. The movement of the shingle batters the pebbles against one another until they become smaller and smaller and more and more rounded, while the tiny particles broken from them are washed farther out to form sand and mud. Wave action is more effective than rivers in rounding small sand-grains, on account of the fact that they are never allowed to rest, but are dragged and thrown to and fro by every tide until fine enough to be carried away in suspension. Not only are the large grains, over $\frac{1}{12}$ of an inch in diameter, thus worn round, but grains even as small as $\frac{1}{50}$ of an inch in diameter may be perfectly rounded by wave action (see Fig. 3). A wide belt of shingle has the temporary effect of checking wave action, which is then expended on the pebbles; but as the latter become smaller, others are washed down from the higher part of the beach to take their place, and new material is again derived from the cliffs thus laid bare.

Ice Work.—In cold climates the sea gains still further power from the masses of ice brought down by rivers, and more still when the edge of the sea itself freezes, or great bergs are brought down from glaciers or by cold currents. When ice is floating in water only about one-tenth of it is above water, the other nine-tenths being submerged, so that large masses become stranded even in fairly deep water. As they sway about under the influence of tides, wind, and waves, they grind away and crush the deposits upon the sea-bed. When moved about by storms all kinds of ice strike and drag the shore-rocks to pieces and carry out the fragments into deeper water. Floating timber, wreckage, indeed anything that the sea can move, all aid in the work of destruction.

Currents.—Marine currents resulting from many causes, and especially those due to the tides in narrow estuaries and straits, which are often very swift and violent, have great power in eroding sunken rocks, sand banks, coast-lines, stacks, and islands. But the chief function of currents is to take the fine sand and mud provided by sea and river denudation and carry them in suspension for great distances. The sediment gradually sinks down to the sea-bed and is deposited over a large area, in company with sea-shells, bones of fish, plants drifted out by rivers, and relics of animals which swam or floated on the sea surface. Thus the material swept off the land is carried a very long way and deposited over many hundreds of square miles of the sea-bed. The currents off the mouth of the Amazon carry out the red mud of that river for a distance of hundreds of miles, and the surface water is sometimes muddy 300 miles from the river's mouth.

Rate of Work.—The rate of marine erosion depends on two main factors—the resistance of the rock and the efficiency of waves. The first depends on the hardness of the rock, its penetration by joints and other fissures; also on its inclination, if seawards landslips and rock-falls are more likely to occur. A very hard rock will wear away slowly unless it is fissured by joints, so that it breaks up and forms shingle. But the shingle will do less work if the rock is hard than if there are soft bands in it, while a soft rock will be rapidly worn by the waves: It will, however, provide little shingle unless it is a clay with boulders in it, a chalk containing hard lumps of flint, or a soft rock interbedded with harder bands. A mixture of hard and soft rock wears away fastest of all. The other factor depends on the frequency of storms, the breadth of sea and sweep of the wind, the range of the tide, the direction of the coast with regard to the prevalent winds, and the presence or absence of any natural protective work, like headlands or reefs, or of encrusting organisms such as seaweeds or corals.

Examples.—To show that this work has a very real significance, an example or two may be taken from parts of the coast of England where the loss of land has been watched and measured. These instances will serve to show the methods adopted in making a quantitative estimate.

Fig. 41 is a map of a strip of the coast of Yorkshire, south of Bridlington Quay. The map was drawn in 1850. The innermost dark line is the coast-line surveyed in 1890, showing that the sea has advanced nearly 100 yards in the northern part of Hilderthorpe Cliff in 40 years. The whole of the Holderness coast-line, 36 miles in length, from Flamborough Head to Spurn Point, made of soft clays and sands intermixed with blocks of stone, and acted upon by the high tides and stormy waves of the North Sea, is being

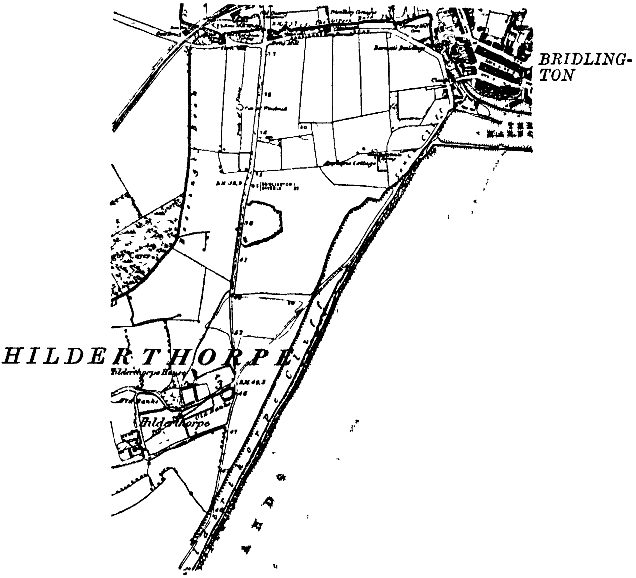

FIG. 41.—Portion of a map of the Yorkshire coast south of Bridlington Quay. The scale is about 3 inches to a mile. The outer line, marked Hilderthorpe Cliff, shows the coast of 1850; the inner dark line that of 1890.

sliced off at an average rate of 2¼ yards annually, and the consequence is that many important towns and villages have been totally destroyed. Thus Ravenspur was so noted a place that Henry IV. landed there in 1399; but in spite of its importance as a rival seaport to Hull, all trace of it has been swept away. Indeed the whole coast has lost a mile in breadth since the Norman Conquest, and many villages, such as Auburn, Hartburn, and Hyde, have completely disappeared.

Again, a picture of Reculvers church in Kent, taken in 1781, shows quite 100 yards of land between the church and the sea; while another, taken in 1834, shows the church at the edge of the cliff. The coast near Eastbourne has lost between 4 and 5 yards annually for the last 110 years. There are many places where the deposition of sediment causes the land to gain upon the sea; but taking the whole map of England into account, the sea is gaining on the land far more than the land upon the sea.

Final Features.—The first action of the sea on a coast made up of different classes of rocks interbedded together will be to eat away the softer rocks more rapidly than the harder rocks; the former will be hollowed back into bays or gulfs, the latter stand out as headlands. But when an outline of this sort is produced, the power of the waves will be concentrated on the headlands, which will now be attacked in front and on both flanks, while the soft beds will be protected by the capes. Thus the total rate of erosion will be diminished, and both hard and soft rock will be worn back at the same rate. Whitesand Bay, in Pembrokeshire, and its protecting headlands, gives a very good example of this, as will be seen from the map (Fig. 42).

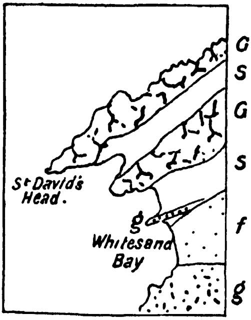

FIG. 42.—Map of Whitesand Bay, Pembroke. G=hard gabbro; g=hard grit; f=flagstone; S =soft slate.

When this state of equilibrium is reached the coast will be pared off evenly, and the sea will slowly and steadily advance upon the land (Fig. 43), and eventually, if nothing else intervenes, destroy it completely. This is not all, for not only will the visible part of the land be worn down, but some of that

FIG. 43.—To show the advance of the sea, making a plain of marine denudation from *a* to *a*.

which extends below the sea-level; for the power of the waves is more or less felt even to as great a depth as 100 feet below the surface. The land will be mown down to about this depth, and round nearly all land-masses soundings show that

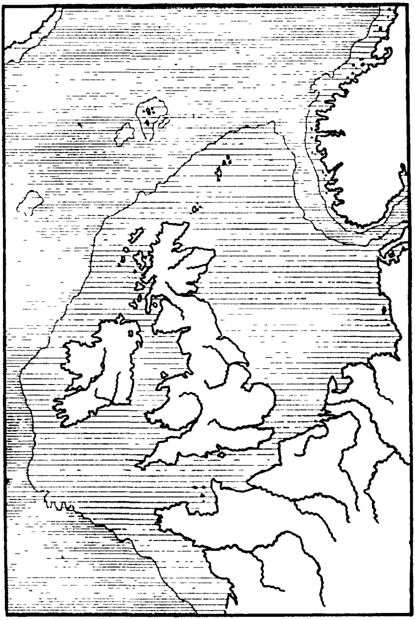

FIG. 44.—Map of Britain surrounded by its shelf of shallow water, a plain of marine denudation.

a shelf exists, occupying the position which the land once held before it was mown down by the waves (Fig. 44). This shelf is called a *plain of marine denudation*, and here and there, on the land, traces of these old denuded plains may be found, planed down by the sea when it was higher, or the land lower, than it is at present.

Rate of Denudation

It will be interesting at this stage to get an idea of the rate of denudation effected by the sea, and by subaërial agents which work above sea-level. From the preceding chapter it will have been gathered that the material borne by rivers summarises the total denudation effected on the *surface* of the land, for they act as scavengers, and bring it all out to the sea. Therefore if we measure the mud, sand, pebbles, and dissolved matter brought to its mouth by a river, we can find out the total rate of the denudation effected by all agents in the area of its basin.

River Work.—Such an estimate has been made with regard to several important rivers, and the result is expressed as the length of time required by the river to lower the whole average area of its drainage basin 1 foot.

The Mississippi	lowers its basin	1 foot in	6000	years
The Hoang-Ho	,,	,,	1464	,,
The Upper Ganges	,,	,,	816	,,
The Danube	,,	,,	6840	,,
The Rhone	,,	,,	1524	,,
The Po	,,	,,	732	,,

Average of 6 rivers and of 3 European rivers about 1 foot in 3000 years.

Taking the area of England as 51,000 square miles, and the average mechanical subaerial denudation as 1 foot in 3000 years, this would yield about 474 million cubic feet of detritus a year.

To the matter mechanically denuded must be added that dissolved by rain, springs, and streams, which is carried to the sea in solution by rivers. The English rivers lower their basins 1 foot in 13,200 years by *solution alone*.

Sea Work.—The denudation effected on the East Coast of England is probably in excess of the average because the rocks are softer, although the waves are less powerful than those on the West Coast. It is probably not incorrect to estimate that the whole English coast retreats at the rate of 1 foot a year. Thus the 1800 miles of English coast-line averaging 50 feet in height will yield 475 million cubic feet of detritus annually, an amount about equal to that removed by subaërial mechanical denudation.

Total Denudation.—The wear and tear of all agents together may therefore be expressed as follows :—

Rivers (mechanical),	1 foot in 3,000 years	= 22 feet in 66,000 years
,, (chemical),	1 ,, 13,200 ,,	= 5 ,, ,,
Sea,	1 ,, 3,000 ,,	= 22 ,, ,,
Total denudation . .		49 ,, ,,

Thus England is being reduced in size at a rate equivalent to 49 feet in height in 66,000 years or 1 foot in 1350 years. Now the average height of the continent of Europe is 671 feet and that of England is probably about the same. At the rate of denudation just given, both would be totally denuded away in less than *a million years*, unless there is some force acting in antagonism to denudation, restoring the balance of land and water by lifting up the land, or making new land by lifting the sea-bed.

RECAPITULATION

On abrupt sea-cliffs the weather, springs, rills, and gravitation have full play, while the sea-waves are able to tear them to pieces by their own *weight*, by the action of *compressed* air, and by the movement of *pebbles*, wreckage, and *ice*. The cliffs are thus in retreat, more rapidly where the coast is stormy and made of soft rock, less rapidly where there are few storms and more shelter, or where the rocks are hard. The outline produced by marine denudation protects the softer rocks in the bays by the survival of *capes* made of the harder beds, but the denuding action is thus concentrated on the harder rocks, and intensified by the supply of abundant *shingle* which acts as artillery.

Eventually hard and soft rocks are mown down *alike* to form a *plain of marine denudation* like that which occurs as a shelf round most of the continents.

The rock broken from the cliffs is worn into rounded pebbles and shingle, and the smaller pieces broken off in the process make sand and mud.

Careful observations of the retreat of coast-lines and the material carried by rivers show that the two agencies are equal in importance, and that the whole land of the globe is being lowered at an average rate of about *one foot* in 1350 *years*. The whole European continent would at this rate disappear in 1,000,000 years unless there is some compensation in the form of upheaval.

QUESTIONS ON CHAPTER VI

1. How are landslips caused? Mention two remarkable instances of such occurrences. (1889.)
2. Write a short account of the action of the sea as a destructive agent, and state what physical features result from a continuance of marine denudation. (O and C.)
3. What use does the sea make of air to aid it in denudation?
4. What are the functions of shingle, ice, and wreckage in marine denudation?
5. Describe the action of the sea on a cliff consisting of chalk with layers of flint. What becomes of the material worn away? (1890.)
6. What are pebbles? How do you suppose they were formed? (1883.)
7. How do you account for the stones in most conglomerates being rounded? (1877.)
8. Give examples of the rate of denudation by rivers and by the sea.

CHAPTER VII

ROCK-BUILDING

IN order to learn what becomes of the sand and mud swept off the land by rivers and the sea it will be well to take three tumblers of water: in one place a spoonful of coarse sand, in a second fine sand, and a third mud or modelling clay, dried and finely powdered. Stir each of them up thoroughly and then allow them to stand. The coarse sand, if free from fine ingredients, will settle very quickly, and leave the water quite clear; the fine sand may take four or five seconds to settle to the bottom of the tumbler; the very finest clay may take two or three days. Indeed a very slight movement will allow the last to remain suspended for a long period, while the others will settle very quickly as soon as the water begins to be appreciably still.

The Building of a Delta

Sorting.—It follows from this that if a stream gradually slackens in speed, the coarser materials will very quickly find their way to the bottom; but the finer materials may be carried a very long way, and be spread over a great area before they are finally deposited. Thus moving water will sort its deposits: the coarser occurring where the water is moving briskly, the finer material only finding rest when visible movement has all but ceased. On a sea-bed we should expect to find coarse material near land, and finer and finer material farther out. The finer material would be spread over a much larger area than the coarse, because of the long time necessary for all the fine suspended matter to drop through the whole thickness of slowly moving water; thus much of it would be carried a very great distance before reaching the bottom.

The phenomena of deposit can be well studied where a great river, bearing vast quantities of suspended material, reaches the sea and builds up what is called a *delta*, from its resemblance to the Greek letter (Δ) of that name. The Nile delta is a characteristic example of this shape, being a great triangle with the apex pointing up the river towards its source, and with the opposite base fronting the Mediterranean. Although a river drops a great deal of detritus in its valley, and particularly where it traverses a flood-plain near its mouth, it usually carries a great deal of matter out to sea. This consists of suspended mud with sand and pebbles rolled along the bed when the current is swift enough.

A Skeleton Delta.—When the river reaches the sea its velocity is at once checked by mixing with a large body of still water, and as this takes place immediately opposite the mouth it is there that the coarser material is at once laid down, in the form of a bank or bar across the mouth of the river (Fig. 45, *a*). The presence of this obstruction causes the river to branch and flow on each side of it as two streams. These streams will soon become bordered by a new deposit for the following reason. So long as the stream is flowing between banks of land the transported matter cannot escape from it; but when it is between banks of water anything which falls into the still water on either side will escape from the current and become piled up there. Thus rows of pebble and sand banks will form on either side (*b b*). For a while the velocity of the stream will prevent any material falling in front to check its course, but after a while the force will slacken again and another bank be formed in front, causing a second division and further banking up of the divided streams (*c*), which will

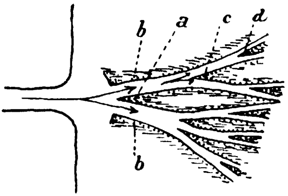

FIG. 45.—Theoretical map to show the formation of a delta. The successive branching points are *a*, *c*, *d*, etc., and the lining of the course by coarse deposit is shown at *b*. The coarser deposits are shown by dots, the finer by lines.

branch again and again (*d*) until the general slackening of velocity will stop the process, and by this time the bulk of the coarse material will have been deposited.

Lamination.—The finer matter, especially that brought down by floods, will spread over the general surface of the salt water much as it would flood the land, and this fine matter will drop down all over the area of the delta, especially where there is least movement between the branching streams with their skeleton banks. This will form an universal sheet of deposit over the whole area, its grain becoming finer farther away from the shore. Now it is commonly the case that rivers are in flood in particular months or seasons, and it is at these times that they bring down their largest supplies of mud. The mud being disseminated in suspended form through a great quantity of water, and spread over a large area, many square miles of the bottom will receive the deposit of a particular flood, and over that area a thin coating of mud will be dropped, varying slightly in thickness from point to point, and on the whole diminishing very gradually in thickness outwards from the shore. Suppose such a supply of mud to form a coat $\frac{1}{80}$ inch in thickness. Less mud, or perhaps none at all, may be laid down until the next flood, so that the first coat will have had time to settle and harden a little before the next one comes in. The next flood may spread out another $\frac{1}{80}$ of an inch, and in this way the delta will be built up of thin sheets, $\frac{1}{80}$ inch in thickness: And if we could obtain a piece of the sea-bed, containing all the mud laid down by a succession of floods, it would be made up of successive thin plates, not necessarily of equal thickness, each representing the history of a single flood. This is one way in which *lamination* is produced, and, in the case supposed, each lamina would cover a large area; in other words the lamination would be of a very regular character.

Lamination may also result from different causes. The mud brought down by different tributaries may vary considerably, that of one being red, another grey, and another blue. If they are all in flood at once a mixed deposit will result, but in a great river like the Amazon or Mississippi first one and then another tributary will be in flood. Each will bring a supply of its own mud, and thus successive laminæ will vary in colour. Differences in composition may occur without marked difference in colour. One tributary may be denuding sandy, another clayey rocks, and a third chalk or limestone; in this case the laminæ will differ in composition. In the Nile delta, sand blown up by wind is deposited between the muds of successive floods, forming alternate laminæ of coarser and finer grain at the top of the mud flat. Again, when the denuded particles are long or flat in shape like mica flakes they will settle down on their flat faces, giving rise to a kind of grain in the sediment, along which it easily splits.[1]

Thus all the different types of lamination met with in rocks find their parallel in sediments, giving another link to the connexion between them and fragmental rocks.

False-Bedding.—The deposit of pebbles and coarse sand in the skeleton of the delta will be of a different character. Velocity must be fairly high to carry these coarse materials, and a slight checking in speed will cause the sudden deposit of a large quantity of them. They will thus tend to be dropped in heaps, the steepness of whose sides will increase according to the coarseness of the material of which they are composed. The velocity of a stream varies from time to time, and so matter deposited at one time may be partially removed at another, and the tops of these heaps may be swept off and deposited on the sides of them in the fashion depicted in the illustration (Fig. 46). We may compare this work to the operation of a workman depositing rubbish with a wheel-barrow. He throws the first load into a heap, and then wheels the next wheel-barrowful to the top of the heap, and shoots it down the side, and so on, building up a series of layers parallel to the side of his first heap. Precisely similar is the coarse deposit of a stream or current. The layers will not be parallel to the flat sea-bed or distributed over a large area like the laminæ of mud, but will be shot down locally in heaps, and the lamina-

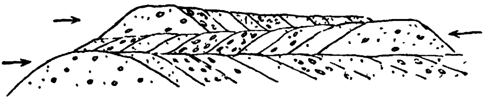

FIG. 46.—Section to show the formation of false-bedding by currents, which are indicated by arrows.

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[1] See Fig. 16, p. 21.

tion will be parallel to their sloping sides. In this way *false-bedding* and *oblique lamination* will be produced (see Fig. 17, p. 22). In a tidal sea, where the material is swept backwards and forwards by waves or currents, the inclination of layers will not be all one way, but the successive layers may cross one another at all angles, so that cross-bedding will be produced. This is illustrated by Fig. 46.

The intermediate material, that is the finer sand and coarser mud, will have deposition structures intermediate in character between the very coarse and very fine, and will be sometimes irregular and at other times regular, according to the width and velocity of the water, and the rate at which the speed slackens.

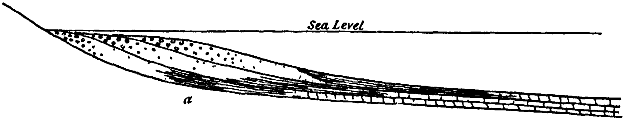

FIG. 47.—Formation of stratification while the shore-line is stationary or rising.

Stratification.—It has just been shown that coarse matter will be forming the skeleton of the delta, while finer matter is being laid down farther out. Thus each bed of clay, when traced in one direction or another, will be found to become gradually coarser until it passes into fine sand, then into coarse sand, and finally into pebbles. A single sheet would be composed of these various materials in different parts of its extent. But the growth of sediment will shallow the water and gradually place the landward end of the delta under con-

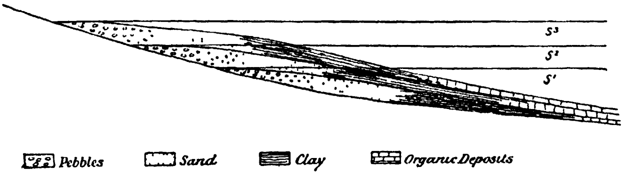

FIG. 48.—Formation of stratification while the shore is slowly sinking, the successive sea-levels being s^1, s^2, s^3.

ditions more like those of a river on land. Velocity will increase, and the fine material, instead of being dropped where previously deposited, will be carried farther out by the currents now that they are swifter. After a considerable interval, we shall find coarse sand carried out and deposited on the top of earlier deposits of fine sand, fine sand on the earlier mud, and the mud still farther out to sea. Thus the seam of fine sand will be covered by a seam of coarse sand, and one of mud by one of fine sand. After a time the deposits will be swept still farther out, and eventually we shall have the conditions represented by Fig. 47. At the point *a* we have a bed of mud overlaid by one of fine sand, and that by a layer of coarse sand. Now this is *stratification*, as defined in Chapter III., and it is by this means that one of the forms of stratification may be produced.

Let us take another case. Suppose, after the delta began to form, the sea-bed and shore subsided and the water became deeper. The velocities would now be checked farther inland, and the coarse deposits would form successively farther and farther in that direction. We should still have stratification, but in reversed order, for now fine materials would be found resting on the coarser deposits (Fig. 48).

Fossils.—Into a deposit of this nature there would be washed down by the river the dead bodies of land animals drowned by floods, and of plants growing by or in the streams, together with the shells and parts of animals which live in fresh water. Such as escaped destruction would come to rest on the lamination planes, and their bones, teeth, shells, and other hard parts would be embedded and preserved. In addition there would be remains of creatures which lived in the mixed salt and fresh (or brackish) water of the delta, and marine creatures washed in by the currents of the sea. The result would be a mingled set of remains of organisms, some characteristic of the land, and others of fresh, brackish, and salt water. The embedding of these in sediment would imitate closely the embedding of fossils[1] in fragmental rocks.

Likeness to Fragmental Rocks.—In this way it is clear that there would be produced an *unconsolidated* mass which would copy, in the nature of material, its regular and irregular

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[1] Lat. *fossus* = dug up.

bedding, its lamination and its fossils, a set of conglomerates, sandstones, and clays, such as are found in the earth's crust. Further, a close study of the sediment would teach us (1) which side of the delta fronted the sea, and which was pointed towards the land, the latter being characterised by the increase in coarseness of deposits, and by the greater thickness deposited in a given time, and (2) the oscillations in the level of the delta, whether it was stationary, so that the deposits were merely pushed outwards as they grew, or whether by depression the fine-grained deposits were brought back ever nearer the land margin, so as to overlie the coarse sediments. Another important point may sometimes be seen. Many deltas, such as that of the Ganges and Mississippi, are built high enough to encourage the growth of vegetation, and forests or grass plains will grow on them. These may be afterwards submerged and covered with new sediment, thus preserving a buried soil or forest which may be still recognisable, teaching us what other movements the delta has undergone. In boring through the Nile delta several old soils were met with below one another and below the present level of the Mediterranean. These could never have been formed below water-level, and hence they prove most conclusively that the delta must have once been higher, and must have subsided not once only, but several times, with stationary intervals between to allow a soil to accumulate on each occasion.

Marine Deposition

Coarse Deposits. — Deposit takes place not merely where rivers enter the sea, but all along its margin, except where currents are so rapid as to prevent the deposit of sediment. Pebble-beaches are to be seen bordering the shore; sand-stretches between high and low tide-marks, and often below the latter; and, beyond that, great mud-flats, generally not reaching for more than 70 or 80 miles from the shore, but sometimes extending 300 miles, and averaging about 150 miles in breadth.

The *pebble-beaches* require little description. They are the raw material of conglomerates, and are made up of whatever rocks are available for denudation by the sea, or are brought by rivers and currents. The pebbles are laid down as shown in Fig. 49, in such a way as to oppose the greatest resistance to being lifted again by currents.

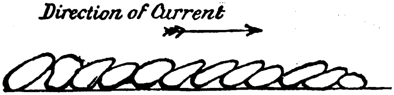

FIG. 49.—Deposition of pebbles under the influence of a current.

The *sand* is interesting because the perpetual movement of the waves imprints on it the beautiful ribbed surface known as ripple-mark, see Fig. 50. Shell-fish, crustaceans like crabs and lobsters, worms, and other animals, moving over it between tide-marks, leave their tracks and burrows, which may occasionally be preserved if a coating of mud or fine sand is deposited upon them. Even rain-prints indented by a passing shower, and cracks caused by the drying and shrinking of sand or mud under the sun's rays where it is left dry by the tide, may, under favourable circumstances, be preserved (Fig.

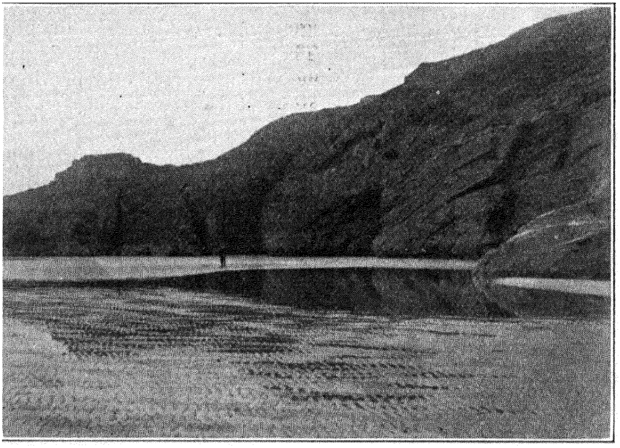

FIG. 50.—Ripple-marking on sand, Criccieth; also formation of sea-caves by denudation along planes of bedding and jointing. (From a photograph by Mr. G. T. Atchison: copyright.)

51). The direction in which the wind blew during a shower of rain may sometimes be determined by inspection of rain-prints. All these marks are sometimes found in fine sandstones and clay rocks or shales, and they are of great use in showing the exact conditions under which the rocks were laid down. For most of them shallow water, often laid bare between tide-marks, is necessary, and where ripple-marks occur at several depths in a mass of sandstone they prove that each seam in which they occur must, while forming, have been continuously under favourable conditions; hence subsidence must have taken place during deposition. The sand on a flat shore, particularly where little denudation is taking place, is sometimes blown up by the wind into little hillocks known as sand-dunes. In these the wind produces ripple-marks and false-bedding, which are only with difficulty distinguishable from those formed in water; while the deposits as a whole are stratified parallel to the outline of the mound (Fig. 22).

FIG. 51.—Slab of sandstone showing tracks of *Labyrinthodon* and sun-cracks, $\frac{1}{12}$. (Z.)

Fine Deposits.—Outside the sand comes clay, and the observations of a number of ships which have been engaged in sounding round the coasts of the great continents show that great sheets of clay—blue, green, or red in colour—are forming there. The usual tint is blue, but red mud is found off the Amazon, and wherever red rocks are being largely denuded. These deposits are very even in texture, fine in grain, well laminated, laid down in very regular sheets, and they contain the relics of marine life, shell-fish, sea-urchins, crustacea, and more minute animals. They are very like many of the clays met with in the earth's crust, such as the Gault, the Oxford Clay, and the Lias (see Chap. XX.)

Organic Deposits

Calcareous Ooze.—Farther out at sea are the regions where the water is so still that no mechanical sediment is borne there, and on those vast areas of the sea-bed nothing whatever is deposited save the relics of marine organisms; these are called *abysmal* deposits. H.M.S. *Challenger* and other surveying ships discovered that this area was generally covered with cream-coloured sticky muds, consisting almost entirely of the relics of organisms. Some were made of tiny chambered shells of creatures called foraminifera, which live at the surface of the water and down to considerable depths in it. The commonest of the foraminifera is called *Globigerina*[1] (see Fig. 136), and the deposit formed by them is called *globigerina ooze*; a sample of it is figured in Fig. 52. Specimens of it are found to be made almost solely of carbonate of lime, with only an occasional fragment of pumice, a few particles of volcanic dust, and one or two skeletons of radiolaria or sponge spicules. If consolidated, this ooze would form a limestone somewhat like chalk in appearance and composition. Globigerina ooze is not usually met with at a greater depth than 2500 fathoms. Another kind of ooze contains many shell-fish known as pteropods,[2] which live at the surface of the ocean, and drop to the bottom when dead.

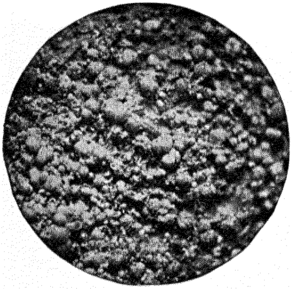

FIG. 52.—Globigerina ooze (about $\frac{8}{1}$).

Diatom Ooze.—Still another ooze, chiefly found in Antarctic regions, is made of the remains of tiny plants called diatoms,[3] which build cases out of silica, and form an ooze known as *diatom ooze*, the composition of which is almost pure silica.

Red Clay.—At still greater depths a fine *red clay* is found on the sea-floor; this consists almost entirely of remains of volcanic dust and decomposed pumice, a rock which is so spongy and light that it floats for vast distances, and at last decomposes and falls to the bottom. The relics of foraminifera

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[1] Lat. *globus* = a sphere, *gero* = I carry.

[2] Gr. *pteron* = a wing or fin, *pous, podos* = a foot.

[3] Gr. *dia* = through, *temno*, I cut asunder.

and pteropods do not here reach the bottom of the ocean, as their carbonate of lime is dissolved by the time they reach a depth of about 2500 fathoms and at the bottom of these great depths. Relics of the minute animals called radiolaria, whose skeletons are made of silica, however, do reach the bottom, as they are insoluble, and they become mingled with the red clay.

Radiolarian Ooze.—At the greatest depths known in the Pacific Ocean, the red clay contains a very large number of radiolaria,[1] forming a siliceous ooze at the bottom (see Fig. 137). In these two last classes of deposits the most durable parts of other marine creatures are occasionally found; teeth of sharks and ear-bones of whales occur, mixed with chemical deposits, such as the minerals called zeolites (see p. 130), and nodules of oxide of manganese. The deposit of all these things takes place with extreme slowness, so that the teeth and ear-bones are barely covered with deposit, although some of them have lain there for centuries.

Other Organic Deposits.—A few other deposits call for a little attention. Where the floor of shallow water is free from sediment there occur deposits of *shells* heaped together. This deposit is composed almost solely of carbonate of lime, and if the water is shallow it may be false-bedded.

In tropical latitudes *corals* grow in clear water, and some of them build such massive structures out of the carbonate of lime of the sea-water that they make up rock masses, and often islands, in the Pacific and Indian Oceans and elsewhere (see Figs. 184, 232).

In other places banks are formed of *sea-urchins*, and, again, the sea-weeds called *nullipores*, which have also the power of secreting carbonate of lime, build up masses of limestone. Skeletons and spicules of sponges not infrequently make a siliceous deposit on sea beds, and remains of them are found in most marine deposits.

All the sediments just described, with the exception of the red clay, are made either of carbonate of lime or of silica, which is obtained by the animals or plants from that dissolved in the sea-water in which they live. It has already been shown that these two substances are dissolved by rain, springs, and rivers, and carried out to sea in solution. They are taken out

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[1] Lat. *radius* = a ray.

of the water by animals and plants, and deposited on the sea-bed at their death. Thus not only matter mechanically denuded in the form of pebbles, sand, and mud, but that carried away invisibly in solution, is restored again to the earth's crust in the stiller waters of the sea. Thus *limestones* and *siliceous deposits* are truly clastic in origin.

Deposit in River Basins

We must now go back to rivers and study some others of the deposits which they form, for a good deal of the matter is deposited temporarily on the land. When a mountain torrent reaches the flatter ground at the base of the mountain it undergoes a sudden checking in speed, so that it can no longer carry all the load of disintegrated matter supplied to it by frost and other disintegrating agencies on the high ground.

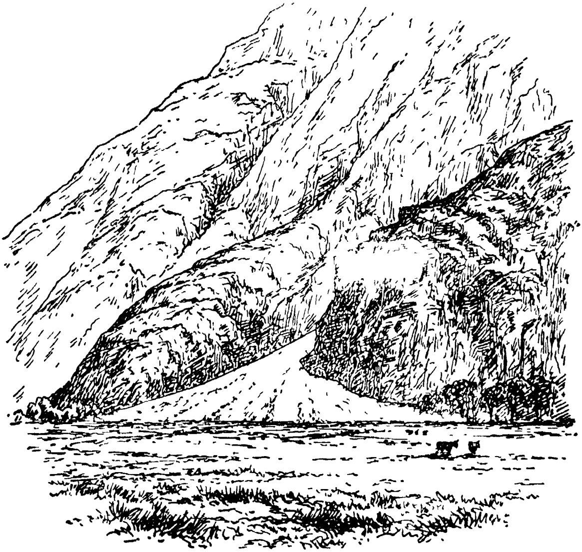

FIG. 53.—An alluvial cone or dry delta, Switzerland. (Drawn from a photograph.)

Great quantities of stones and sand are dropped here, forming what are known as alluvial cones or dry deltas (Fig. 53). The rapid piling up of this material causes the streams to shift their courses occasionally, and so the deposit becomes spread over a large area, and it gradually encroaches on the plain until the slope of the stream is reduced to an even curve, and no further deposit takes place.

Gravels.—In the wider part of its valley below the mountains a river has a lower velocity and takes up but little new material, contenting itself with carrying what it already has. As its velocity varies from point to point, this material is at times deposited, and at others picked up and swept along. The velocity of a straight stream is greatest at the top and the middle, the bottom and sides being retarded by friction. When it bends from side to side its velocity is often greater towards the outer part of the curve, and less on the inside. It therefore cuts away its hollow or concave bank (Fig. 54), and deposits denuded material in the slacker cur-

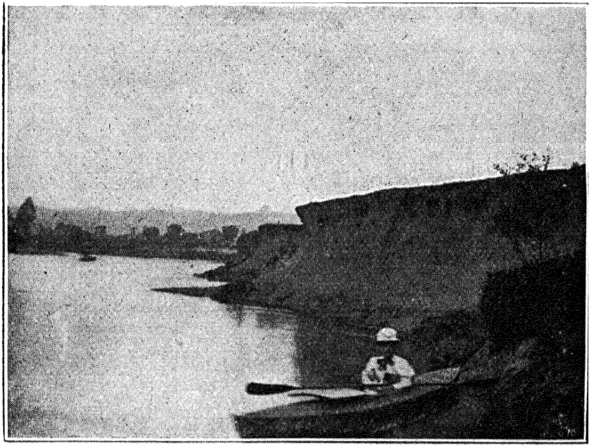

FIG. 54.—Small cliff of gravel on the River Severn. This is the concave bank and it is being eroded; the opposite bank which is only just seen has a spit of gravel deposited on it.

rent on the projecting or convex bank. As this process continues the river's course shifts; it gradually works away the bank on one side, and its bed moves farther and farther in that direction, obliterating its old course by gravel deposited on the other side (Fig. 55). Bit by bit the whole space between the rocky sides of the valley is traversed by the river, and as it meanders about it may be found now in the middle, now at one side, and now at the other of its gravel plain.

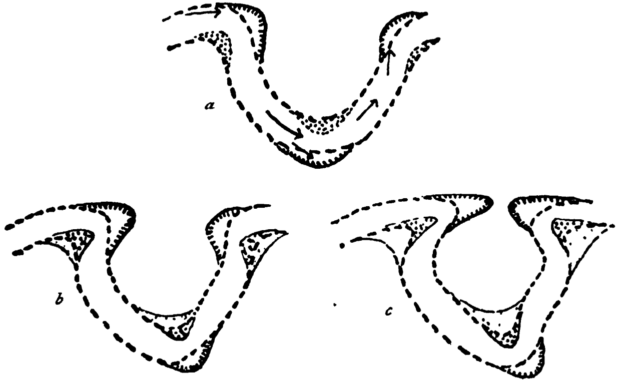

FIG. 55, *a*, *b*, *c*.—To show the successive changes in the position of a river-curve as it erodes the concave bank and deposits gravel on the convex bank

Gravel-making is usually done when the river is not cutting rapidly downward, but if uplift of the land or increased supply of rain causes the stream to carve its way downward again, it may undermine and destroy most of its previously deposited gravel plain. Little bits of it are left, however, here and there sticking to one side or other of the valley, serving as an index

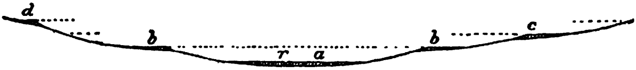

FIG. 56.—Section across a river valley to show the present level of the river *a*, and the old gravel terraces *bb*, *c*, *d*, the last being the oldest.

to show what the level of the floor of the valley once was. Occasionally two or three of these terraces may be found one above another, as shown in Fig. 56, *a*, *bb*, *c*, *d*.

Alluvium[1]—When a river reaches flat ground, as it usually does near the sea, it is very liable to floods, and unless it is kept in by embankments, it frequently overspreads this plain with its muddy waters, and deposits sheet after sheet of mud, which fertilises the ground, and in the state of nature gradually builds the plain up higher and higher. As the coarser material is deposited near to the stream, the deposit here becomes thicker and the river-bed begins to rise little by little above the plain, until it gets in an unstable and very dangerous position, from which it must escape at some time or other, and cut out a new channel for itself. The same kind of thing happens frequently in deltas, and is one of the causes of the branching of a river in this part of its course.

Lake Deposits.—When streams enter a lake each forms a delta of its own. The finer material is carried into the still waters of the centre, and a mud-flat is formed there; with it are associated deposits of shell-marl and occasionally diatomaceous earth. If the lake be drained, this flat will be found to be surrounded by belts of sand, that by patches of pebbles where the rivers enter, and, in places where the lake has precipitous rocky sides, by a belt of coarse, angular, frost-chipped detritus, which, if consolidated, would make a breccia (Fig. 57). The presence of this breccia, and the disposition of the detritus in rough rings; the absence of signs of tidal action; the presence of fresh-water and terrestrial organisms only; all serve to dis-

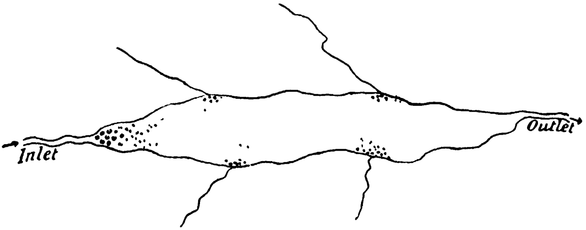

FIG. 57.—Diagram to show the deposit of detritus in a lake.

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[1] Lat. *alluvio*, an inundation.

tinguish these deposits from those laid down in the sea. It will, of course, have been seen that all river deposits except deltas will contain no marine remains, and what few fossils are preserved will be of fresh-water (see Fig. 248) and terrestrial organisms (see Fig. 267), while plant remains are likely to be more common here than in any other deposits.

In salt lakes, such as the Great Salt Lake or the Dead Sea, similar mechanical deposits are being laid down, but they are mixed with a different class of deposits, chemical in origin, which will be described in Chapter XI.

Order and Significance of Bedding.—Another point which will have been noticed is the order in which deposits are laid down. The earliest will be on the sea- or river-bed, and each successive one will come on the top of that previously laid down. Thus, if the series of sediments was uplifted, we could tell the age of each bed with reference to the underlying older ones, and the overlying newer ones. This, which is called the *principle of superposition*,[1] is of great value in ascertaining the age of rocks, and forms one of the chief tests of age. A second test of age will also be easily understood. The rocks which have been broken up in order to contribute pebbles and sand-grains to a deposit must necessarily be older than the deposit which contains them as fragments. This furnishes what is known as the *test by contained fragments*. Further, each lamina in the deposit indicates a slight change in condition of some sort—successive floods, due to successive years or rainy seasons, or the flooding of different tributaries, or the varying strength of the carrying currents. Each large stratum or bed indicates a more important change still; shallow water succeeding deeper water, or the reverse, due either to extensive growth of the deposit, or to uplift or depression of the sea-bed. In endeavouring to make out the history of ancient sediments these features must all be taken into account.

Rate of Deposit.—The average and maximum rate of deposit may be ascertained in the following way, which we owe to Dr. A. R. Wallace. The whole area of the land is being denuded mechanically, at the average rate of one foot in 1500 years, and the material thus obtained is all that is

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[1] Lat. *super* = above, *positus* = placed.

available for building up mechanical sediments. This land area measures roughly 57,000,000 square miles. But sediment is only being deposited on the margin of the continents, that is, along a length of 100,000 miles, the belt of deposit averaging 280 miles in width. This gives an area of 28,000,000 square miles, about half the size of the denudation area. Thus, one foot denuded from all the land would make two feet when piled up on the smaller area, and the average rate of mechanical deposition will be one foot in $\frac{1500}{2} = 750$ years.

This, however, only represents the average. A study of Figs. 47 and 58 will show that the deposit of a given period rapidly thins in deep water, while the maximum rate will be found where sand and pebbles are being laid down near land. As so many of the rocks are sands, conglomerates, and other rapidly-made deposits, it is necessary to ascertain at about what rate such rocks may form. The shape of the wedge of deposit is such that if the material beyond 30 miles from shore (black) were placed on that within 30 miles it would be equal to the dotted part, and would complete the parallelogram shown in Fig. 58. That is, if all denuded matter were laid down within 30 miles of shore the rate of deposit over that area would be the same as the maximum rate in the wedge. This area will be about 3,000,000 square miles, or one-nineteenth of the denudation area, and the rate of fastest deposition will be one foot in $\frac{1500}{19}$, or about 80 years.

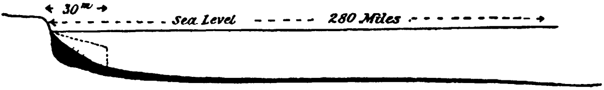

FIG. 58.—Diagram to show area of deposit of sediment, and in black the thickness deposited in a given time at varying distances from the shore. The dotted portion represents the theoretical piling up of all sediment deposited between 30 and 280 miles from shore, so as to make a mass 30 miles wide and of same thickness throughout as that sediment deposited at maximum rate

RECAPITULATION

The denuded material swept out to sea by rivers is deposited there in the form of *deltas* like those of the Nile and Mississippi. It is *sorted* by the gradual slackening of the water as it reaches the stiller sea. The rivers tend to branch out into "*distributaries*," lining their banks with the *coarser* deposit and spreading the *finer* material over the larger intervening areas. The sand and mud will become *laminated* if the supply is discontinuous, as is generally the case, and while the fine matter will be spread out in great *sheets*, the coarser will be thrown down in heaps and will become *false-bedded.*

Along the whole sea-coast fine deposits will be met with farther out to sea than coarse ones; a zone of *pebbles* will be succeeded by one of *sand*, and that by one of *mud.* Outside the regions to which currents can carry mud there are found deposits of *calcareous* or *siliceous ooze* made from the remains of animals or plants; these bring back to the earth crust the matter denuded by *chemical agencies*, such as solution.

If the sea-bed be *stationary* or *rising* the tendency will be for coarser sediment to overlap the finer, but if it be *subsiding*, the finer material will overlap the coarser. In this way *stratification* arises, the older strata being found *below* the younger.

Some of the denuded matter finds a temporary or permanent rest within river-basins in the form of *gravels*, *alluvia*, or *lake deposits.*

The material mechanically denuded from the *whole* land-surface is deposited within the *area of mechanical deposit* bordering the coasts, which is much smaller than the area of denudation. In consequence the *thickness* deposited on this area within a given time will be greater than the thickness removed from the whole denudation area. Thus the *maximum rate of deposition* appears to be about *one foot in* 80 *years.*

QUESTIONS ON CHAPTER VII

1. What are the several agencies by which the waste of land is brought about? Describe the state in which the waste material is carried away, and what eventually becomes of it? (1884.)

2. Describe the process of the formation of river deltas, and give examples of the same kind of process having gone on in England. (O and C.)

3. Explain carefully the sorting of material during the formation of a delta.

4. In what different ways may lamination be produced?

5. Mention the characters which would satisfy you that a deposit has been formed (1) in shallow water; (2) in fresh water; (3) in a lake. (O and C.)

6. Coarse-grained sandstones are often irregular and inconstant. Why is this? (1892.)

7. How may it be inferred that certain rocks were formed in shallow water? (1886.)

8. What are ripple-marks and rain-pittings? What inference may be drawn from their occurrence? (1891.)

9. Describe the structure and mode of formation of sand-dunes. (1885.)

10. What is gravel, and how has it been formed? (1880.)

11. Note some of the characters which indicate deep-water deposits. (1890.)

12. What mineral substances are carried down by rivers? What becomes of these when the rivers reach the sea? (1888.)

13. Give a short account of the formation of sedimentary rocks. (O and C.)

14. Compare deposited sediment with the clastic rocks. Estimate the average and maximum rate of deposit of sediment in the sea.

CHAPTER VIII

ROCK STRUCTURES AND EARTH-MOVEMENT

Differences between Sediment and Rock. — The sediments which have just been described differ from rocks in several important particulars. Rocks are generally *hardened* in some way; they occur *above the sea-level;* the layers or beds are not usually flat and horizontal, but *tilted*, or *inclined*, and often thrown into wave-like curves, or crumpled into minute folds; they are frequently crossed by *fissures* or narrow cracks, and sometimes they split into *thin plates* which are not parallel to the bedding. Most of these appearances can be explained by natural causes which may be observed at work, or else they may be imitated by simple experiments.

Hardening

Pressure.—Sometimes this is effected by pressure, especially if the sediment is made of irregular grains, which will interlock, or if the larger ones are set in a muddy paste which may be driven amongst the grains so as to bind them together. The extremely fine, flour-like clay used to make encaustic tiles is pressed in a mould by means of a die and a screw which exerts a pressure of several thousands of pounds on a square inch; the clay is converted into a moderately hard substance like the shales and solidified clays sometimes found as rocks. The same thing would occur if several hundreds of feet of sediment were piled upon one another; the bottom layers would be consolidated, for each thousand feet of sediment exerts a pressure of not less than half a ton on every square inch of its bottom layer. This pressure squeezes the grains close to one another so that they interlock or are held together by the surface-tension of the thin films of water between them. A familiar example of this method of hardening is the solidification of a "dried" road by a steam-roller.

Rock layers are often pressed end on, by what is called lateral pressure (see page 113), and this effects further solidification, as is seen when soft shales are converted into hard slates.

Cementing.—But there is a more effective method than this, known as cementing, because it is analogous to the cementing of single bricks together to make a wall. Semi-fluid mortar is placed between the bricks, and this becomes solid by chemical change and holds the bricks tight together. If we can introduce something between the grains of sand or pebbles of a sediment which will become solid, it will hold them tight together in the same way. This happens when a muddy lane freezes. The water between the grains of mud passes into solid ice, which cements the particles together so that the mud becomes like a solid rock, and is as hard to break.

Now, many solid substances dissolve in water, and may be again deposited in the solid form if the water evaporates. Place a little dry sand in a saucer, and wet it with a strong solution of alum; then place it in front of the fire, and let it dry slowly. Repeat this process two or three times if necessary. The water will be driven off, and the sand will be found in a solid cake, having its grains cemented by the alum crystals deposited among them.

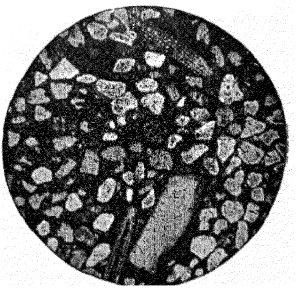

FIG. 59.—Section of a cemented deposit from the bed of the Irish Sea. It is made of bits of quartz and shell fragments, cemented by carbonate of lime (about $\frac{9}{1}$).

In nature the chief substances which act as cements when deposited from solution in water are *carbonate of lime*, *oxide of iron*, and *silica*. Some salts of iron and carbonate of lime dissolve in water charged with carbonic acid. Such water percolates amongst the grains of sediments, and losing its carbonic acid by evaporation, drops carbonate of lime or oxide of iron amongst them, binding them into a solid mass. Very many sandstones are cemented in this way, and this is why they crumble to pieces when acted on with hydrochloric acid in the laboratory, or more slowly when rain charged with carbonic acid falls on them in the field.

Silica is less easily dissolved, but it is taken up by water which already contains potash or soda in solution, and by a fall in temperature or by some chemical change deposit and cementation may happen, much the same thing occurring as in the deposit of siliceous sinter from geysers and hot springs. The difficult solubility of silica renders rocks which are cemented by it very durable.

Other cements, such as carbonates of magnesia or iron, sulphate of lime or barium, and certain silicates are similarly deposited. Sometimes two or more solutions meet, and if chemical reaction takes place a solid precipitate may form and act as a cement. Where calcareous springs occur, or when active chemical change is going on, modern sediments are found sometimes to be cemented into solid rock. Fig. 59 represents a section of a deposit found on the bed of the Irish Sea which has been cemented in this fashion. Gravel cemented into solid masses round rusty old kettles and horseshoes is not uncommon.

Concretions.—It is not likely that cementing material will always be evenly disseminated through a rock. Where the supply or evaporation is greatest more may be deposited than elsewhere, and thus solidified lumps, or concretions,[1] as they are called, may arise in a looser deposit (Fig. 60). Again, the supply of cement may come from the solution of shells or organic remains in the rock. If the rock is not very porous the solutions may not travel far, but be deposited in a knot round the organism. This is very common in clays, in which lumps of impure carbonate of iron (clay ironstone) or carbonate of lime, often containing a fossil plant or shell inside them, are extremely common. Calcareous concretions are found in some modern sediments.

As water travels along bedding planes and fissures of rocks the concretions are often elongated in these directions, and

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[1] Lat. *con* = together, *cretus* = grown.

sometimes form more or less complete but irregular bands. Concretions must not be mistaken for pebbles. The latter are of shapes which would be produced by wearing and rolling; the former are made of some single substance like carbonate of lime or iron or of silica, are often irregular in shape, show traces of bedding planes passing through them, or possess a radial or concentric structure; occasionally there are hollow spaces or cracks inside them lined with crystals.

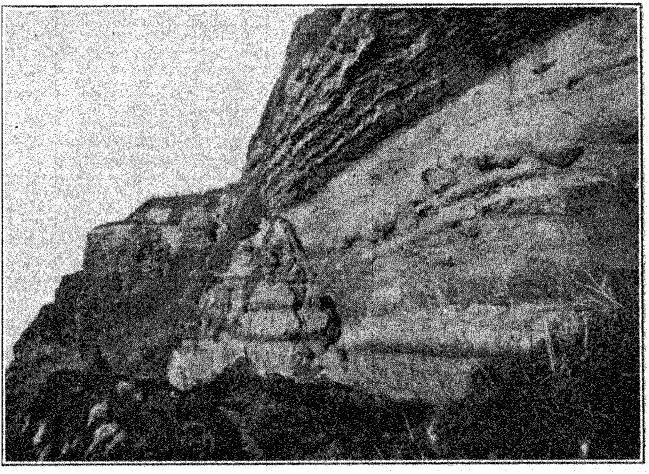

FIG. 60.—Corallian sandstones and limestones, Castle Cliff, Scarborough; to show bedding, and concretions in the lower part of the section. (From a photograph by Mr. A. E. Nichols: copyright.)

Flints.—But as the water drops one substance out of solution it is often able to take up another, and an interchange takes place. Water in the chalk dissolves up the little sponge skeletons made of silica, putting down carbonate of lime in their place as it does so. The silica will be deposited elsewhere, and new carbonate of lime taken up to make room for it. As a rule a substance will be deposited where some of it already exists, and thus the silica is gradually deposited in knots or bands at the point where the greater number of sponge-skeletons occurs, and it is removed from the rest of the rock. This is the origin of lumps of *flint* made of nearly pure silica which are found in chalk, a pure limestone out of which most of the silica has been dissolved. A similar cause acting on a calcareous clay often separates out the carbonate of lime into bands, leaving non-calcareous beds of clay between them. The illustration of a cutting in the Wenlock Limestone shows the appearance of a highly calcareous clay which has been treated thus (Fig. 61).

FIG. 61.—Cutting in the Wenlock Limestone, Wenlock Edge. Beds of concretionary argillaceous limestone.

Preservation of Fossils.—This also accounts for the changes which many fossils undergo. A fossil shell made of carbonate of lime may be dissolved out completely, and only the mould of stone, in which it lay, left to mark its place; or it may be replaced particle by particle by carbonate of iron or silica, and its minutest details of structure copied and replaced by the new material. The most beautiful example of this is the *replacement* of fossil wood by silica in the form of opal. A microscopic section of such a fossil enables the character of the wood to be seen as well as in a bit of modern wood.

Colouring.—Strongly coloured cements are generally responsible for the colouring of rocks, particularly those made of colourless quartz grains or white china-clay. Oxide of iron gives brownish yellow, brown, or red colours according to the amount of water combined with it; carbonate of iron blue; carbonate of lime white, pale pink, or grey; salts of manganese pinks, purples, and reds. Some coloration is due to the prevalent grains. Green colours are due to grains of glauconite[1] (silicate of iron) or other silicates derived from the decomposition of augite or hornblende. Dark and black rocks are usually coloured by carbon, grey and bluish rocks by finely-disseminated pyrites.

Heat and Lateral Pressure.—After an encaustic tile has been pressed it is fired, when chemical changes occur in the clay, hard, glassy or crystalline silicates being formed, usually in proportion to the amount of heat used. A ringing, porcelain-like substance is thus produced, which is like some of the indurated clays or *porcellanites.* Other chemical reactions may take place under the influence of heat and water, or both, and alter the structure of a sediment by new growth taking place within it. Crystals so formed will interlock and form a very compact substance. Slates, gannister, quartzite, and limestones are frequently solidified in this fashion. A limestone, originally made entirely of remains of organisms like corals or shells, may be acted upon by water, the carbonate of lime dissolved in one place being deposited in another in a crystalline form, which will bind it all up into a hard, partly crystalline substance, in which the traces of fossils may be much obscured.

Elevation and Submergence

If the fragmental rocks which build up the land masses were deposited in the sea they must have been elevated, or else the sea must have retired. Conversely we may expect that regions once land may have been depressed beneath the sea. There is abundant evidence that both these kinds of movement are now going on.

Elevation.—The much indented coast of Sweden, north of Stockholm, where the islands and rocks are well known to fishermen, has given abundant proof that it is being slowly uplifted; and marks placed on the coast in 1820 are being

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[1] Gr. *glaukos* = bluish green.

raised at rates varying from 2 to 3 feet in a century. That this movement has been going on for a long time is proved by the occurrence of beaches like those now seen at sea-level, but raised in great terraces to heights varying from 50 to 600 feet above sea-level along the Norwegian coast. Similar but lower raised beaches are known in Scotland and England, and a good example is figured (Fig. 62).

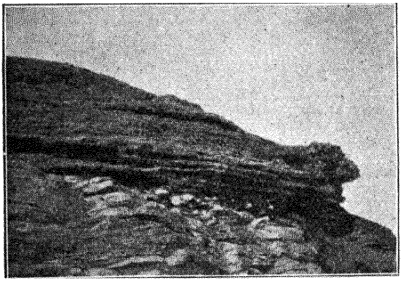

FIG. 62.—Raised beach resting on folded Devonian strata, Hope's Nose, near Torquay, Devon. The beach is covered with cemented sand.

Subsidence.—It is less easy to obtain proofs of subsidence, but convincing evidence is frequently obtainable.

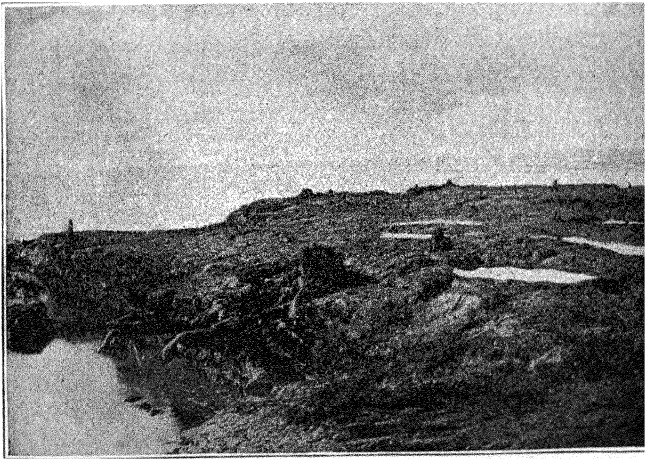

FIG. 63.—Submerged forest at Leasowe, Cheshire; submerged 6 feet at high tide. (From a photograph by Mr. C. A. Defieux: copyright.)

Round many of the shores of Britain there are relics of old forests which are submerged at high tide, and sometimes even at low tide. The figure annexed is taken from such a forest at Leasowe, on the peninsula of Wirral in Cheshire; the trees are submerged in 6 feet of water at high tide (Fig. 63). Trees of this magnitude must have grown above the sea-level and almost certainly at some distance from the shore, so that the amount of subsidence is probably not less than 20 or 30 feet. Similar conclusions follow from submerged streets, and houses buried in marine deposits, in the south of Sweden. That large areas of the Pacific Ocean are slowly sinking appears to be proved by the growth of coral reefs there. Several layers of soil and turf were met with far below the sea-level in boring through the delta of the Nile, giving conclusive proof of subsidence during the growth of the delta.

The loss of land by subsidence beneath the sea must be carefully distinguished from loss by denudation, just as gain of land by deposit of sediment at the edge of the coast must be distinguished from gain by uplift. In the cases just considered the *levels* of the land have undergone a change relative to the level of the sea.

Earthquakes.—Examples of more rapid uplift and downthrust are associated with earthquakes and volcanic eruptions. Earthquakes are great shocks and trembling of the ground, due sometimes to the sudden formation of steam in volcanic eruptions, and sometimes to the cracking and movement of the ground in the formation and slipping of faults (see p. 106). The results of earthquake shocks include the fissuring, fracture, and overthrow of buildings, the trembling and cracking of the ground, waves of sound and great waves at sea, and frequently the permanent lifting or subsidence of the ground.

Oscillation.—Earthquakes are common in the neighbourhood of Vesuvius and the other volcanoes of the Bays of Naples and Baiæ, and evidence of earth-movement in the area are common. The "Temple of Serapis," in the latter bay, three of the marble pillars of which are still standing, was erected before B.C. 105. The pillars were partly buried in marine and fresh-water deposits and in volcanic ash, and some time before the close of the fifteenth century they were submerged in the waters of the bay to a depth of about 23 feet, as is evidenced by the marks caused by marine shell-fish which bored into the marble of the columns. They were uplifted clear of the water by the year 1538 at the time of the eruption of Monte Nuovo, and since that date they have slightly subsided, so that water now comes on to the floor of the "Temple." Here movements of uplift and depression have alternated in the same place.

In South America, on the coast of Chile, after the earthquake of 1822, a large area, calculated as 100,000 square miles, was lifted on an average 3 feet above the sea; and after the earthquake of 1855 in New Zealand, along one side of a crack 90 miles long, the ground was elevated about 9 feet above the rock on the other side. These instances prove that it is the land and not the sea which is moving, for as the sea is level one part cannot rise while another is falling, nor is the level likely to rise at one time and fall at another at the same place.

Folding of Strata

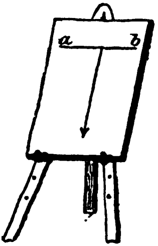

Fig. 64.—Diagram to illustrate dip and strike.

Dip and Strike.—Rock beds seen in a quarry or railway cutting are often found to incline in one direction or another, and at varying angles. Support a blackboard on an easel so that it slants downward, and then pour a little water on it; this will flow down the shortest way, or along the steepest slope, down the board (Fig. 64). Now draw a line at right angles to this on the board, and it will be found to be horizontal. Replacing the board in imagination by a stratum of rock, the steepest line down it is called the *dip*, and the rock is said to incline or dip towards the east, north, south, west, or whatever the compass bearing of this line may be. The angle of dip is the amount of inclination with the horizontal plane measured along this line. The horizontal line along the stratum is called the *strike* of the rock, and is always at right angles to the dip.

Order of Strata.—Next place one book flat on the table, and place a second so that its lower end rests on the table and its upper end against the other book, and so that it inclines or dips towards the left; lay several other books one after another against this so that the lower end of each rests on the table and the whole series dips to the left (Fig. 65). You now have a rough model of a series of strata dipping down into the earth's crust. They dip from right to left, and the upper edge of each book is horizontal and runs along the strike.

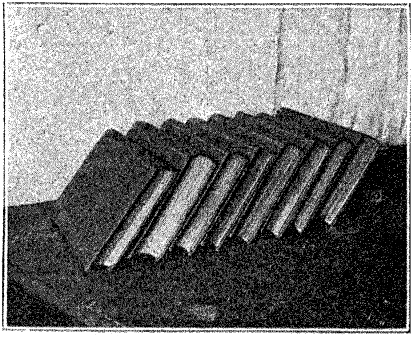

FIG. 65.—To illustrate a succession of dipping strata.

Outcrop.—Similarly a pile of stratified rocks tilted up in the same way would come up to the surface of the earth from below, and if the surface of the earth were horizontal they would come to it, or *crop out* as it is called, in a series of parallel bars, each of which would correspond with the strike of a bed of rock. The first book laid down is to the right, the last to the left, the newer ones having been laid one by one on the older ones, overlying them as it is called. In any series of dipping strata, if tilted and not overturned, each older one dips in a direction towards the next newer one, and dives under it. In other words, if you walk in the direction towards which the rocks are dipping you advance from older to newer rocks, and *vice versa.* On the other hand, if you walk in the direction of the strike you keep in the same bed.

It will be obvious that horizontal strata will outcrop on an inclined surface, while if both bedding and surface be horizontal the outcrop of one bed will occupy all the ground.

Whether the beds are horizontal or inclined, the outcrop will be irregular if the ground be irregular, and this irregularity will be greater the lower the dip of the beds.

Map.—It would be quite easy to indicate on a map the outcrop of the books or rocks on the horizontal surface. Such a map would consist of a series of lines parallel to the strike of the rocks, and some conventional symbol like an arrow might be used to indicate the direction of the dip. The inspection of such a *geological map* would enable you to say which rock or book was laid down first and which last. (See Fig. 78.)

Geological Section.—A *horizontal* section expresses what would be seen by cutting the strata or books through along any given line. To show the true amount of inclination of the beds it should be taken in the direction of the dip, that is, at right angles to the strike. A section taken in any other direction will make the angle of dip appear less, while one taken along the strike will make the layers appear horizontal. This can easily be studied by taking a wedge of modelling clay and piling a series of sheets of differently coloured clay on it. The whole pile can then be cut through in various directions and all these points noted.

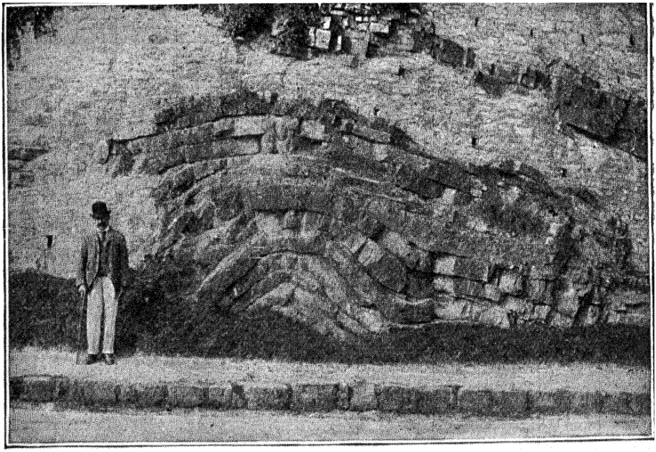

FIG. 66—Anticline of Carboniferous Limestone at Chepstow. (From a photograph by Mr. H. L. P. Lowe: copyright.)

Folds.—If a railway section or quarry is large enough it may often be seen that the angle of dip varies in amount from place to place. Sometimes the bed becomes horizontal, or it may even be found to dip in the opposite direction (Fig. 66). In other words, strata are found to be thrown into *waves* like the surface of the sea or like a disturbed and crumpled tablecloth.

When the strata are seen in a section to dip away to the right and left from a point the curve is said to be an *arch* or *anticline*;[1] when towards a point, a *trough* or *syncline*.[2] The roof of a house, a railway arch, or a book half opened and placed upside down on the table, are all familiar models of anticlines ; a trough, a rainwater gutter, or a half-open book resting on the back of its cover on the table, of a syncline (Fig. 67). These examples will show that anticlines and synclines may be regarded as being bent over lines or *axes*

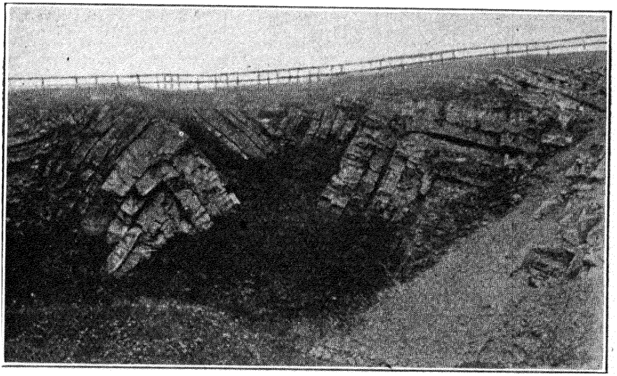

FIG. 67.—Two anticlines and a syncline in Carboniferous Limestone at Draughton, near Skipton. A fault or thrust-plane also occurs to the left. (From a photograph by Prof. E. Waymouth Reid, kindly lent by Mr. A. S. Reid: copyright.)

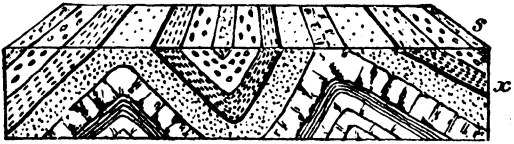

FIG. 68*a*.—Diagrammatic scheme of section (x) and outcrop (s) of the folds seen in the preceding figure.

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[1] Gr. *anti* = opposite, *klino* = I incline.

[2] Gr. *syn* = together, *klino* = I incline.

which run parallel to the strike of the rocks. Thus the roof-tree would represent the axis of an anticline, and a pencil lying in the bend of a half-open book the axis of a syncline.

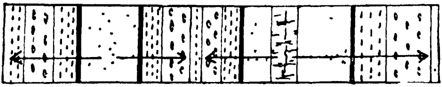

FIG. 68*b*.—Map of the strata seen in the preceding figure, arrows show direction of dip.

A map of either would give a series of parallel lines (Fig. 68*b*). In synclines the arrows representing direction of dip would converge to the central line, and in anticlines they would diverge from it.

Synclines and anticlines are only two parts of one single curve-system, and they usually occur together and alternate with one another. In such a case it is customary to speak of the different parts of the folds as the *arch limb*, *trough limb*, and *middle limb* respectively. These different parts can be recognised in the annexed diagram (Fig. 69).

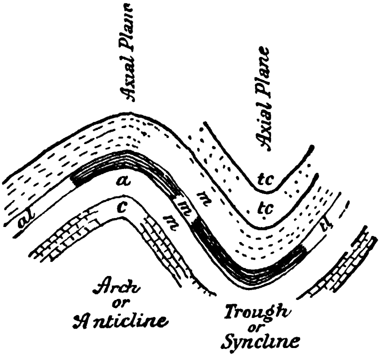

FIG. 69.—Diagram to show the parts of a fold. *ac*=arch core; *tc*=trough core; *m*=middle limb; *al*=arch limb; *tl*=trough limb. (After Lapworth.)

Classification of Folds.—Folds vary much in character, and they are best classified according to the relative steepness of the two sides of a fold. If both limbs make the same angle with the vertical plane through the axis the fold is spoken of as *symmetrical.* More usually one side is steeper than the other, when the fold is called *unsymmetrical*, a very common type. Occasionally the strata on one side of such a fold become vertical, or they may actually be upside down, when the fold is spoken of as an inverted fold, or as an *overfold* (Fig. 70). A coal-seam or other band of rock is sometimes met with twice, or even three times, in the same shaft owing to the occurrence of inverted folds. The order of succession will be inverted in the middle limb of overfolds ; the same strata will be met with again, but in reverse order, while markings such as worm-tracks, rain-prints, and ripple-marks will be seen upside down.

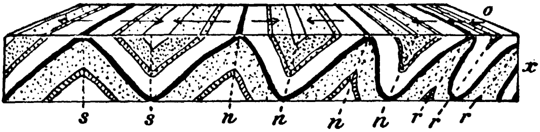

FIG. 70.—Set of folds showing the axial planes. *s*=symmetrical ; *n*=unsymmetrical ; and *r*=inverted folds.

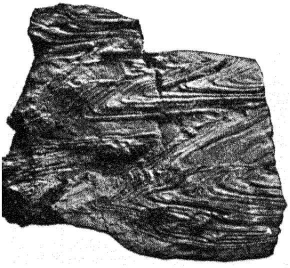

FIG. 71.—Contorted limestone ; ⅛. (From a specimen belonging to H.M. Geological Survey.)

The folds are symmetrical in regions little disturbed. They grow less symmetrical, and eventually become inverted, in regions of great disturbance like mountain chains. Great symmetrical curves are often miles across (Figs. 243, 298), while in a highly contorted district there are dozens of small folds in the length of a foot (Fig. 71), and even sometimes in an inch (see Fig. 85). Such rocks are spoken of as puckered or *contorted* (see Fig. 167, p. 236).

Cause of Folding.—There can be no doubt that folds originate from the application of lateral pressure. This is clear from the fact that inverted folds are most common in contorted districts, and also from the examination of the rocks on the limb and crest of such a fold (see Fig. 75). The beds are found to be squeezed out and become *thin* in the limb, and to get *thicker* at the crest and trough (Fig. 72, *a*). If a thick plate of clay be squeezed at right angles to its surface it will become thinner, if squeezed from its ends it will become thicker. Lateral pressure would, therefore, tend to make a stratum thinner in the limb and thicker in the crests and troughs of folds.

FIG. 72.—Overfolded beds including a seam of coal which has thinned out in the limbs and swelled out in the crests and troughs *a a*. (B.)

Experiments in Folding.—Folding can be easily imitated by squeezing a pile of paper (Bradshaw with the back cut off does very well) or a pile of cloths between two books, when loaded with a third. A still better method is to get a wooden box, open at one end and with one side replaced by thick glass or hinged. A piece of wood is made to slide easily along the length of the box. Three or four sheets of modelling clay coloured with different pigments are then placed between the closed end of the box and the sliding piece. They are weighted down with shot, and then the sliding piece is forced slowly up to the closed end, if with a screw so much the better. The gradual contortion is watched through the glass, or by occasionally opening the hinged side. By this simple apparatus folds of all kinds can be produced. The greatest contortion will be near the moving panel, where overfolds can frequently be produced. It will be observed that the folds form ridges and troughs extending along lines which are at right angles to the direction of the pressure, just as waves at sea are at right angles to the wind. Lines parallel to the ridges and troughs are the axial lines (Fig. 73). It

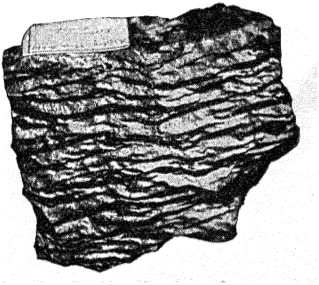

FIG. 73.—Surface of a piece of contorted mica-schist, Banffshire. To show *course* or *trend* of folds. ⅕.

will be a useful exercise to cut off the tops of the folds with a knife or fine string, and to make maps of the surface so exposed, indicating the direction and amount of dip by arrows. If the cut surface of the folds is horizontal it will be found that the breadth of a layer at its *outcrop* on this cut surface will be least when the layer is vertical (Fig. 74, *c*); and that the less its inclination the wider its outcrop will become (Fig. 74, *dab*).

A band or patch of newer rock surrounded by older is spoken of as an *outlier* (Fig. 74, *b*), one surrounded by newer rock in the crest of an anticline as an *inlier* (Fig. 74, left of *c*; see also Fig. 166). Outliers and inliers may also result from simple denudation of horizontal strata without folding, the former being on the hilltops, the latter in the valleys. This is illustrated by the section Fig. 256, p. 289.

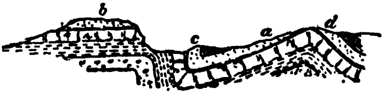

FIG. 74.—Section to show dependence of extent of outcrop on slope of the ground and dip of the beds. The same bed is wide at *a* and *b*, but narrow at *c* and *d*.

Cross Folds.—Simple anticlinal and synclinal folds are the result of lateral pressure in one direction, which will be at right angles to the axes of the folds, or, what is the same thing, at right angles to the strike of the beds. But rocks may have been bent again by a second pressure coming more or less at right angles to the first. The effect of this will be to convert each trough into a *basin*, and each arch into a *dome* or *pericline*.[1] In the first case the strata dip from all sides to a central point, and in the second they dip away from a central point (see Fig. 298) This can be imitated in the box by thrusting the strata of clay first in one direction and then in a second at right angles to it. The outcrops of such strata become more complicated. In their simplest forms they are circles, but they may be ovals, or figures of greater complexity.

RECAPITULATION

Sediment, transported and deposited by the agents of denudation, differs from clastic rocks in several particulars; it is often *hardened*,

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[1] Gr. *peri* = around, *klino* = I incline.

lifted above the sea, its layers *folded* and broken by *faults*; sometimes it splits or *cleaves* in a direction which does not correspond with its lamination, or it is traversed by planes of discontinuity which are called *joints*, while at certain places it may be *crushed* until it loses all resemblance to sediments.

Most of these things can be readily explained by the processes which a sediment is likely to undergo as *time lapses.*

Thus the mere *weight* of the sediment as it accumulates will account for some of the hardening, and some is explained by the deposit of *cement* from the percolating waters which hold carbonate of lime or other substances in solution; this action will also account for flints and other *concretions.* Further hardening may be effected by *pressure*, *heat*, and *chemical reactions.*

The *lifting* and *subsidence* of land and sea-beds finds its parallel in many parts of the earth at the present day, and this movement could hardly take place without bending the strata into the curves known as *anticlines* and *synclines*, *basins* and *periclines.* The energy for this work is generally supposed to come from the slow *shrinkage* of the interior of the earth as it loses its original heat.

QUESTIONS ON CHAPTER VIII

1. How has sediment, originally soft, become converted into hard rock? (1889.)
2. Explain the difference between pebbles and nodules. (1886.)
3. What are flints, and how are they formed?
4. Give a short description of the different proofs of the slow rise and fall of the land. (O and C.)
5. Explain the meaning of the terms "dip" and "strike." (1881.)
6. What is meant by the outcrop of a stratum? (1891.)
7. Draw a section showing the following structures: anticlinal, inlier, outlier. (XII.)
8. Define the terms—anticlinal, outcrop, dip, synclinal, inversion. Explain by means of diagrams. (1883.)
9. By what means is the folding of rocks effected? Describe an experiment to illustrate the method.
10. Define the terms dip, strike, anticlinal axis, synclinal axis, and give diagrams illustrating the two latter. (O and C.)
11. What are outliers? How have they been formed? Illustrate your answer by a sketch section. (1885.)
12. (*a*) Explain what is meant by an "anticlinal," and draw a section to illustrate one.
    (*b*) Explain what is meant by an "outlier," and draw a section to illustrate one. (1895.)

13. Draw a diagram showing inversion of strata. How may inversion be proved? (1891.)

14. Draw a continuous section through sedimentary strata, showing both a synclinal and an anticlinal arrangement of the beds. (1878.)

15. What are "submerged forests"? How have they been formed? (1886.)

16. What are "raised beaches"? What conclusion is drawn from them? (1878.)

CHAPTER IX

FAULTING, CRUSHING, CLEAVAGE, AND JOINTS

Faults

IN many natural sections of rocks the strata are found to be broken off short, and beyond the crack some well-marked seam of coal or other rock may be shifted up or down. Such a shift is called a *fault.* Imagine a stratum bent until it becomes overfolded; the middle limb becomes thinner and thinner until it can no longer stand the strain, and it snaps; the rock on one side slides upwards, the other side downwards (Fig. 75). A fault caused by strong lateral pressure like this is called a reversed fault or thrust-fault, and such faults frequently occur in regions of intense pressure and folding.

Kinds of Faults.—There are other faults which result from the stretching of the strata, and they are called normal or ordinary faults. It is quite easy to distinguish between the two. The crack of the fault is said to *hade* if it inclines from the vertical plane. Thus in Fig. 76 the crack hades towards the right 25° from the *vertical* plane (not from the horizontal plane as dip is measured). Now, in Fig. 76 the right side is the one which is thrown down; this is the character of a *normal* or tension fault (see also Fig. 168). On the other hand, in Fig. 77 the hade is also to the right, but here the right side is thrown up, and the fault is a *reversed* or pressure fault. In miners' words a normal fault hades to the *downthrown* side, a reversed fault hades to the *upthrown* side. On studying the two diagrams it will be seen how the total length of strata is diminished in Fig. 77 as if by lateral pressure, where reversed faults occur; while it is increased in Fig. 76, as if the strata had been stretched out to form normal faults. The amount of upward or downward movement, that is, the length of the line

FIG. 75.—Overfold with the middle limb pinched out, Donegal. (From a photograph by Mr. R. Welch: copyright.)

a b, is called the *throw* of the fault (Figs. 76, 77), and the length of the line *b c* is called the *shift* of the fault.

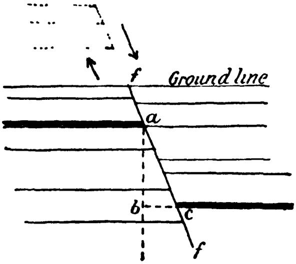

FIG. 76.—Section across a normal fault *ff*, fault plane, angle *bac* = hade, *ac* = slip, *ab* = downthrow, *bc* = shift.

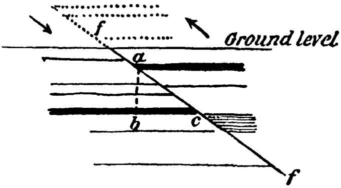

FIG. 77.—Section across a reversed fault, angle *bac* = hade, *ac* = overslip, *ab* = upthrow, *bc* = overshift. The dotted portion has been removed by denudation in this and the preceding figure.

Effect on Outcrop.—In following coal-seams underground it is evidently very important to understand the character of the faulting in order to know whether to look for a lost bed of coal above or below the point where it is broken off. A fault is seldom seen to form a cliff or irregularity at the surface owing to the denudation of a projecting rock mass. Its presence might, therefore, never be suspected, while its effect in a case like that in Fig. 78 might be to lead to the belief that two beds of coal (*c*) occurred when there is only one, or in other cases to conceal perhaps the only bed that occurred (*a*). It is by observing whether beds are ever repeated or concealed, by the appearance of sudden changes in the dip and strike of rocks, or of sharp jointing and fracturing in them, that faults can be detected and their nature ascertained.

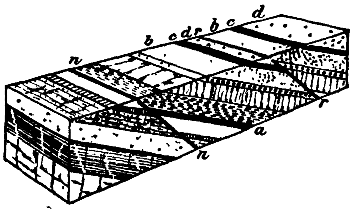

FIG. 78.—Section and surface of faulted ground to show that the bed *a* is concealed by the normal fault *n*, but the seam *c* repeated by the reversed fault *r*.

Experiments in Faulting. — Pressure-faults can be imitated by the box described on page 102, if a thin layer of powdered plaster of Paris is dusted between the layers of clay, and then the whole allowed to stand for an hour or two, till the plaster sets into little rigid plates. The application of gentle, steady pressure will cause the formation of little faults, the seams being driven forward and upward from the pressure board. Normal faults are not so easily imitated, but if downward pressure be applied to parts of a pile of clay and plaster strata with a strong flat ruler, something of the sort can be produced.

Course.—Although in section faults appear as lines of crack, they are in reality crack *planes*, and they run across the country (see Figs. 309 and 78) at right angles to the pressure or tension; that is, they run parallel to the axes of the folds and the strike of the strata; this direction is known as their *course.* Clearly these strike-faults are connected with the same force which produced the folding—*lateral pressure.* In addition to strike-faults there are others at right angles to the strike or parallel to the direction of the dip, and the whole system seems bound up with the folding movement.

Slickensides.—The rocks at the sides of faults are often folded, crushed, and broken, and the jaws of the fault are polished, scratched, and striated, evidently by rubbing against one another. These surfaces are known to quarrymen as slickensides. The crack is often filled with crushed rock fragments or kneaded clay, and sometimes with deposits of crystalline minerals; and they often form the channel by which subterranean water escapes to the surface (see Fig. 305, p. 327). If this is charged with mineral matter in solution the latter is sometimes deposited there, forming mineral veins, in many of which ores of metals like tin, copper, lead, and zinc are found. In fact, such veins form an important source whence these metals are derived.

Throw and Grouping of Faults.—The throw of faults varies from a fraction of an inch to thousands of feet; a good example is the 90-fathom fault in Northumberland, which

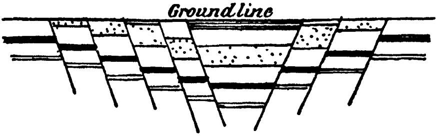

FIG. 79.—Section of trough-fault and step-faults.

throws the coal-seams 540 feet. Faults generally occur in groups, and a set of normal faults may let the strata downwards in a series of steps called *step-faults* (Fig. 79), or a portion of the strata may be let down by a pair of faults into a trough as shown in the middle of Fig. 79. These are called *trough-faults.* One large fault frequently dies out at its ends by branching out into a series of minor faults (Fig. 80), or a number of sub-parallel, branching faults occur in a group (Fig. 81). Thrust-faults are further illustrated in Chap. XVIII.

FIG. 80 —Map of branching fault. *a*=main fault; *bc*=branches.

FIG 81.—Map of a group of faults.

Crush-Breccias and Conglomerates

Breccias.—The crack plane of a fault is often filled with crushed fragments derived from the rock-walls by the earth-movement which has produced the fault. This is fault-rock or fault-breccia, and it is compacted into solid rock by fine clay, or by the deposit of a mineral cement such as calcite or quartz. During folding the beds of rock must necessarily glide over one another in order to take up their new positions, and the principal movement takes place as a rule where a hard and soft rock are in contact with one another. The junction surfaces of such rocks are often marked with slickensides. If the hard and soft beds shade off into one another through a series of beds of intermediate softness, the latter are often torn up into fragments, and a *crush-breccia* is thus formed. A compact, microscopic, crush-breccia is called a *mylonite* (see p. 192).

Conglomerates. — If the movement is intense the separated fragments are dragged along and roll over one another, and their corners and edges are worn away, converting them into pieces like pebbles. In this way a *crush-conglomerate* is produced. The aspect of a crush-conglomerate will be seen in Fig. 82. Sometimes the harder fragments part along joint-planes, at others they are pinched off at the turns or middle limbs of small folds, and in each case breccias are first formed and then conglomerates, as the fragments become worn. These breccias and conglomerates will differ from those deposited by water action in three ways: (1) the crushed character of "matrix" and fragments, (2) the presence of "pebbles" in a fine "matrix," (3) the "pebbles" are all made of one kind of rock.

FIG. 82—To show the formation of a crush-conglomerate in limestone. The middle limbs of the folds are gradually pinched off. Ilfracombe. (After Marr).

Along thrust-planes, when one rock glides over others, both the rocks above and those below the thrust-plane may be broken up, and contribute to the formation of a *thrust-conglomerate*, which will not differ much from a crush-conglomerate, except that two or three types of fragments may be present in it.

Other effects of intense earth-movement may be seen in the bending and cracking of pebbles, the cracking and straining of sand-grains, and the kneading and crushing of clays and shales. Further effects of this action will be stated in Chapter XV. In some conglomerates the harder pebbles indent the softer, and limestone pebbles may be partly dissolved at their contact with others. In both New and Old Red Sandstones indented, scarred, and broken pebbles are very common.

Cleavage

Structure.—Many rocks, especially the older, fine-grained rocks, split into thin plates along planes not parallel to their bedding, but often at a high angle, even a right angle, to it. Roofing slates are thus produced, and the structure is called *slaty cleavage* to distinguish it from the cleavage of crystals, quite a different phenomenon. If a section of a slate is cut for the microscope it is found that the elongated constituents of the rock are turned so that they are now parallel to the cleavage-planes, and thus they enable the rock to split more easily in this direction than in any other (Fig. 83). A microscopic section of an ordinary clay sediment shows that the flat and elongated flakes are laid parallel to the bedding, in the direction in which they would be laid on the sea-floor where the sediment was formed (compare Figs. 12 and 16). Something must have turned them on end. If the rock contains pebbles (see Fig. 104), concretions, or fossils (Fig. 84), they are also found to be flattened on the cleavage planes, hinting that they have been squeezed flat by pressure. Further, cleaved rocks are frequently much contorted, and the strike of the cleavage planes runs parallel to the axes of folding, indicating, like the faults, some close connexion with the force which produced contortion (Fig. 85).

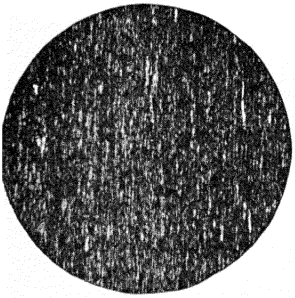

FIG. 83.—Microscopic section of a piece of cleaved slate, to show the arrangement of the fragments parallel to the cleavage which is upright (about $\frac{20}{1}$).

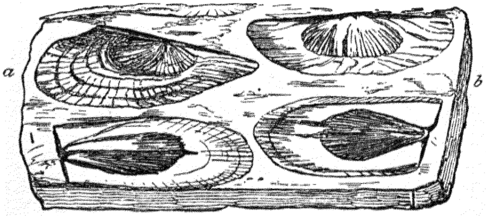

FIG. 84.—A piece of slate showing the distortion of a shell according to its position with regard to the cleavage plane. The shells are not only flattened across the cleavage planes, but drawn out in one direction (*a b*) along them. (B.)

Experimental Cleavage.—Take a lump of clay and mix it up with bits of shellac, and then cut it across to make sure that the flat bits of shellac are scattered about it in all directions. Now place it in the pressure box, squeeze it flat, and again cut it through at right angles to the flattening. The scales will be found to have arranged themselves at right angles to the pressure and parallel to the axes of folding which would have occurred if the clay had been put in in layers. Clearly, the same pressure which produced the folding may produce the arrangement of particles which is to be found in cleaved slates.

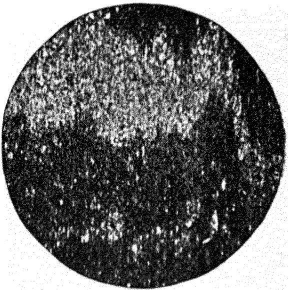

FIG. 85.—Microscopic section of a slate showing contorted bedding, and cleavage (upright), also elongation of particles along the cleavage planes (about $\frac{20}{1}$).

Occurrence.—As might be expected, cleavage is most perfect in close-grained homogeneous rocks, such as clays, and it is these which become most easily converted into roofing slates. In coarse-grained, hard rocks the cleavage passes into less regular fissures which tend to set themselves at right angles to the bedding. It is found to be best developed in ancient rocks which have suffered most from lateral pressure, and especially in regions of great movement and contortion. In England, rocks later than Carboniferous date are never cleaved, while it is only in South-west England and South Wales that rocks of Carboniferous and Devonian ages are ever cleaved. In Wales and in Cumberland, and a few other parts of England, well-cleaved slates are found amongst older rocks.

Joints

Structure.—While cleavage results from a new *grain* imparted to the rock by pressure, the structure called jointing is the occurrence of definite fissures or cracks, along which the rock is actually broken across, although it has usually not moved up or down along them. These fissures run generally at right angles to the bedding, and often in two sets at right angles to one another. The face towards the reader in Fig. 86 is formed of one such *master-joint*, and a second set of cracks runs back at right angles both to the stratification and to the first set of joints. Even when minor fissures are pre-

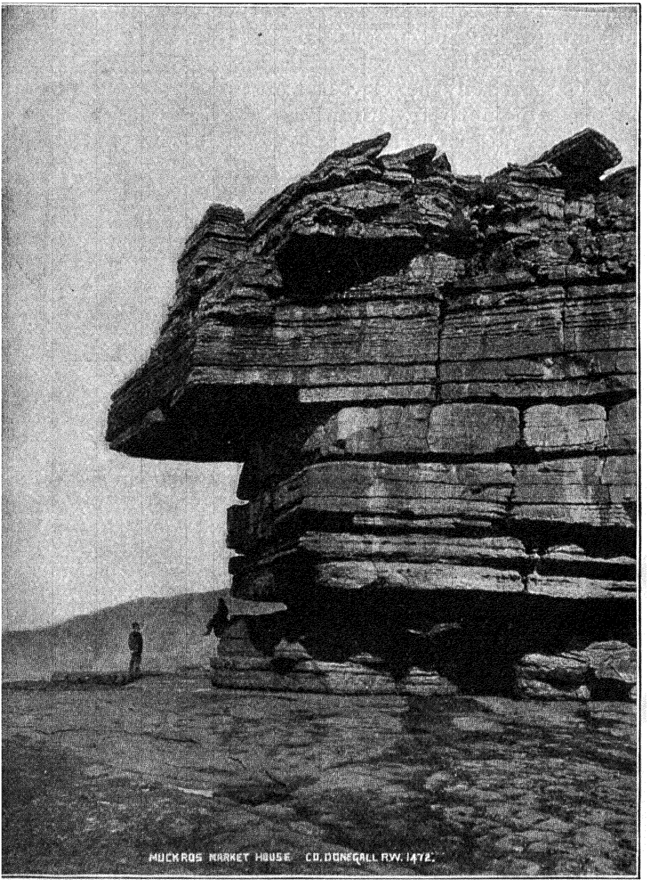

FIG. 86.—Carboniferous strata, Muckros, Donegal. To show bedding, lamination, and two sets of joints at right angles to the bedding and to each other. (From a photograph by Mr. R. Welch : copyright.)

sent the great sets of *master-joints*, as they are called, form rectangular sets, and by means of them and the bedding planes it is possible to excavate stone into roughly cubical blocks. This is well seen in a lump of coal. If split open along the bedding plane the surface soils the fingers. At right angles to this there is usually a bright, long joint, along which the coal breaks easily ; this is the *face* or cleat. At right angles to both comes the *end*, which is usually a much less perfect joint-plane. Comparing a set of strata to a pile of sandwiches, one set of joints is like a set of cuts with a knife dividing them into "fingers." A second set of cuts at right angles to the last would divide them into cubes or dice (see Figs. 15, 25, 40, 50).

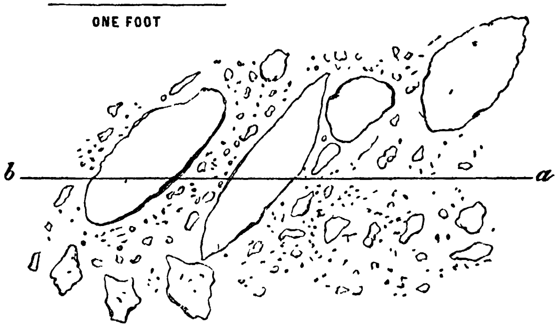

FIG. 87.—Joints (*a b*) cutting through the pebbles and matrix of a conglomerate. (B.)

Causes.—Some of the irregular joints are, doubtless, mere shrinkage cracks caused by the heating or drying of the rock. Similar fissures are seen in dried mud or starch. But that this is not the origin of those large rectangular fissures called master-joints is clear from the fact that hard pebbles and fossils are cut through by the joint-planes as readily as the matrix of the rock (Fig. 87, *a b*). Clearly, they must have been formed when the whole rock had been hardened, so that it was as easy to cut through pebbles as the sandy matrix. Further, master-joints, like faults, generally run in two sets—one in the same direction as the strike, and the other set in the direction of dip. This indicates a connexion with the causes which produce folding and faulting, and this is confirmed by the fact that joint faces are often slickensided, and show slight traces of movement and faulting. Although they have never been satisfactorily explained, joints are, doubtless, due to mechanical movement such as twisting, and the down-thrust and up-rise to which all rocks have been more or less subjected.

Experimental Joints.—A simple experiment which gives the best imitation of jointing that can be produced without elaborate apparatus is to fasten a glass microscopic slide on to paper with gum, and, when it is dry, to twist the two ends sharply in opposite directions with pincers or with the fingers protected by a cloth. Two sets of cracks roughly at right angles to one another and to the surface of the glass will be produced. Sharp joints very similar to these are frequently found near to faults, and where the rocks have been subjected to twisting and to severe and localised movement.

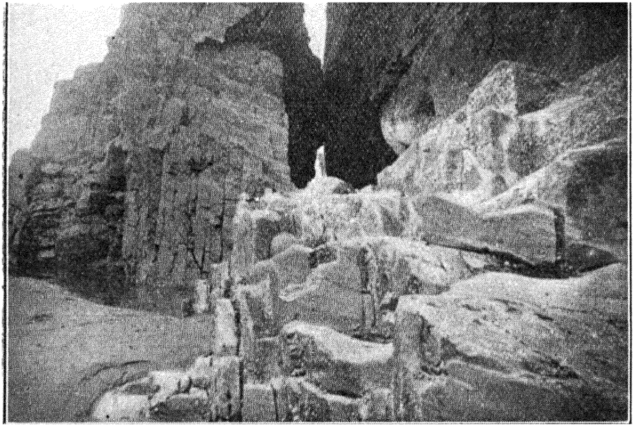

FIG. 88.—Joints in Lingula Flags near Criccieth, Carnarvonshire. The sea is excavating caves along these joint-planes. (From a photograph by Mr. G. T. Atchison: copyright.)

Occurrence.—Jointing is found in all rocks but the most modern, and it is of the highest value to the stone-mason and coal-miner in enabling them to extract blocks of stone and coal with the minimum of trouble and waste. They also are the planes of weakness along which denuding agents work in forming caves and valleys (Fig. 88). When stone is built into walls with joint faces outwards, it lasts much better than tooled stone.

RECAPITULATION

The *lateral pressure* to which rocks are subjected must result, when it is intense, in rupturing the strata, and making them slip and form *reversed faults.* The stretching felt locally during earth-movement will also give rise to normal or *tension-faults.* These structures are of considerable theoretical and practical importance in reading the succession of rocks in a disturbed district.

The movement sometimes makes itself felt in other ways, as in crushing whole masses of rock and making *crush-breccias* and *crush-conglomerates.*

Acting on shales, clays, or other rocks of even grain, the pressure may compel the fine flat particles to *rearrange* themselves so as to take up less room. The new grain thus given to the rock will allow it to split into thin leaves in the direction of the flat particles; this is *cleavage*, which gives rise to roofing slates.

Twisting, folding, and alternate up-and-down movement cause the formation of other planes of fracture, discontinuity, or weakness, which are known to quarrymen and geologists as *joints.*

QUESTIONS ON CHAPTER IX

1. What are faults? By what evidence may they be traced on the ground? (1885.)

2. (*a*) What is meant by the geological term "fault"?
   (*b*) Explain the "throw" and "hade" of a fault.
   (*c*) Draw a section to illustrate a normal fault.
   (*d*) Draw a section to illustrate a reversed fault. (1895.)

3. Draw a diagram showing trough-fault, inverted strata, and inlier. (1893.)

4. Explain the terms—dip, strike, cleavage, fault. (O and C.)

5. Show that the gradual subsidence of a large area of the earth's crust causes contortions, and that gradual elevation causes faults. (O and C.)

6. Faults are seldom apparent at the surface. Why is this? (O and C.)

7. Explain the terms bedding and cleavage. How would you distinguish these in rock? (1893.)

8. Describe the appearance of a bit of fossiliferous slate, and show how it has acquired its characters.

9. How are crush-breccias and crush-conglomerates formed?

10. Describe experiments to illustrate faulting, cleavage, and jointing.

11. What are joints? How are they caused? What is their effect in producing scenery? (O and C.)

CHAPTER X

MINERALS

Rocks Defined.—In Chapter II. it has been shown that granite is made of three different kinds of constituents, each of which is a crystalline mineral, while sandstone is made of minerals also, but each one is broken and rounded. Thus we may define each of these rocks as an *aggregate of minerals.* A rock like pure sandstone or limestone is composed of *one* mineral only, the former of quartz, the latter of calcite. More usually rocks, like granite and dolerite, are complex and composed of *two or more* minerals.

Chemical Facts.—The chemist finds that everything accessible to him in the earth's crust is made of one or more of a number of substances which he calls *elements;* these are the simplest substances he can obtain, and none of them can be split up further by chemical methods. Consequently they are called elementary substances or *elements.* All natural bodies consist of one or other of these elements, or of combinations of two or more of them. Thus iron, lampblack and diamond, gold, and silver are elements, brass and bronze are mixtures of two or more elements, and quartz, sugar, felspar, and glass compounds or mixtures of two, three, four, and more elements severally.

About seventy elements are known, but most of them are only found in very small quantities, and as a matter of fact only the following are at all common in rocks :—

Oxygen . .	47	Magnesium . .	2
Silicon . .	28	Sodium . .	2·5
Aluminium .	8	Potassium . .	2·5
Iron . .	5	Carbon, Chlorine and minor constituents	1·5
Calcium . .	3·5		

They are placed in order of abundance, and the approximate percentage of each in the earth's crust is indicated.

Elements and Compounds.—A few elements, such as carbon, sulphur, gold, and copper, sometimes occur uncombined as minerals, but the greater number of minerals found in rocks are compounds. The simplest compounds consist of two elements combined together. The *oxides* are formed from the combination of oxygen with some other element; examples are, oxide of silicon called silica, and the oxides of iron. The *sulphides* are compounds of elements with sulphur, such as sulphide of iron or lead; the *chlorides*, compounds of chlorine with another element like sodium.

Many of the elements have a bright, metallic lustre, are dense, hard, solid, and good conductors of heat and electricity. These are called *metals*, and their oxides are known as *bases.* The rest of the elements are known as *non-metals*, and their oxides are called *acid oxides.* Basic and acid oxides frequently combine together, forming compounds which contain three or more elements. Thus the non-metals, silicon, carbon, and sulphur, form acid oxides; and the metals, iron, calcium, magnesium, aluminium, and potassium, form the basic oxides known as oxide of iron, lime, magnesia, alumina, and potash respectively. The compounds of these two sets of oxides with one another are known as *silicates*, *carbonates*, *sulphates*, etc. Thus we have silicate of iron or alumina, carbonate of magnesia, and sulphate of lime.

Minerals as Chemical Compounds.—Most of the rock-forming minerals consist of oxides, chlorides, or sulphides, or of carbonates, sulphates, or silicates. The commonest of them, however, belong to the last class, and they are often complicated in composition, consisting of two, three, or even more basic oxides combined with the silica. Thus orthoclase felspar is a silicate of two basic oxides, alumina and potash. The determination of minerals by chemical analysis is therefore a long and difficult task, and it is in many cases needless, because each mineral has usually certain marked properties of its own by which it can be recognised with tolerable certainty.

Properties of Minerals

The chief of these properties are the following :—

1. Crystalline form.
2. Cleavage.
3. Hardness.
4. Specific gravity.
5. Lustre and feel.
6. Colour and streak.

Crystalline Form.—All minerals have a tendency to occur in a definite geometrical shape, which is known as a *crystal.* Now crystals may occur in hundreds of different shapes, but just as the millions of inhabitants of the world may be referred to one or other of five different races,—the black race, the yellow race, the red race, etc.,—so all crystals may be referred to half a dozen comparatively simple types. All crystals may be regarded as solid geometrical figures bounded by *planes* or *faces*, and although the size of the planes may vary, the angles between corresponding planes in different crystals of the same mineral are exactly the same. These geometrical figures may be represented by models in wood or glass, and then it is not difficult to regard them as built up on a simple scaffolding or framework of lines. For instance, if a cube is taken, and the centre point of each of its six faces marked, a knitting-needle may be driven through the centre points of each opposite pair of faces. Three knitting-needles will be required ; they will all meet at one point, and each one will be at right angles to both of the other pair. This will be the simplest form of scaffolding possible, and the three needles, which may now be called the *axes* about which the cube is built, will be all equal and all at right angles to each other. This defines one system of crystals, which may be called the *isometric* or *cubic system* because its three axes are equal and its simplest form is a cube (Fig. 89).

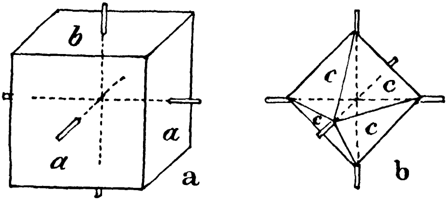

FIG 89 —The cubic system. a = a cube made of pinacoid faces (*a*, *b*) ; b = an octahedron made of pyramid faces (*c*)

Now, suppose the cube is stretched so that the topand bottom come farther apart, the other four faces will become oblong instead of square, and the needle parallel to them will be longer than the other pair, though all three will still be at right angles (Fig. 90, *a*). This defines a second type of system known as *tetragonal*,[1] in which the three axes are at right angles, but one is longer (or shorter) than the other pair (dimetric [2]).

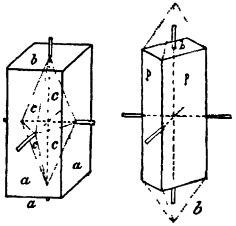

FIG. 90.—The tetragonal (dimetric) system. *a*, pinacoids (*a*) capped by base (*b*), pyramids inserted (*c*); *b*, a prism (*p*) capped by pyramid faces.

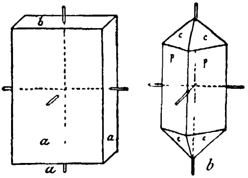

FIG. 91.—The orthorhombic (trimetric) system. *a*, pinacoids (*a*) capped by base (*b*); *b*, a prism (*p*) capped by pyramid faces (*c*).

Next stretch the cube also from right to left. The axes are still at right angles, but unequal (trimetric [3]), and all the faces have become oblong (Fig. 91, *a*). This is the *orthorhombic system.* Now distort the figure last produced by dragging one needle, and with it the faces parallel to it, so

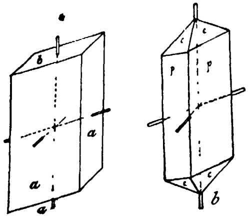

FIG. 92.—The monoclinic system. *a*, pinacoids (*a*) capped by base (*b*); *b*, a prism (*p*) capped by pyramid faces (*c*).

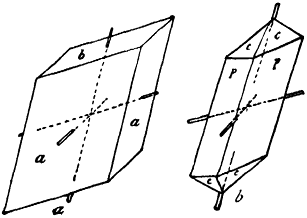

FIG. 93.—The triclinic system. *a*, pinacoids (*a*) capped by base (*b*); *b*, a prism (*p*) capped by pyramid faces (*c*).

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[1] Gr. *tetragonos* = four angled.

[2] Gr. *dis* = double, *metron* = a measure.

[3] Gr. *treis* = three.

that while it remains at right angles to one of the other pair of axes it is not at right angles to the other (Fig. 92, *a*). This is the *monoclinic*[1] *system*, with three unequal axes, one of which is not at right angles to one of the others. Lastly, distort the figure in the other direction also, so that no two axes are at right angles, and we have the *triclinic*[2] *system*, in which none of the axes are equal or at right angles (Fig. 93, *a*).

One other system remains, which is most simply expressed by four axes, three making angles of 60 degrees with each other, and in the same plane, and one longer or shorter than the other three, but at right angles to the plane containing them. This is the *hexagonal*[3] *system* in the dimetric group, which is best considered after the tetragonal system.

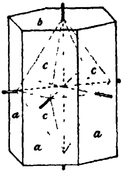

FIG. 94*a*.—The hexagonal system. Pinacoids (*a*) capped by base (*b*); a hexagonal pyramid (*c*) inserted.

In these imaginary experiments the axis which has been kept most nearly upright may be thought of as the *vertical* axis, and the planes parallel to it and to one of the cross axes are called *pinacoids*,[4] while that on which the figure rests is called the *base*, a name which may also be applied to the top plane parallel to it (see Figs. 6 and 7). If faces had been made by splitting off the edges where two pinacoids meet, they would be called *prism* faces (Figs. 90-93), while a pointed cap or pyramid-like roof built on the top or bottom of the figure would consist of *pyramid* faces (see Figs. 10 and 90-94). These four classes of faces are often present in crystals, and the result is that crystals are usually either column-shaped from the development of prisms, tabular from development of one pair of pinacoids or the base, or pointed from the predominance of pyramid faces. In all figures the pinacoids are marked *a*, the prisms *p*, the base *b*, and the pyramids *c*. It sometimes happens that minerals do not take any crystalline form, but occur in formless lumps, when they are said to be *amorphous*.[5]

Cleavage.—Crystals have a tendency to break, or *cleave*,

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[1] Gr. *monos* = single, *klino* = I incline.

[2] Gr. *treis* = three, *klino* = I incline.

[3] Gr. *hex* = six, *gonia* = angle.

[4] Gr. *pinax* = a plank, *eidos* = form.

[5] Gr. *a* = not, *morphe* = form.

as it is called, parallel to one or more important faces of the crystal, and this property often renders it easy to find out their crystalline systems. Thus orthoclase felspar is monoclinic, splitting parallel to the base and one pinacoid (see Fig. 6), two faces at right angles to one another, while plagioclase felspar, being triclinic, breaks parallel to the same pair of faces which are not at right angles in that system. Again, some minerals, like quartz, do not cleave at all, but break irregularly, while others of similar shape, like mica, cleave easily into thin plates parallel to the base (see Fig. 7). Cleavage shows that crystals are built up internally on some plan and so have a grain which corresponds to their external form, and this is borne out by such tests as that of polarised light, which reveal the internal structure.

Hardness.—If one substance is harder than another it will scratch it, and a scale of minerals may be arranged in which each member scratches the one below it, and is scratched by the one above it on the list. In this scale quartz (No. 7) is harder than steel, and scratches it, while a good knife will scratch felspar (6) with difficulty, and any knife will scratch apatite (5). An unknown mineral is tested until one mineral is found below it which it will scratch, and another above it which will scratch it, and thus its position on the scale is determined.

1. Talc.	Scratched with the finger-nail.	6. Felspar.	
2. Gypsum.		7. Quartz.	Not scratched with a knife.
3. Calcite.	Scratched with a knife.	8. Topaz.	
4. Fluor.		9. Corundum.	
5. Apatite.		10. Diamond.	

Specific Gravity.—The weight of a piece of a mineral compared with that of an equal bulk of water is called the specific gravity. This is often extremely useful, and in a rough way the weight in the hand is sufficient to distinguish minerals containing the heavy metals from the rest. Thus galena is readily distinguished from graphite,[1] and the heavy barytes[2] from calcite.

Lustre and Feel.—A mineral may look metallic and silvery, like galena or graphite, brassy like pyrites, pearly like mica or selenite, glassy like quartz, opalescent like opal, or iridescent,

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[1] Gr. *grapho* = I write.

[2] Gr. *barys* = weighty.

with a play of colours, like labradorite. Hydrous silicates of magnesia, like talc and serpentine, are greasy to the *feel*.

Colour.—Colour is very variable, and cannot be relied upon with any certainty. The green colour of chlorite, epidote, and olivine, the dark colours and opacity of iron ores, the pale colours of calcite and felspars, are all fairly characteristic. When drawn over unglazed porcelain some minerals leave a streak of colour, like graphite (black), hæmatite[1] (red), or copper pyrites (brown).

Characters and Classification of Minerals

Classification.—The following classification of the rock-forming minerals will be sufficient for the needs of this book:—

1. *Oxides* of silicon (quartz) and iron (magnetite and hæmatite).
2. *Chloride* of sodium (rock-salt).
3. *Sulphide* of iron (pyrites).
4. *Carbonate* of lime (calcite and aragonite), with magnesia (dolomite).
5. *Sulphate* of lime (gypsum).
6. *Silicates*—(*a*) anhydrous, such as felspar, mica, olivine; (*b*) hydrous, such as chlorite and serpentine.

Silica,[2] or oxide of silicon, occurs in the crystalline form of *quartz* as clear, transparent crystals belonging to the hexagonal system. These are usually made up of a six-sided prism, capped by a six-sided pyramid, as shown in Fig. 10. The prism may be long or short (see Fig. 94 *b*), or altogether absent, while certain sides may be more strongly developed than others. The prism faces are striated with fine, transverse lines, but the lustre of all faces is bright and glassy. There is no cleavage, the crystal breaking into irregular pieces, which are hard enough to scratch steel or glass (7 on the scale). The specific gravity is 2.7. The crystals are sometimes milky white, purple (when the crystal is known as amethyst), yellow, brownish

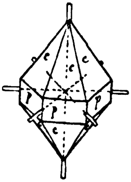

FIG. 94 *b*.—Crystal of quartz, made up of 6 prism faces (*p*), 6 pyramid faces (*c*) above and 6 below.

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[1] Gr. *haima* = blood.

[2] Lat. *silex* = flint.

(smoky quartz or cairngorm[1]), blue, or pink (rose quartz). The amorphous forms are known as opal, which has usually a beautiful play of colours; chalcedony,[2] milky and occurring in masses like a bunch of grapes; agate and onyx,[3] which are usually banded in different colours; jasper and bloodstone, opaque and tinted with shades of green and red; and flint and chert, which are dark in colour with a waxy lustre. Broken quartz-crystals are the commonest constituents of stratified rocks, and unbroken crystals occur embedded in some of the crystalline rocks or in the veins which traverse shattered rocks.

Oxides of Iron.—Of these *magnetite* and *hæmatite* are the commonest. The former belongs to the cubic system, and crystallises in octahedra (see Fig. 89*b*, p. 121). It is opaque and black, with octahedral (pyramidal) cleavage, hardness 5 to 6, heavy, specific gravity 5, metallic lustre, and black streak. It is magnetic, and attracts one end of a compass needle. *Hæmatite* is usually of blood-red colour, and its streak is always red. It crystallises in the hexagonal system in plates which have a bright silvery lustre, or else the crystals are bound together into kidney-shaped masses; the hardness is 5 to 6, and the specific gravity 5. *Limonite* is a yellow or red oxide of iron combined with water; it often forms the colouring matter of rocks. A compound of oxide of iron with oxide of titanium crystallises in the hexagonal system and is a common constituent of igneous rocks; it is called *ilmenite.*

Chlorides.—The commonest mineral of this group is *rock-salt*, a chloride of sodium which crystallises in the cubic system in forms the faces of which are frequently stepped. The cleavage is into cubes, the hardness very low (2), as crystals can be scratched with the finger-nail; the specific gravity is 2.3, the lustre glassy, and the colour from water-clear to blue or reddish.

Sulphides.—The chief of these is sulphide of iron or *pyrites*,[4] which crystallises in cubes with a bright brassy lustre; the cleavage is cubic and imperfect, the hardness 6, the specific gravity 5, the streak black; the mineral is opaque.

Carbonates.—The commonest of these salts occurring as minerals are the carbonates of lime and magnesia. *Calcite*[5] is carbonate of lime, crystallising in the hexagonal system usually in the form of a modified six- or twelve-sided pyramid;

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[1] Cairngorm, a Scottish mountain.

[2] Chalcedon, in Bithynia.

[3] Gr. *onyx* = a nail.

[4] Gr. *pyr* = fire.

[5] Lat. *calx* = lime.

but the peculiarity is, that in each case only half the full number of faces is developed, in the former case each alternate face, and in the latter alternate pairs of faces. The first form is called the rhombohedron, because the faces are rhombuses; the second the scalenohedron, because they are scalene triangles. In all cases the cleavage breaks the crystal up into rhombohedra, and the crystals cleave very easily. The hardness is 3, so that crystals are not scratched by the finger-nail, but very easily by a knife, the lustre is glassy or pearly, the specific gravity 2.7, and the crystals are colourless (Iceland spar), or of white or pale rose tint. The mineral occurs in veins in many kinds of rocks; it makes up the mass of limestones and marbles, and it results from the decomposition of other minerals in the basic crystalline rocks. Occasionally the carbonate crystallises in the orthorhombic system, or occurs in coral-like masses, when it is called *aragonite*.[1]

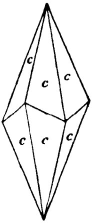

FIG. 94*c*.—A scalenohedron of calcite (dogtooth-spar).

When carbonate of lime and carbonate of magnesia are combined together the mineral is called *dolomite*[2] or pearl spar (from its lustre) which also crystallises in the hexagonal system and in rhombohedra. All carbonates are dissolved by hydrochloric acid with effervescence due to the escape of carbonic acid. Dolomite has a specific gravity of 2.9, and it only effervesces with strong acid, or when powdered; calcite or aragonite with dilute acid, and without being powdered.

Sulphates.—*Anhydrite*[3] is sulphate of lime, and *selenite* is the same compound combined with water. The latter crystallises in the monoclinic system, showing pinacoids, along which cleavage occurs, prisms, and other faces of roof-like type, which are known as *domes*. The lustre is pearly (hence the name, from Gr. *selene*, the moon). The hardness is low (2), the specific gravity 2.2, and the crystals usually colourless; two crystals are often so united as to form a shape like an arrow-head. Crystals are not uncommon in clays, and the amorphous or massive form is known as *gypsum*.

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[1] Named from Aragon in Spain.

[2] After Dolomieu the French geologist.

[3] Gr. *a* = not, *hydor* = water.

Silicates.—These compounds form the largest group of rock-forming minerals, and many crystalline rocks are mere aggregates of silicates. They may be broadly classified into three groups: *normal*, those in which the amount of basic oxide balances the acid oxide, silica; *acid*, in which silica is in excess; and *basic*, in which the basic oxide is in excess.

Felspar.—This is the most important group of rock-forming minerals as it occurs in almost all igneous rocks. Felspars are silicates of alumina combined with silicates of potash, soda, or lime, and form a connected series, one end of which is acid and the other basic, as is illustrated by the annexed table:—

Orthoclase [1]		Potash	Felspar	Acid	Monoclinic.
Plagioclase [2]	Albite [3]	Soda	,,		Triclinic.
	Oligoclase [4]	Soda-lime	,,	Normal	
	Labradorite [5]	Lime-soda	,,	Basic	
	Anorthite [6]	Lime	,,		

The two primary divisions of the felspars are the monoclinic and the triclinic. The cleavages, following a pinacoid and the base, are at right angles to one another in the first group, which is hence called *orthoclase* or straight-cleaving (see Fig. 6); but they are not at right angles in the second set, which are hence called *plagioclase*, or skew-cleaving felspars. Pinacoids, prisms, domes,[7] and bases are usually developed, the hardness is 6, so they are only just scratched by a knife of very good steel; the lustre is glassy, the specific gravity 2.6 to 2.8, and the colour white to pink or green. In the orthoclase felspars of igneous rocks a single divisional plane, called a twin-plane, divides the crystal into two distinct structural halves parallel to a pinacoid face (see Fig. 5); but in plagioclase there are many such planes, so that the prism, basal faces, and one pinacoid appear to be finely striated.

The Micas[8] are silicates of alumina with potash or magnesia. The potash micas are white and of normal composition, and the chief of them is called *muscovite;*[9] the

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[1] Gr. *orthos* = straight, *klasis* = breaking.

[2] Gr. *plagios* = askew, *klasis* = breaking.

[3] Lat. *alba* = white.

[4] Gr. *oligos* = small, *klasis* = breaking.

[5] From Labrador in America.

[6] Gr. *a* = not, *orthos* = straight.

[7] Lat. *domus* = a house (roof).

[8] Lat. *mico* = I glisten.

[9] From Muscovy (once called Muscovy glass).

magnesian micas are black and basic, and *biotite*[1] is one of the most important of them. They are really monoclinic, but they mimic the hexagonal system by crystallising in six-sided columns (see Fig. 7), which cleave very readily parallel to the base into six-sided, glittering, pearly leaves, that are flexible and elastic. Their hardness is low, about 2 to 3, their specific gravity 2·8 to 3, and they occur chiefly in the acid igneous rocks; flakes of them are common in sediments, and they form a most important constituent of the foliated rocks.

Hornblende[2] is a normal silicate of lime, iron, and magnesia. It is monoclinic, the crystals being usually long six-sided columns, which are black, brown, or green; the hardness is 5 to 6, the specific gravity 3.2, and the lustre horny, while the two planes of cleavage make an angle of about 120° with one another. Actinolite[3] is a fibrous and asbestos[4] a thread-like variety of hornblende. Hornblende is more common in acid and intermediate rocks than in basic rocks, and is also frequent in foliated rocks.

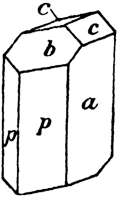

FIG. 94*d*.—A crystal of hornblende. *a* = pinacoid, *p* = prisms, *b* = base, *c* = pyramids.

Augite[5] has practically the same composition as hornblende, crystallises in the same system, and has about the same colours, specific gravity, and hardness. The crystals are, however, generally more stumpy, eight-sided, with glassy lustre, and the two cleavage-planes, parallel to the prism-faces, make an angle of almost 90°. It is common in basic crystalline rocks, and is not often associated with quartz.

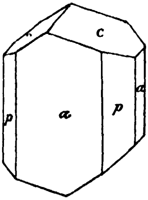

FIG. 94*e*.—A crystal of augite. *a* = pinacoids, *p* = prisms, *c* = pyramids.

Olivine is a basic silicate of magnesia with some iron, crystallising in the orthorhombic system; it has no cleavage and a glassy lustre, so that it looks at first like quartz, but is distinguished by its beautiful olive-green colour, whence its name, its more ready decomposition, its specific gravity 3.5,

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[1] From Biot the French mineralogist.

[2] After its horny lustre.

[3] Gr. *aktis* = a ray, *lithos* = a stone.

[4] Gr. *asbestos* = inconsumable.

[5] Gr. *auge* = lustre.

and its hardness, which is 6. It occurs in basic rocks (see Fig. 9).

Silicates of Alumina.—A group of minerals having this composition occurs in the metamorphic rocks. They differ from one another in composition and crystalline form, but are all basic in composition. As a type andalusite[1] and chiastolite[2] may be taken; they are both orthorhombic, and they occur in foliated rocks, and in sediments metamorphosed by heat; they frequently contain abundant inclusions of impurities arranged parallel to the axes or outlines of the crystal.

The Garnets are composite silicates of lime, alumina, iron, etc., which crystallise apparently in the cubic system in twelve- or twenty-four-sided forms. They are red or green, and have a hardness of 7.

The Hydrous[3] Silicates are usually formed from the decomposition of ordinary silicates, and are common in crystalline rocks, especially in the more ancient ones. *Chlorite*[4] is a green hydrous silicate of alumina, iron, and magnesia, crystallising in the monoclinic system; *serpentine* a hydrated silicate of magnesia, usually amorphous, and green, yellow, or red; and the *zeolites*[5] form a great group of silicates of many bases, which are usually white in colour, and fuse readily under the blow-pipe. Hydrated magnesian silicates like talc and serpentine usually have a soapy feel. *Kaolin* is a hydrated basic silicate of alumina.

RECAPITULATION

All *rocks*, of whatever kind, are *aggregates of minerals*, which in turn are either chemical elements, or, in the majority of cases, chemical compounds.

Some of the minerals are compounds of two elements, generally a metal with a non-metal, such as the sulphides and chlorides; the more important rock-forming minerals are either *oxides*, like silica and magnetite, or *compounds of basic and acid oxides* like the silicates and carbonates.

While the chemistry of mineral compounds is complicated and

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[1] From Andalusia.

[2] Gr. *chiastos* = marked with letter χ, *lithos* = a stone.

[3] Gr. *hydor* = water.

[4] Gr. *chloros* = green.

[5] Gr. *zeo* = to boil.

difficult, each mineral has usually some *physical properties* by which it may be readily recognised. Such properties are the form, cleavage, internal structure as revealed by polarised light, hardness, specific gravity, lustre, feel, colour, and streak.

All crystalline minerals have shapes which conform to one or other of six systems of form called *the crystalline systems.*

The silicates include the *felspars*, recognised by their colour and cleavage; the *micas*, by their cleavage, softness, and elasticity; *hornblende* and *augite*, hard dark minerals, discriminated by their lustre and cleavage angle; *olivine*, by its olive colour and absence of cleavage; and the *garnets* and hydrous silicates.

QUESTIONS ON CHAPTER X

1. What are elements, oxides, acids, and bases? Give examples of each, occurring as minerals.

2. Enumerate the principal characters by means of which minerals may be recognised.

3. Draw rough figures of one example belonging to each of the crystalline systems.

4. How does a "mineral" differ from a "rock"? Mention three examples of each (1888.)

5. Write the names of the six elements which are of most importance in forming the known crust of the earth, giving two examples for each element of minerals or rocks containing it. (1884.)

6. Write the names of six simple minerals which are of importance in the composition of rocks. (1887.)

7. Name six of the chief rock-forming minerals. Under each name give an example of a rock in which the mineral largely occurs. (1882.)

8. How would you distinguish between calcite and felspar? How do these minerals originate? (1894.)

9. How would you distinguish quartz from felspar, hornblende from augite, olivine from serpentine, garnet from magnetite?

10. State the chemical composition, the crystalline system, and the specific gravity of the following common rock-forming minerals:—

    (*a*) Quartz.
    (*b*) Orthoclase felspar.
    (*c*) Augite.
    (*d*) Magnetite. (1896.)

11. State what you know about the mineral mica.
    Name two igneous rocks in which mica is found.
    Name two metamorphic rocks in which mica is found.
    Name two aqueous rocks in which mica is found. (1897.)

CHAPTER XI

SEDIMENTARY ROCKS

Classification

THE great group of Sedimentary Rocks comprises all the fragmental or clastic rocks which are made of broken rocks, minerals, or organisms, together with a few others which are not, strictly speaking, of clastic origin. The clastic rocks contain no unbroken minerals except those, generally in the cement, which have formed subsequently to deposition. The other sediments usually contain unbroken crystals, and are sometimes entirely made up of them. Sedimentary rocks are divided into three classes according to their method of formation, and each class is subdivided into minor groups :—

Mechanically formed	Arenaceous[1]	Sandy and pebbly rocks
	Argillaceous[2]	Clays and shales
Organically formed	Calcareous[3]	Limestones
	Ferruginous[4]	Ironstones
	Siliceous[5]	Flints and cherts
	Carbonaceous	Coals
Chemically formed	Carbonates	Limestones
	Sulphates	Gypsums
	Chlorides	Rock-salt.

Mechanically-formed Rocks

The mechanically-formed rocks are made of large or small pieces of other rocks, either simply broken off, or obtained after decomposition or disintegration has taken place. The coarser are called arenaceous rocks, or psephites[6] (pebble-rocks), and

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[1] Lat. *arena* = sand.

[2] Lat. *argilla* = clay.

[3] Lat. *calx* = lime

[4] Lat. *ferrum* = iron.

[5] Lat. *silex* = flint.

[6] Gr. *psephis* = a pebble.

psammites[1] (sand-rocks), and the finer ones argillaceous rocks, or pelites[2] (clay rocks).

Arenaceous Rocks.—*Breccia*[3] is a coarse rock made of sharp-edged or angular pieces of stone, which have been simply broken from some other rock and cemented together by a paste of fine mud or sand, or by a deposit of carbonate of lime or some other chemical substance (Fig. 95). The fragments have been broken by frost or percussion, but have not been worn or rounded during transport. A talus broken from a cliff by frost, or subsoil broken by frost from the solid rock below the soil, would give typical examples of *breccias* when cemented. Also the blocks broken from cliffs by the sea, if not worn and rounded before being cemented into a solid mass, would give rise to a *breccia*. If frost-broken blocks fall upon a glacier they may be carried a long distance, and this is almost the only way in which fragments can be transported far without losing their sharpness. Such blocks, shot down on the moraine at the end of the glacier amongst the mud and sand carried by the glacier and its stream, will form a *moraine breccia*. Again, the rock broken up by force exercised in faulting often fills the fissure with *fault-breccia*, and occasionally considerable masses are broken to bits by this action, and form a crush-rock or *crush-breccia* (see p. 110). Breccias are of much use in determining the place where frost or ice have acted in time past, or to indicate where the rocks have been submitted to great crushing force. (See also p. 152.)

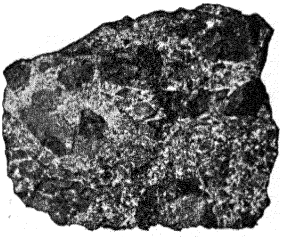

FIG. 95.—Breccia of flint fragments, Selsea, Hants (about $\frac{1}{6}$).

Conglomerate.—When coarse fragments are worn and rounded they become pebbles, and if cemented together they form a conglomerate (see Fig. 2). The pebbles may be derived from any kind of pre-existing rock, granite, or other crystalline rock, sandstone, quartzite, or even another con-

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[1] Gr. *psammos* = sand.

[2] Gr. *pelos* = clay.

[3] Italian *breccia* = rubbish (of broken walls), pronounced bréchia.

glomerate. Sometimes pebbles are broken out, as pebbles, from a pre-existing conglomerate. Between the interspaces of the larger pebbles occur smaller and smaller ones, and usually a still finer matrix of sand or mud. Only very exceptionally do large pebbles occur in a fine matrix, the pebbles generally graduating down into the matrix. The cement may be sand or mud, carbonate of lime, silica, oxide of iron, and many other substances. As pebbles are formed on the sea-beach or in river-channels, conglomerates will be formed from cemented sea-shingle or river-gravels, and in the deposits of deltas and shore-lines; indeed they will always indicate that they were formed in the shallow water of rivers, lakes, or seas. Pebbles may occasionally be carried some distance from the shore by powerful marine currents. Conglomerates occur in wedge-shaped masses, not regular beds, and they are usually false-bedded. Occasionally the pebbles in a conglomerate are found to be encrusted with marine organisms, but fossils are not common, except when the pebbles are broken from a fossiliferous rock, and the fossils occur inside the pebbles. Such fossils are obviously older than the conglomerate and are spoken of as *derived fossils.* They are of great use in ascertaining the particular rock from which the pebbles have been broken, and those which were undergoing denudation at the time the conglomerate was being formed. In Fig. 96 there is a pebble of crinoidal limestone which has certainly been derived from the Carboniferous Limestone. Somewhat rarely conglomerates are formed by crushing, when the crushed fragments are rolled round and worn during the movement of the rock. *Crush-conglomerates* are usually made of large fragments belonging to one or two types of rock only, embedded in a fine matrix, which shows signs of kneading, crushing, and movement (see p. 111).

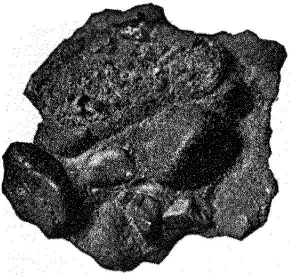

FIG. 96.—Conglomerate containing a pebble of crinoidal Carboniferous Limestone (from the collection of H.M. Geological Survey), about ¼.

Sandstone.—This rock has already been partly described. It consists of rounded grains of quartz, felspar (see Fig. 11), augite or hornblende, with tourmaline, rutile, zircon, and many other minerals, together, usually, with flakes of mica and minute fragments of close-grained rocks. Green-sands and green sandstones usually contain irregular grains of a green silicate of iron called glauconite, mixed with the sand-grains. Sandstones are classified according to their cements into calcareous, dolomitic, ferruginous, or siliceous sandstones, and the colouring matter, which usually varies from white through grey, to yellow, brown, or red, is often due to the amount of compounds of iron contained, and the state of their oxidation or hydration; in some cases the amount of iron in the cement warrants the working of the stone for iron-ore. Sands are now forming in river-beds and deltas, and on the shallow sea-bed, so that sandstones must have originated under similar conditions. The beds are not so irregular as those of conglomerates and breccias, but, when traced far enough, they are seen to thicken in one direction and to thin in another, so that they are wedge-shaped or lens-shaped. Sandstones are generally laminated and frequently false-bedded, showing that they have been laid down in shallow water disturbed by currents; this is borne out by the occurrence of ripple-marks, tracks of animals, and occasionally by sun-cracks (see Fig. 51) and rain-prints.

When sand-beds have no very marked bedding, but can be cut easily into blocks for building, they are called *freestones*, but when they split easily into great slabs along the bedding, which is especially the case when there are flakes of mica deposited on these planes, they are worked for flagging and are called *flagstones*. The Old Red Sandstone of North Scotland and the Carboniferous sandstones of Yorkshire yield excellent flagstones. If the sand is mixed with clay and consolidated by pressure only, it is easily washed down into mud, and is locally called *mudstone*. An ill-consolidated argillaceous sand is called a *loam*. When the sand-grains are angular and sharp-edged the rock is called a *grit*. Some of the older grits are made chiefly of bits of felspar and felsitic rock, and are much hardened; they are called *greywacké*.

Fossils are not uncommon in sandstones, particularly in those with a calcareous or ferruginous cement, but where the texture is very open the organic remains have often been dissolved.

Argillaceous Rocks.—The basis of these sediments is pure china-clay or kaolin, a silicate of alumina hydrated, that is, containing much water in its composition; but this is mixed with various impurities, and coloured by iron salts and organic matter. Sometimes *clays* are massive and not laminated (see Fig. 12), but usually they are finely laminated or banded, in thin layers which easily split apart; they are then called *shales* (see Fig. 16). In some shales there are as many as a hundred of these thin laminæ in an inch. One lamina differs from another slightly in colour or composition, and the parting planes are frequently sprinkled with fine flakes of mica. False-bedding is unusual in clays and shales, which show all the signs of slow and quiet deposition in moderately deep water, either in lakes, flood-plains and deltas of rivers, or the sea-bed. For this reason beds of clay spread over a large area are very even in thickness, and only thin out very slowly. They usually pass in one direction into sandstones and in the other into limestones. Pure white clays suitable for pottery and pipe-making are called *china-clays* and *pipe-clays;* those devoid of lime and alkalies *fire-clays*, because they will stand very great heat without fusing or losing their shape. A pure clay which falls to pieces in water is called *fuller's earth*, and is used for cleansing cloth and taking the grease out of it. *Till* and *boulder-clay* are clays deposited by ice, which are stuffed full of boulders of stone (see Fig. 281). When hardened by compression and cleaved clay-rocks pass into *slates.*

Clays and shales generally contain fossils, which at times are flattened out along the planes of lamination; very often only the pearly interior of the shells is preserved, the outer part having been dissolved away, and some clay-fossils preserve traces of the original colouring of the shell. It is not unusual to find certain shells in the position of growth, particularly those which burrow into the sea-bed or stand upright upon it.

Organically-formed Rocks

The organically-formed rocks are made from the remains of once living organisms which have parts sufficiently hard to contribute to the making of rocks.

Calcareous Rocks.—The *limestones* consist chiefly of carbonate of lime, with varying amounts of such impurities as clay or sand. Many organisms build shells or skeletons of carbonate of lime, and where these live abundantly in a sea or lake their remains accumulate at the bottom as masses of limestone. Foraminifera (see Figs. 14 and 52), corals, crinoids or sea-lilies (see Fig. 13), echinoids (or sea-urchins), crustacea, mollusks (or shell-fish)—all have skeletons or shells of carbonate of lime, and many limestones are made of them. The sea-weeds (*algæ*), called nullipores, also form limestone masses. Some of these organisms live in moderately deep water, but most of them where the water, whether deep or shallow, is clear and free from sand and mud; hence limestones do not contain much sandy or muddy impurity.

Chalk is a soft, white, earthy limestone containing abundant tests of foraminifera; the Carboniferous Limestone is in places made up entirely of crinoid stems and plates; in other places it is made of coral blocks and débris, as the Wenlock and other limestones are. Some Tertiary limestones are made of fresh-water and land snails; the Red Crag of broken marine shells. Many of the Secondary and some other limestones are *oolitic*, that is, they are made of a number of minute grains, about as big as the head of a small pin, put together so that the rock looks like a bit of fish-roe (see Fig. 226); hence it is called roe-stone or oolite.[1] Oolites are sometimes false-bedded; their character and mode of origin will be explained later on (see p. 272). *Marls* are mixtures of clay and calcareous matter. Limestones occur in far-reaching sheets, not usually laminated and rarely false-bedded. This structure, however, occurs at times in oolitic limestones, in coral deposits, and in some shelly limestones. Limestones, being made up of fossils, yield them abundantly, but the better specimens are found in impure and clayey examples, where the impurity washes or weathers away. Where the stone has been long exposed to the action of the weather in old walls or the spoil banks of quarries, beautiful examples of fossils may often be found.

Ferruginous Rocks of organic origin are made generally of carbonate of iron, and they are usually limestones in which the carbonate of lime has been wholly or partially replaced by carbonate of iron (see p. 271 and also p. 141).

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[1] Gr. *oon* = egg, *lithos* = stone.

Siliceous Rocks.—Radiolaria and sponges are the chief animals, and diatoms the chief plants, which build skeletons of silica. In many limestones and some sandstones layers and nodules of *chert* and *flint* are found. They are black, brittle rocks, with a conchoidal or hackly fracture, and microscopic examination reveals that, though a great deal of secondary silica has in most cases been deposited after the rock was formed, the original constituents were spicules of sponges or tests of radiolaria. *Tripoli*, *infusorial earth*, and mountain meal, are incoherent deposits made out of the siliceous remains of diatoms.

FIG. 97.—Peat bog at Armoy, Antrim, with roots of trees *in situ*. (From a photograph by Mr. R. Welch : copyright.)

The Carbonaceous Rocks are made up chiefly of carbon combined with oxygen, hydrogen, nitrogen, and a certain amount of earthy matter which is left behind as ash when the rocks are burnt. The more purely carbonaceous of these rocks are burnt for fuel. *Peat* is the best example of the formation of such a rock at the present day. It is made of the stems, leaves, roots, and other parts of mossy plants, only slightly altered by the process of decay, so that some of the gaseous elements, oxygen and hydrogen, have escaped, and a higher proportion of carbon remains. As a small lake or pond becomes silted up, the mosses and other plants gradually encroach on the narrowing area of water; when they die down, new generations grow on the top, and the under part slowly becomes converted into peat, which, in course of time, fills up the lake (see Fig. 97). *Lignite*[1] or *brown-coal* represents the next phase. It is evidently made up of fossil wood, as the microscopic structure and sometimes the fibrous character of the wood in it are preserved; but a larger proportion of gaseous elements has been eliminated. *Coal* is the next stage, and in that the original woody structure has generally been perfectly destroyed. Microscopic sections sometimes reveal traces of woody fibre, bark, and, as in the section given in Fig. 98, spores of plants, which are found to be allied to the ferns, horse-tails, and club-mosses.

FIG. 98.—Microscopic section of coal showing macrospores (from the collection of Mr. E. T. Newton), about $\frac{8}{1}$.

Chemical Character.—The annexed table shows the gradual change in composition as we pass from wood to peat, thence to lignite, household coal, and *anthracite*.[2] As the gaseous constituents disappear the amount of carbon increases relatively, and in anthracite, the most stony coal, the amount of gas is very small.

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[1] Lat. *lignum*=wood.

[2] Gr. *anthrax*=carbon.

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
Peat	54	5	31	10
Lignite	67	6	24	3
House Coal	78	6	14	2
Anthracite	91	3	4	2
Graphite	98-99	...	...	2-1
Cannel	67	8	12	13

Microscopic Aspect.—As the chemical composition changes so does the microscopic aspect, and in anthracite the vegetable structure is entirely destroyed. Coal appears to have been produced by the growth of plants whose remains have gradually become mineralised when buried up in sediments, and the greater the mechanical movement the rock has undergone, the further it is changed towards anthracite. In very highly disturbed districts graphite, a pure carbon, is found, and this may represent the last stage in the transformation when all the gases have been eliminated.

Field Relations.—Coal is usually found resting on an *under-clay* or "seat earth" which has the composition of fire-clay and the character of the soil of a river delta. The fossil trees of the coal are frequently found erect, and they send down rootlets which penetrate the fire-clay (Fig. 99). Many coals have doubtless originated by the growth of forests on the spot where they now stand; after centuries of growth they have been buried up by beds of sand when the delta subsided and its surface was again covered with water. When numerous coal-seams occur one above another this process must have been repeated again and again; in some cases dozens of times. Here and there old sandbanks occur in coal-seams marking the course of muddy streams through the swamp (see also p. 255).

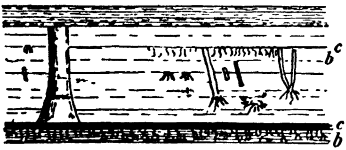

FIG. 99.—Section of sandstones with coal-seams *c*, trees and fire-clays *b*, or under-clays penetrated by rootlets, Nova Scotia. (After Sir J. W. Dawson.)

Method of Origin.—*Coal* is the result of the growth of vegetation on the low swamps and flood-plains near the mouths of rivers and on the delta deposits at the mouth. Deltas, such as those of the Ganges, have great forests and jungles upon them, and these in some ways appear to recall the conditions which must have prevailed during the deposit of the coal-bearing rocks. The cypress swamps of Virginia, the "sunk country" on the Mississippi delta, the forests of the Amazon, and the mangrove swamps of tropical countries, all probably give some clue to the geography of the Epoch when the great coal-seams were being formed.

In peat bogs an *iron ore* is sometimes found. It is due to accretion from water round minute diatoms, which fall to the bottom after their death and make a kind of clay ironstone. The occurrence of a similar clay-ironstone in beds of clay associated with coal-seams is rather suggestive.

Cannel coal is dull and lustreless, and it shows very little vegetable structure; it sometimes contains fossil fishes and shells, and passes at its edges into bituminous shale, which is merely clay loaded with plant remains. These facts indicate that cannel is not formed by the growth of vegetation in place, but by the drifting of it into ponds. This conclusion is borne out by the composition of cannel. It contains so large an amount of inflammable gas that it will kindle at a candle; this would have escaped had the decomposition taken place in the air, but would remain in vegetable matter decomposing under water; while its proportion of ash, so much larger than that of other coals, indicates that mud and sand were washed into the pools together with the rotting vegetation.

Chemically-formed Rocks

Occurrence.—There are sometimes found interbanded with marls, clays, sands, and other sediments, beds of rock which show no clastic structures, but are made up of crystalline material. Some limestones show this character, and also certain dolomites, gypsums, and rock-salt. Such deposits are frequently unfossiliferous, and it is quite certain that rocks of this group owe little or nothing to organic remains. The substances of which the rocks are composed are, however, commonly found dissolved in small quantities in fresh water (carbonates of lime and magnesia, and sulphate of lime), and in larger quantities in salt water (sulphate of lime and salt), especially in that of salt lakes. All that is required is that the solvent should be evaporated, and the dissolved constituents will crystallise out and fall to the bottom.

Chemical Deposition.—In the case of springs laden with carbonate of lime or magnesia this happens readily when the spring reaches the open air; carbonic acid escapes, and carbonates of lime and magnesia—no longer soluble in the water now it is free from carbonic acid—fall to the bottom. Petrifying [1] springs are well known; they deposit their carbonate of lime round twigs, moss, or any other objects placed in them. On a larger scale, as in Central France or Rome, they deposit considerable masses of crystalline carbonate of lime, called *travertine*, which harden, and are often used for building-stones in Rome.

To bring about the deposition of sulphate of lime and salt it is requisite that the *water* should be evaporated, but this can never take place to a sufficient extent in the open ocean. But when rivers in hot climates pour into inland lakes, from which the surplus is removed by evaporation alone, it is only the pure water which escapes as vapour, the saline substances being left behind. This goes on year after year until the water becomes perceptibly salt, and at last quite briny, as in the Great Salt Lake and the Dead Sea. When the amount of dissolved matter becomes larger than the water can carry, it is deposited, and falls to the bottom among the sediments. Large quantities of gypsum (sulphate of lime) and rock-salt (sodium chloride) have been thus deposited on the bed of the Dead Sea.

The presence of this class of deposit indicates that the strata have been laid down in inland salt lakes, whose waters have been highly concentrated in a dry climate. Intensely briny water is most unsuitable for the life of organisms, as seen in the Dead Sea and the Great Salt Lake, and while fossils are very scarce in the sediments associated with gypsum and rock-salt, they are almost entirely absent from the chemical deposits themselves.

Carbonates.—Carbonate of lime is sometimes deposited

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[1] Gr. *petros* = a rock.

in lakes, but more commonly in springs and streams. *Travertine* (see p. 40) is a chemical deposit thus formed. In certain lakes a mixed deposit of carbonates of lime and magnesia occurs, and may form magnesian limestone or even *dolomite*. The proportions of the two constituents vary very much. The rock is often curiously false-bedded, crystalline in structure, and full of concretions of crystalline calcite or dolomite. It generally contains few fossils, and when quite pure, none at all. Such fossils as do occur possess thickened, stunted, and dwarfed shells, as though they had lived under conditions highly unfavourable to them (see Figs. 213, 214).

Sulphates.—Of these the chief is sulphate of lime or *gypsum*.[1] This is now being deposited in many inland lakes, and especially in and about the Dead Sea. It usually occurs in irregular patches in marls and clays, and is quite devoid of fossils. Alabaster is a pure form of gypsum.

Chlorides.—Sodium chloride, table salt or *rock-salt*, is the commonest of this group. It is one of the most abundant salts in sea-water and in the Great Salt Lake, giving the waters their briny taste. It is found in beds of marl, is crystalline in structure, and quite devoid of fossils. Chlorides of magnesium and potassium are sometimes found in association with it.

Silica.—Hot springs deposit silica round their vents in the form known as *sinter*, sometimes forming a considerable rock mass.

Red Rocks.—The marls, clays, and sandstones interbedded with chemical deposits are often stained deep red from the deposit of hydrated oxide of iron amongst them. This is also probably due to concentration and the deposition of salts of iron in the inland seas.

RECAPITULATION

The Sedimentary rocks may be best classified according as they were formed *mechanically*, *organically*, or *chemically*.

The mechanical group is again divided according to the *coarseness* or *fineness* in the *grain* of its constituent rocks, and still further by their exact method of *origin*, or the nature of the *cement* which binds the particles together. Thus we have breccias, conglomerates, sandstones, grits, clays, and shales with all their varieties.

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[1] Gr. *gypsos* = chalk or gypsum.

The Organic rocks are best divided according to their *chemical composition*, the animal or plant remains which contribute to their formation, and the parts of the sea-bed or land-surface where they originated. Thus we have the calcareous rocks or limestones, the ferruginous rocks including the ironstones, the siliceous rocks and the carbonaceous rocks, coal and peat.

The chemically-formed rocks were made by *precipitation* or *reaction*, and they are best classified according to their composition. Many of them originated in *inland salt lakes*.

QUESTIONS ON CHAPTER XI

1. In what ways may breccia be formed? (1893.)

2. What is conglomerate? Compare it with breccia, and state what each proves. (1887.)

3. On what ground are aqueous rocks divisible into those of (*a*) mechanical, (*b*) chemical, and (*c*) organic formation? Name two rocks in each group, and describe them chemically and physically, and say where they may be found *in situ*. (O and C.)

4. Give a brief account of the ways in which stratified rocks have been formed, and of the materials from which they have been derived. (O and C.)

5. What is sediment, and how have sedimentary rocks been formed? (1881.)

6. What is a sandstone? How has it been formed? (1886, etc.)

7. What is grit? How has it been formed? (XII.)

8. Explain the difference between "slaty cleavage" and "flaggy structure." Give an example of the latter. (1881.)

9. What is the difference between slate and shale? (1888.)

10. Define shale, slate, and flagstone, and explain their origin. (1879.)

11. Describe the mode of formation of limestone rocks. (1888.)

12. Define and classify the following rocks: chert, breccia, conglomerate, sandstone, dolomite, marl, mudstone, shale, travertine. (XII.)

13. Briefly describe some rocks which are mainly of organic origin. (1885.)

14. Mention the main differences between clay, marl, and loam. (1887.)

15. Point out some important examples of accumulations now forming in consequence of organic agencies, and mention cases to prove that such agencies have operated extensively in former geological periods. (O and C.)

16. What is peat? Under what conditions is it formed? (1882.)

17. Describe peat, and state the conditions under which it may be formed. (1892.)

18. Describe the characters and probable mode of formation of peat coal, and anthracite. (1883.)

19. What is peat, and how is it formed? (O and C.)

20. Enumerate the different kinds of deposits that may be formed in lakes. (O and C.)

21. To what is the colour of red rocks generally due? (1888.)

22. Describe the origin of rock-salt. (1881.)

CHAPTER XII

VOLCANOES

THE *crystalline rocks* which we studied in the second chapter are very different from those which have been proved to originate as sediments, in the fact that all their chief constituents are either uninjured crystals or else crystalline material which has never been worn or rounded. We came to the conclusion that they must have been formed by some process which allowed crystallisation to take place. Now there are three ways in which crystals may be easily formed—sublimation, evaporation from solution, and solidification from fusion. Three simple experiments will illustrate these methods.

Experiments on Crystallisation. — Take a little ammonium chloride and heat it in a test-tube. It will gradually disappear, being changed into vapour. Some of it will settle again as a white ring on the cold part of the tube. On examination with a lens this will be found to be crystalline. This is an example of *sublimation.* Dissolve some sulphate of soda or carbonate of soda in water (ordinary washing soda will do perfectly), and then put it in a warm place, and suspend a crystal of soda in it by a piece of string. Leave it for a few days, watching it day by day. The string will become coated with crystals deposited from the solution as the water gradually disappears by *evaporation.* A third experiment is to melt some bismuth in a ladle and let it cool. When the crust has solidified a hole is made in it, and the rest of the liquid contents emptied out. The crust is then broken up, and on examination its under side will be found to consist of beautiful step-like crystals of metallic bismuth. This is crystallisation from a state of *fusion.* The crystals of rocks are hardly likely to have been formed by sublimation or evaporation, as they are not volatile like ammonium chloride, or soluble in water like soda, so it is more probable they may be the result of deposit from a state of *fusion*.

Now fused rock is poured out in a red-hot, fluid state by volcanoes, so that it will be advisable to look at the products of active volcanoes in order to see if we can learn anything about the origin of crystalline rocks.

Definitions.—Volcanoes are conical mountains ending at the top in a cup-shaped hollow called the *crater*.[1] From the bottom of the crater a fissure runs down into the interior of the earth, and from it escape vast volumes of steam, accompanied by stones, ashes, and dust, and sometimes by a current of white-hot molten stone called *lava*, which wells up in the crater and flows from the side of the cone. Steam escapes at nearly all times from the craters of active volcanoes, but especially is this true when great eruptions occur. Then, not only from the crater itself, but from numberless fissures in the side of the cone, enormous volumes of steam shoot up into the air, and all the time lava is flowing it is enveloped in a cloud of steam which rushes up from it. Steam, therefore, has evidently much to do with volcanic action, and it will be well to study first the operation of steam alone. This may be done in Iceland, or the Yellowstone Park in the Western States of America, where the hot springs known as *geysers*[2] are to be seen in full activity.

Types of Volcanic Action

Geysers.—These occur in old volcanic districts where the ground a little way below the surface is still intensely hot, so that the water which trickles into the rock fissures becomes much heated, and is finally converted into steam. From some of the fissures steam, accompanied by boiling water and fragments of rock, is blown high into the air at certain intervals. Then a rest occurs, of longer or shorter duration, and at the end of it a new and similar eruption takes place. Round the top of the fissure there is usually a basin-like depression or crater in which some of the water rests between times, and this is encrusted with silica deposited from solution by the boiling water

[1] Gr. *crater* = a cup or bowl.

[2] Icelandic = *a roarer*.

as it evaporates and cools. In the famous hot springs of New Zealand beautiful terraces of white, pink, and rose coloured siliceous deposit called sinter were formed in this way, but they were destroyed by a renewed outbreak of volcanic activity in the year 1886. Several famous geysers occur in Iceland, one of which can be hastened into eruption by throwing clods into it. Others occur in the Yellowstone Park of the United States. They all appear to be due to a similar cause, the gradual heating of water in the cracks of rocks until a sufficiently high temperature is reached to generate steam.

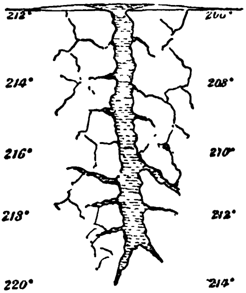

FIG. 100.—Hypothetical section of a geyser pipe showing temperature before eruption (on the right) and at the moment of eruption (on the left).

The mechanism of geysers is very simple. Water fills the long fissures and cracks in the heated rocks, and becomes gradually heated by contact with the hot rock of the sides. As the heat of the rock increases downwards, the water in the lower part becomes hotter than that at the surface, and soon attains a temperature (212°) at which it would boil if it were at the earth's surface (Fig. 100). It does not boil, however, at 212° because the pressure of the overlying water forces it to remain in the liquid state. The heat at last grows so great that, high as the pressure is, the water begins to boil in some part of the fissure, and the steam evolved, expanding very much, pushes some of the water out at the surface. The pressure of this water is thus removed from that below, and it now boils violently at the diminished pressure, and steam is evolved with great rapidity and in enormous volume not only at the bottom, but throughout the fissure, so that the whole of its contents are ejected with great violence, blowing out any chance clods or stones which may obstruct its path, and rising into a column of mingled steam and boiling water to a height sometimes of hundreds of feet.

Constant Activity.—A somewhat similar type of eruption is to be seen at Stromboli, off the north coast of Sicily. This volcano is in constant activity, and on looking into the crater there are seen to be a number of openings from which different types of eruption take place (Fig. 101). From some there come roaring puffs of steam, something like those from geysers. From others molten lava is seen to be pushing up; it rises into great bubbles, which burst and give off puffs of steam. The steam is evidently mixed with the molten lava, and, as it expands, forces it to the surface; it then blows the liquid lava into bubbles, which expand and break, and so the steam escapes. The scum of the bubble as it breaks is torn off by the steam, and carried up in the form of drops or dust of red-hot rock. From a third class of openings lava quietly wells forth and flows away, giving off much steam as it does so.

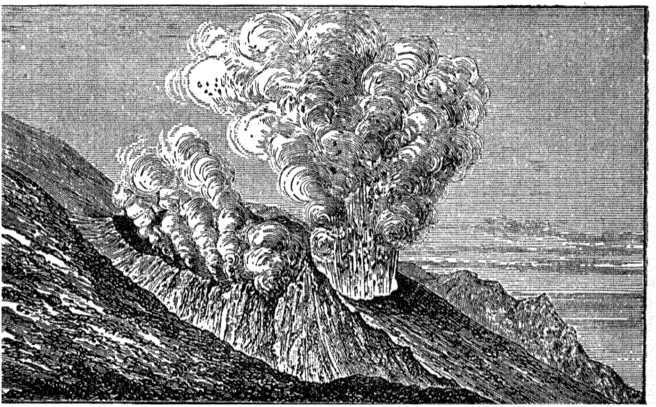

FIG. 101.—Stromboli in eruption. (After Judd.)

In a volcano such as this the temperature below is evidently much higher than under the geysers. Instead of water there is molten stone mixed with water or steam, and the weight of a column of this mixture, two or three times greater than that of water, allows the steam to acquire a correspondingly greater pressure before it has force enough to eject it. Lava in this state has been compared to porridge, a mixture of oatmeal and water. If the porridge is boiled and well stirred the steam bubbles up, as in the second class of openings mentioned above, but if it is not stirred the steam accumulates at the bottom until the pressure is high enough to eject the whole of the porridge into the fire.

Intermittent Activity.—Proceeding next to one of the larger volcanoes, there is one great point of difference. Although steam and ashes are almost always escaping to some extent, there is usually a long interval of rest between the greater outbursts, varying from a few years to a century or more. The result is that some of the products of the last eruption solidify at the top of the pipe ; the crater walls also crumble down, and the whole of the top gets more or less plugged up, and cannot be cleared out until great force has accumulated. The weight of all this material, and the force necessary to break away a passage through it, has to be added to that of the column of steam and lava in the pipe in estimating the temperature to which the steam must be raised before it is able to find its escape. In the course of years the temperature, and with it the steam-pressure, will gradually rise, and slowly the column of lava and steam will make its way to the surface, removing one after another of the obstacles in its way. This is the cause of the earthquakes so often felt before a great eruption. At last the steam is able to force a way out and escape with very great violence, shattering and fissuring the cone, blowing out the rocks which oppose its passage, shattering many of them to dust, breaking them red-hot from the sides of the vent, and carrying up the scum of the lava from which it is escaping. The opening of fissures, which show the glowing mass of lava beneath, and in some cases give forth lava, and in all cases steam, makes the mountain appear to sweat fire. The dust and steam during the eruption of Vesuvius in 1872 rose to a height of not less than five miles, and then was caught by the wind and fell in showers of rain, dust, and mud over a large area (Fig. 102). Then lava escaped in three main torrents, which gave off immense quantities of steam and swept down the cone, overwhelming two whole villages on their way. This marked the crisis of the eruption, which then quieted down. The emission of ashes and dust in the eruption of Vesuvius in A.D. 79 covered Pompeii and other cities, while dust mixed with water formed a stream of mud which buried up the town of Herculaneum. After a long period of activity in a volcanic district eruptions become less and less frequent, until at last they cease altogether and the volcano becomes extinct. It is then attacked by the weather and gradually denuded away.

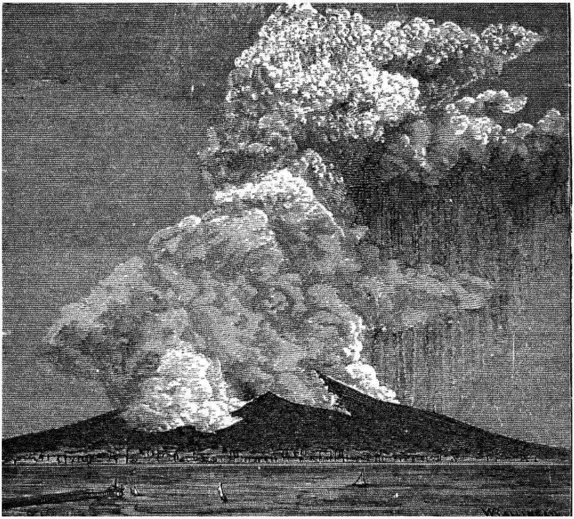

FIG. 102.—The eruption of Vesuvius in 1872. (From Sir A. Geikie's *Elementary Lessons in Physical Geography.*)

Fissure Eruptions.—Another type of eruption takes place in the large volcanoes of the Sandwich Islands, Kilauea and Mauna Loa. Lava gently wells forth with very little explosive action, and little or no tuff and ash are ejected. The great lava-sheets of Antrim and the Deccan lavas in India have probably been poured out by eruptions of this class.

Volcanic Products

Pyroclastic Material.—These examples teach us that a volcano gives rise to two chief types of rocks, ashes or fragmental rocks, and lavas. The blocks, dust, and ashes which constitute the first class of rocks may be deposited dry as volcanic breccia, tuff, ash, and dust, or they may be worked up by water into mud. The fragmental material will consist first and foremost of drops of lava torn off when liquid by the escaping steam, and solidified while whirling through the air with the steam escaping from them. These are called volcanic bombs and lapilli (little stones), and the escaping steam blows the molten rock into bubbles, so that it has a spongy texture, like bread or slag from a furnace; pumice is one of the common rocks thus produced (Fig. 103). From the same source come broken crystals and fine threads and dust of volcanic glass. Mixed with these will be fragments torn from previously consolidated lava and ash, and even from the other rocks on which the volcanic cone has been built.

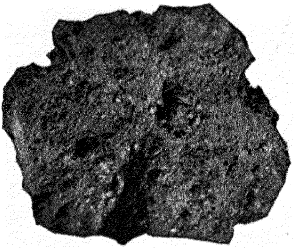

FIG. 103.—Pumice from Krakatão, showing the slaggy structure (about ⅓).

Coarse Deposits.—The heaviest and largest blocks drop quite near to the vent, and some of them inside it, when they are thrown up again and again until they are broken smaller and rounder by friction, and eventually find rest outside the crater. The heterogeneous, ill-stratified pile of fragments thus formed is called a volcanic agglomerate,[1] or a breccia if the constituents are angular (Fig. 104). Towards the close of the eruption the vent becomes filled with a mass of agglomerate,

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[1] Lat. *ad* = together, *glomerare* = to gather in a heap.

penetrated by and associated with dykes of the lava which has consolidated on its way upwards; such masses frequently mark the site of ancient volcanic necks or vents.

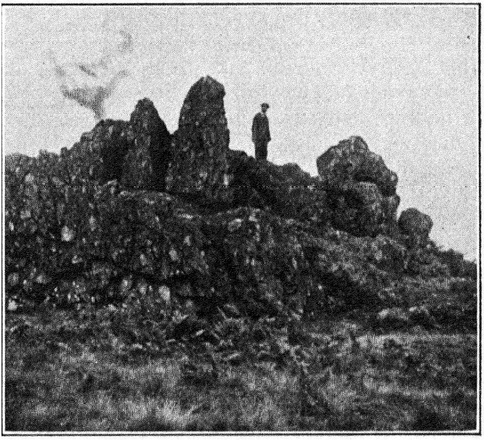

FIG. 104.—Volcanic agglomerate in Charnwood Forest. The large bombs have been turned on end or squeezed flat by the pressure which has cleaved the rock.

Fine Deposits.—Finer material travels farther before reaching the ground, as it is more easily carried by the wind, and the products of each eruption will form a sheet of tuff (Fig. 105), ash, and dust, thickest near the crater, and getting thinner farther away; the sheet will be interstratified with other sheets, and will extend farthest in the direction of the prevalent wind. The finest dust from the great eruption of Krakatão in Sunda Strait in 1884 was thrown so high that it was caught in the higher currents of the atmosphere and blown many times round the earth; particles of it were dropped in America, Europe,

FIG. 105.—Volcanic tuff made up o bits of lava, glass, and minerals, in carbonate of lime (about $\frac{8}{1}$).

and even in Japan, a journey of over 25,000 miles. Such dust will be distributed over the seas and oceans, and though it is barely perceptible amongst ordinary sediments, its presence becomes a conspicuous feature in deposits which are accumulating so slowly as globigerine ooze, or the red clay and radiolarian ooze of great ocean depths. The light, spongy pumice also floats for great distances before it becomes waterlogged and sinks to the bottom. After the Krakatão outburst one steamer could hardly use its screw for several hours on account of the amount of floating pumice it went through (see Fig. 103), and hardly a dredge was hauled up by H.M.S. *Challenger* from great depths which did not contain a certain amount of rotted pumice.

Distinctive Characters.—The stratification of the coarser material will be very imperfect and the deposit ill-sorted, coarse and fine matter being more or less irregularly mingled. The finer ashes and dust will be rather better stratified, and even in some cases laminated, in consequence of the intermittence of eruptions. Fossils are wholly absent, or, if occasionally present, consist of trees and the bones of land animals overtaken by the eruption. By the characters stated sediments originating from volcanoes may be readily distinguished from those laid down in water.

Lava.—When the molten lava is flowing, the steam expands, now that the pressure on it is diminished, and escapes in immense quantity, blowing the lava to bits as it does so. This produces blisters, and the upper part of the stream becomes quite slaggy and scoriaceous from the bubbles of steam. As the upper part of the stream flows faster than the part underneath, the slaggy crust, advancing like a pile of cinders, tumbles down in front, and lines the floor on which the lava moves forward. Thus both the under and upper surfaces of the stream become slaggy (Fig. 106). The interior loses its heat much more slowly, and may take many years in becoming quite cool; it is found to be more compact and stony in

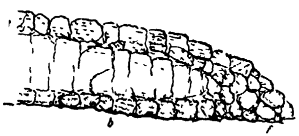

FIG. 106.—Ideal section across a lava-stream to show the slaggy upper (*t*) and under (*b*) surfaces, the slaggy front (*f*), and the more compact and stony middle portion (*m*).

character, and in many ways it approaches some forms of crystalline rocks, particularly in having crystals of minerals scattered through it. Indeed many thick lava-streams seem to be made up almost entirely of such crystals, and these are mostly of minerals which occur in crystalline rocks, felspar, augite, hornblende, olivine, and leucite.[1]

Volcanic Cones

Formation of Cone.—If a volcano gives out nothing but fragmental products, as was the case with some of the old volcanoes of Central France, these would be piled up round the vent in conical heaps (Fig. 107). When sand is rained down on the table or in an hour-glass or egg-boiler it forms a conical shape, the slope of which is as steep as that at which sand will rest. If it were blown up first through a hole in the table it would also settle in a heap, but the driving up of the sand would keep open a central pipe ending in a crater-like hollow, round which the cone would be formed. This may be imitated by an arrangement of pipes connected with bellows and fed with different coloured sawdust. The cone may be cut through and the arrangement of the sawdust examined (Fig. 108). It is precisely that of a scoria cone, made of layers or strata of different colour, inclining outwards from the centre. The ravines cut by streams in many cases reveal this structure. But an additional peculiarity is noticeable. As the central funnel is kept open by the blast of steam and lava, some of the dust will fall towards it, and this will be stratified in

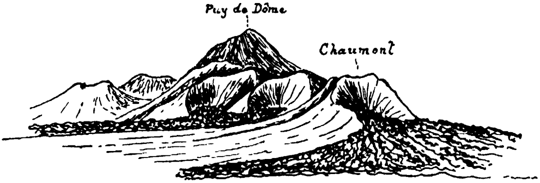

FIG. 107.—Scoria cones in the Auvergne, breached by lava streams. (After Scrope)

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[1] Gr. *leukos* = white.

sheets parallel to the crater, and these will dip inwards towards the centre. This is called the *internal talus*, and it has been observed in old volcanoes which have been broken into by streams or the sea.

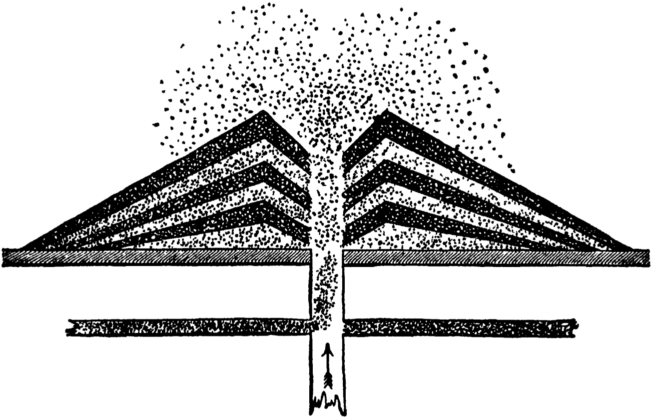

FIG. 108 —Model of scoria cone made in sawdust. (After Woodward.)

When a cone emits only lava this will flow away from the vent. If the lava when it issues is very hot, and does not soon become viscous, the angle of slope will be small, but if the lava comes out at a low temperature and is very viscous it soon stops flowing, and forms a beehive-shaped cone with abrupt sides.

Complex Cones.—But most cones pour out both lava and ash at different parts of the same eruption or in different eruptions, and thus lava and ash will become interstratified.

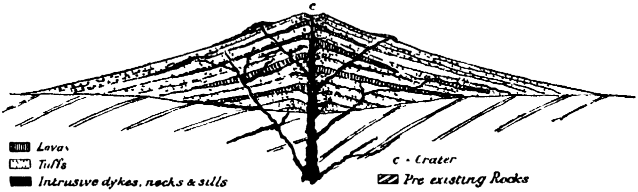

FIG. 109.—Ideal section across a complex volcanic cone.

The broken edge of the old cone of Vesuvius called Monte Somma gives a good example of this, and it can be seen to be made up of alternating masses of lava and ash, with breccia, dust, and mud-flows like those which come from the volcano at the present day. No single lava-stream covers the whole cone. Each one flows along any depression it may meet with, taking the easiest course (Fig. 109). Thus lavas of different dates may occupy positions side by side, and unless one crosses another at some point, it may be difficult to ascertain their relative age.

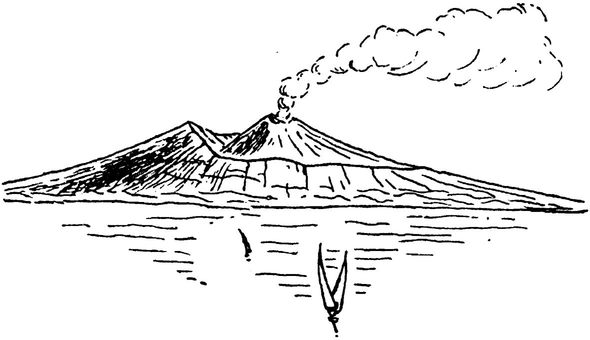

FIG. 110.—Vesuvius, showing the old crater-ring of Monte Somma and the new cone situated within it. (After Phillips.)

On the whole, each addition of lava or ash will tend to raise the height of the cone, and there is every reason to suppose that the whole of the visible cone has been built in this way by one eruption following another. This is most instructively shown in the case of Vesuvius. When first known the volcano was cone-shaped with a flat top, in which was a crater-like hollow. Much of one side of this top was blown away during the great eruption of A.D. 79, the broken cone in the form of ashes and dust burying up Pompeii; the other side is still left, and forms the "collar of Vesuvius," a cliff known as Monte Somma (Fig. 110). On the irregularly rent surface thus produced the successive eruptions of the last eighteen centuries have built up the present cone of Vesuvius, which rises out of the hollow beneath Monte Somma. Again and again the top of this new cone has been blown off, and smaller cones have been built there, growing in size till the scar has been obliterated.

Parasitic Cones.—Nor is this quite all, for in some of the larger cones, like Etna, eruption does not take place from the summit, but from the weak points on the sides, and small cones from 200 to 600 feet high are built there, the more active ones gradually burying up the smaller ones in their neighbourhood (see Fig. 109). Indeed, there is good reason to believe that Etna was originally a twin volcano, but one twin has grown so much larger and stronger than the other that it has completely buried it up, and formed a single cone.

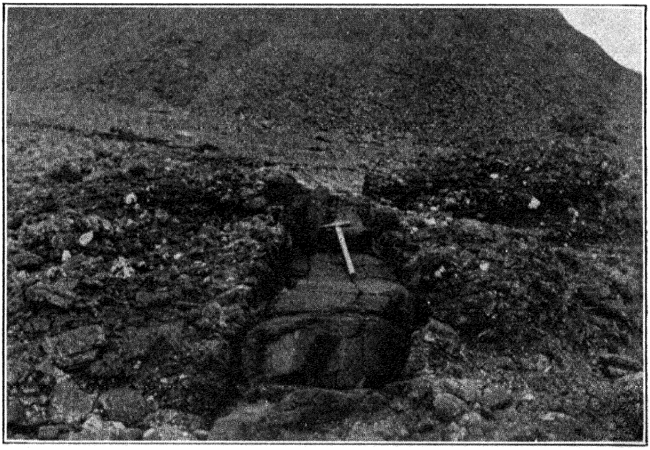

FIG. 111.—Dolerite dyke piercing Carboniferous conglomerate, Isle of Man.

Pipe of Volcano, Dykes.—The central pipe of the volcano has been frequently spoken of. This is the narrow passage kept open by lava forcing its way upwards, and when the activity dies down it is left partly filled with the solidified lava which has been forced in from below, partly by the blocks of stone and ash tumbling in from above. Fissures in the cone are connected either with this central pipe or with the reservoir of lava below, and they are filled with lava welling up, which may never reach the surface, or may reach it and thrust itself out to build parasitic cones (see Fig. 109). The lava solidifies in these fissures, and makes masses of rock which were intruded in the melted state among the lava and ashes of the cone (see Fig. 109). These masses become harder than the ashes and other rocks among which they are found, and stand out like walls when they are denuded; hence they are called dykes. They will, of course, be later in date than the rocks into which they have been intruded. If the reservoir of lava is very deep down, or if fissures extend beyond the base of the cone, dykes may traverse the sedimentary rocks on which the cone is built (Fig. 111). Thus we can argue from finding dykes penetrating sediments that there has once been a volcano above them, or an attempt to establish a volcano. Such dykes are of frequent occurrence in sediments, and are useful guides in ascertaining the date of volcanic activity.

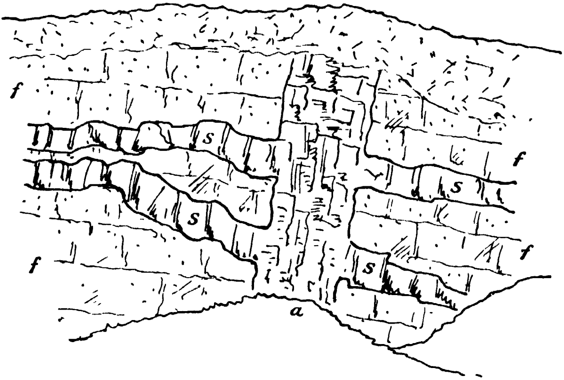

FIG. 112.—A dyke of basalt (*a*) piercing sandstone (*f*), and sending out intrusive sheets or sills into it (*s s*).

Sills or Intrusive Sheets.—But, striving to reach the surface by an easier course, the lava may thrust itself in between the bedding-planes and form intrusive *sills*. These are difficult to distinguish from bedded lava-streams, as they may run parallel to the bedding for long distances (see Fig. 109). Usually, however, they will be found to cross the bedding or send dykes and tongues across the rocks at some point or other, and by their heat they bake not only the rocks below, as a lava-stream does, but also those above. Again, the strata above a lava-stream may contain pieces weathered from it, while in a sill this will not be the case, but, on the other hand, the molten rock may have broken up and enclosed in itself not only bits of the bed below it, but of the one above (see also p. 159, Fig. 112).

Submarine Volcanoes

So far we have dealt chiefly with material deposited on land. Most volcanoes are near the sea, and the ash frequently reaches the sea. Sometimes the coarser blocks fall into water, and being rounded by the waves, are added to the beach conglomerates, which are then distinguished as *volcanic conglomerates.* Some lava-streams reaching the sea seem to be broken up by the steam suddenly evolved. Other volcanoes occur actually in the sea, and their lavas and ashes are deposited on the sea-bed in interstratified layers associated with ordinary sediments; and the beds of ash may contain the fossil remains of fish, shell-fish, and other marine creatures killed and buried up by the eruption and its detritus. A bed of volcanic ash full of fossils occurs at the summit of Snowdon (see Fig. 168, p. 237).

RECAPITULATION

The crystalline rocks cannot be sediments, but they must have originated by the deposit of crystals from sublimation, solution, or *fusion.* The last is the only likely source, and as fused rocks are poured out by *volcanoes*, it is necessary to study volcanoes and their products.

Steam is evidently an important factor in most kinds of volcanic eruption, whether in geysers, or eruptions of the Stromboli, Vesuvian, or Sandwich Island types. *Cones* with a *crater* at the top are built up out of the rock ejected in a *clastic* condition (*ash* and *tuff*) or in a *molten* condition (*lava*).

The clastic material forms *irregular beds* of tuff, breccia, and agglomerate or more *regular beds* of fine ashy material. The fused material crystallises into hard rock with slaggy under and upper surfaces, but with a stony interior in which the proportion of *crystalline* to *glassy* constituents increases with the thickness of the stream and the deliberateness of cooling.

The stratified, clastic, and crystalline rocks of the cone and the older rocks of the floor on which it is built are intruded upon by *dykes*, *sills*, and *pipes* of more crystalline lava.

QUESTIONS ON CHAPTER XII

1. What part does steam play in volcanic eruptions? (1894.)

2. What are the most abundant substances ejected from volcanoes? (1882.)

3. Give a short account of the action of a volcano. (O and C.)

4. Describe the origin and mode of formation of volcanic ashes. (1885.)

5. How does a volcanic ash or tuff differ from a breccia? (1890.)

6. How are insular and continental volcanoes generally distributed? Illustrate your answer by reference to the volcanoes of the old world. (O and C.)

7. Draw a section of a volcanic cone, and explain its formation. Is there any relation between the slope of the beds constituting the cone and the dip of the strata below it? (O and C.)

8. (*a*) Of what different kinds of materials are volcanic cones built up?
   (*b*) Draw a section showing the internal structure of a scoria or "cinder" cone.
   (*c*) How is the crater of such a cone formed?
   (*d*) What is meant by a parasitical cone? (1896.)

9. What are the following rocks, and how have they been formed—chalk, clay-ironstone, conglomerate, lignite, roofing-slate, and volcanic tuff? (O and C.)

10. Explain under what circumstances eruptive rocks may be stratified. (1894.)

11. In the case of a cone-shaped hill, how would you determine if this were a volcano? (1888.)

12. Explain fully the meanings of the terms—dip, strike, fault, dyke. (O and C.)

CHAPTER XIII

VOLCANIC ROCKS

General Character of Lavas.—A minute study of the characters presented by lavas when they have cooled and solidified shows so many points of resemblance to certain types of crystalline rocks, that we are compelled to believe that the latter have had the same method of origin as the former. Differences of very considerable importance doubtless exist, but they can all be accounted for by causes which are to be seen in action, so that they do not present any real obstacle to the acceptance of this conclusion. We will examine first the minuter characters seen in cooled lavas, that is, their *texture*, next their *structures* on a larger scale, then their chemical and mineralogical *composition*, and, lastly, the differences between them and the crystalline rocks which come nearest to them in character.

Texture

Glass and Crystals.—Certain lavas look just like bottle-glass, and when examined in thin sections by the microscope no trace of crystalline texture can be made out in them. In the process of manufacturing window-glass a mixture of silicates is fused and allowed to cool somewhat rapidly; the result is the familiar character of glass, a substance in which no crystalline texture is observable; the constituents have not had time to sort themselves out into crystalline compounds, and a structureless body, which has no action on polarised light, is the result. If, however, the molten mass cools more slowly, it becomes cloudy and partially opaque, and even stony; this is due to the formation of minute crystals, which break up the light as it passes through the mass.

Similarly with lavas. Those which cool quickly become glassy and structureless; indeed they are dark-coloured glasses. More usually there is sufficient time taken in the process of cooling to allow of the formation of small imperfect crystals, which are well seen in a slide of obsidian lava. In the lavas from Vesuvius crystals of the two minerals leucite and augite, large enough to be seen with the naked eye, are common, floating as it were in the glassy groundmass or matrix of the stone (Fig. 113). These are indeed floated up in the lava when it wells up to the surface, having formed during slow cooling on the way to the surface. The lavas of Etna contain similar crystals of augite, olivine, and felspar. Crystals like this, conspicuously larger than those of the rest of the rock, are spoken of as *porphyritic crystals*, and they are a common phenomenon in many crystalline rocks (see Fig. 5).

FIG. 113.—Microscopic section of Vesuvian lava, containing crystals of felspar, augite, and leucite in a black glass (about $\frac{6}{1}$).

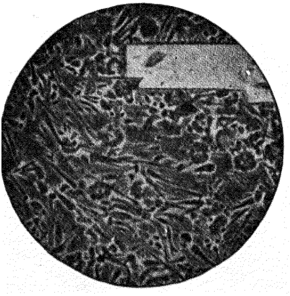

FIG. 114.—Microscopic section of pitchstone from Arran, showing porphyritic crystal of felspar and feathery microlites in a glassy base (about $\frac{6}{1}$).

Embryo Crystals.—On examining a thin slice of such a lava under the microscope it will be seen that the matrix contains tiny, imperfect or embryo crystals of recognisable minerals in the form of minute rods, plates, or globes, possessed of some but not all the properties of crystals. These are called *crystallites* or microlites,[1]

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[1] Gr. *mikros* = small, *lithos* = a stone.

and they are often arranged in beautiful radiating or feathery groups, like the minute crystallites of which snow-flakes are built (Fig. 114). Such groups are skeletons of larger crystals, and when time has been allowed in their formation, the skeleton is filled in by others until a perfect crystal is built up, just as a cube may be constructed of an aggregate of smaller cubes. It is no doubt owing to this method of building that we are able to recognise, by such tests as polarised light, cleavage, etc., that fragments of mica or felspar are bits of broken crystals. When the minute crystallites are grouped in small spheres the groups are called *spherulites*,[1] and the matrix of the rock is said to be spherulitic; an example of this texture is shown in the annexed figure (Fig. 115).

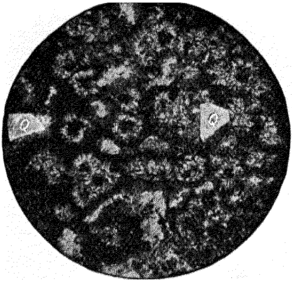

FIG. 115.—Microscopic section of spherulitic quartz-porphyry containing porphyritic crystals of quartz (Q) in a spherulitic matrix (about 6/1).

Flow-structure.—The gradual development of crystals and crystallites in a lava-stream as it is flowing makes it more and more viscous, so that it moves like pitch or syrup. It becomes streaky by the dragging out of the glassy threads which begin to form in it, and by the little crystals setting themselves parallel to the motion of the stream just as straws will in a stream of water. This may be imitated in a pitch-glacier like that described in Chapter V., by scattering bits of split matches on its surface; they will be seen in the course of a day or two to have moved downwards and to have set themselves parallel to the sides of the stream. This

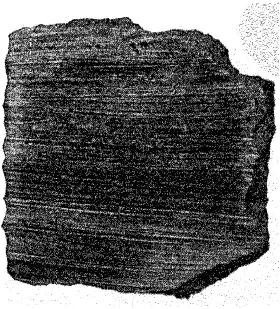

FIG. 116.—Flow-structure in rhyolite, from the north of Ireland (about ½).

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[1] Gr. *sphaira* = a sphere, *lithos* = a stone.

streaky or banded texture is called *flow-structure*, and it is well seen in the examples figured (Figs. 116 and 119). The bubbles formed by the escaping steam are also dragged out by the flow, and help to accentuate the streakiness.

Structures

Columnar Jointing.—When lava has cooled sufficiently it becomes solid, and other characters of importance are developed. All hot things shrink on cooling, and large ones become so much strained that they generally crack. One of the most characteristic results of shrinking, when due to cooling from one surface, is the formation of sets of cracks dividing the surface into hexagons which fit closely together like the cells of a honeycomb; these cracks extend downwards at right angles to the surface, dividing the whole into columns or prisms, which are six-sided and fit closely together; this is called *columnar structure*, and it is commonly seen in lava-streams and masses of crystalline rocks (see Fig. 126). A simple experiment will illustrate the formation of these figures. If a number of cigarettes be packed as close as possible together it will be seen that each of the inner ones touches six others. Now squeeze them together in the hand; each one will become flattened where it touches another, and thus the inner ones will become six-sided (Fig. 117). It is a similar cause which makes bee-cells hexagonal; the bees all start together as near as convenient, and each one tries to build a round cell; but each cell comes into contact with six others, and acquires six sides by pressure. If instead of pressure throughout the mass we imagine an evenly distributed stretching or *tension*, each particle drawing its immediate neighbour to-

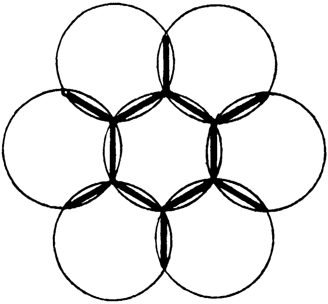

FIG. 117.—To show the production of hexagons from circles pressed in close contact.

wards itself, it is easy to imagine that something quite similar will follow, and evenly distributed hexagons will form on the cooling surface, packed together so as to occupy the whole space. As the parts below the surface become solid and contract, the cracks extend downwards, breaking the whole mass up into symmetrical hexagonal columns. A little starch should be mixed into a stiff paste with cold water and allowed to dry slowly; on examination it will be seen to have split up into rough columns, many of which are six-sided, running down from the surface, the first part to solidify; this is the result of shrinkage as the starch dries. Many of the lavas of such volcanoes as Etna, and crystalline rocks of similar composition, are columnar. Fingal's Cave in Staffa and the Giant's Causeway in the north of Ireland are well-known examples. (See also Fig. 126.)

Spheroidal and Perlitic Structures.—Further shrinkage often breaks the columns by cross-joints, and not infrequently the spaces enclosed by the columnar and cross-joints scale up into spheres rather like the coats of an onion; this is a further result of the shrinkage, and it may sometimes be produced without the previous development of columnar joints; it is called *spheroidal jointing*, and examples of it are common both in lavas and crystalline rocks. The annexed example (Fig. 118) is taken from a dyke in Northumberland. Certain

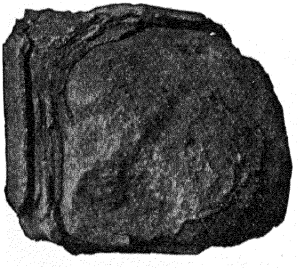

FIG. 118.—Spheroidal structure in basalt, from a dyke in Northumberland; (about $\frac{1}{4}$).

FIG. 119.—Perlitic texture in pitchstone, from Mexico; it also shows flow-structure; (about $\frac{9}{1}$).

of the glassy rocks and lavas, when examined in thin sections, are seen to have a similar texture on a very small scale. This is called *perlitic texture*, and it, together with flow-structure, is illustrated in Fig. 119.

Chemical Composition

Acid and Basic Rocks.—The analysis of lavas and crystalline rocks shows that they are both complex mixtures of a number of chemical compounds which in their simplest form may be regarded as oxides of a number of elements. Two chief classes of these oxides may be at once recognised: (1) Oxide of silicon, called silica; (2) Oxides of various metals, such as aluminium, iron, calcium, magnesium, sodium, and potassium. The latter, or basic, oxides are called alumina, iron oxide, lime, magnesia, soda, and potash respectively. It is convenient to express the composition of rocks by balancing the proportion of silica (or silicic acid as it is sometimes called) against the percentage of the basic oxides present. Those in which silica predominates, over 65 per cent being present against 35 per cent of the basic oxides, are called *acid* rocks; those with from 65 to 55 per cent of silica and 35 to 45 per cent of basic oxides are known as *intermediate* rocks; and those with from 55 to 45 per cent of silica and 45 to 55 per cent of basic oxides are called *basic* rocks. The rhyolite and obsidian lavas of Lipari are examples of acid lavas, the andesites of Cotopaxi of intermediate, and the basalt and tachylyte of Etna and the Sandwich Islands of basic lavas.

Mineral Composition.—The individual minerals in both lavas and crystalline rocks are all of them definite chemical compounds, and the chemical composition of a rock or lava can be obtained from a knowledge of the minerals present in it. Lavas can be classified by means of the minerals which they contain, and it is convenient to take the felspar group as the basis of the classification. There are two great groups of felspars, those which are made of silicate of potash combined with silicate of alumina, called orthoclase felspars, and those in which varying proportions of soda or lime take the place of potash, called plagioclase felspars. We may classify lavas as follows:—

	Examples.	Chemical Composition.
1. Those with orthoclase and quartz .	Rhyolite	Acid
2. Those with orthoclase and plagioclase	Trachyte	Intermediate
3. Those with plagioclase and hornblende or augite	Andesite	
4. Those with plagioclase and augite or olivine	Basalt	Basic.

Classification.—But we can further subdivide the classes of lavas according to their texture, and whether they are principally made up of crystals or glass. This will also indicate the slowness with which they have cooled, and hence some of the circumstances of their formation :—

	ACID.	INTERMEDIATE.		BASIC.
	ORTHOCLASE.		PLAGIOCLASE	
	Quartz.	Hornblende or Augite.		Augite or Olivine
Glassy . . .	Obsidian, Pumice	Trachyte-glass	Andesite-glass	Tachylyte
Partly Crystalline .	Rhyolite	Trachyte	Andesite	Basalt

Many crystalline rocks are so much like lavas in their chemical and mineralogical composition that it is not considered necessary to have separate names for them, and they can both be classed according to the scheme given above.

Differences between Lavas and Crystalline Rocks

Consolidation.—The materials of which a volcanic cone is made may be expected to undergo certain changes owing to lapse of time. First comes the consolidation of tuffs and ashes in the same ways as sediments are compacted. Abundant mineral matter is brought up in the state of vapour, or mixed with steam, or dissolved in the hot springs, and this material will be deposited as cement, while vertical and lateral pressure will act on a cone just as elsewhere. An additional cause exists in the heat of dykes and intrusive sills.

Deposition of Minerals.—Connected with cementation is the deposit of minerals in fissures and cavities of the rocks. Sulphur, salt, chloride of iron, salts of ammonia, and various silicates are brought up and deposited in fissures in the lava or on its surface. Generally they are deposited directly, but often they react on the rock, and decompose some of the minerals, converting them into others. This is especially seen in the steam-holes and bubbles which become gradually filled with white or green minerals like quartz, calcite, chlorite, or the hydrated silicates known as zeolites (Fig. 120). The lava loses its slaggy, sponge-like, or bread-like character, and acquires the aspect of almond-toffee in consequence of the white kernels in the darker rock. Thus while modern lavas are often slaggy like pumice, this texture is uncommon in crystalline rocks, and even when it is seen is generally due to the more easy weathering out of the minerals in the cavities. Rocks with the bubbles filled up with minerals are called *amygdaloidal*,[1] an example, partly weathered out, is shown in Fig. 120.

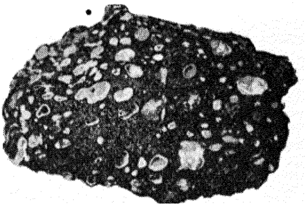

FIG. 120.—Basalt with amygdaloidal structure; the steam-holes are filled with crystallised silicates; Giant's Causeway, Antrim (about ⅓).

Alteration of Minerals.—The penetration of acid and other vapours, and of heated water, decomposes many of the crystalline minerals, dissolving some of their constituents and replacing them by water of constitution or by other compounds. Thus augite and hornblende become converted into calcite and chlorite, felspars into kaolin and mica, olivine into serpentine, and leucite into felspar. Minerals of this class are much more common in the crystalline rocks than in the products of modern volcanoes.

Alteration of Texture.—Again, the glassy texture is by no means a permanent one, and many of the old Roman glass vessels which have lain buried for centuries are found to have

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[1] Gr. *amygdale* = an almond.

become partially crystalline. An imperfectly crystalline texture replaces the glasses of older lavas, and sometimes the glass entirely passes into an aggregate of spherulites. It is hardly to be wondered at that glasses are somewhat rare in the crystalline rocks, especially the older ones, and that their place seems to be taken by the stony, imperfectly crystalline, and spherulitic textures which are very common.

Resemblances between Lavas and Crystalline Rocks

Composition, Texture, and Structure.—In spite of these changes it is possible to parallel a part of the great group of crystalline rocks so closely with modern lavas that it is unnecessary even to give separate names to them; and the crystalline rocks are given such names as basalt, andesite, and rhyolite, even when their exact connexion with any particular volcanic cone cannot be traced. The jointing, vesicular texture, porphyritic, perlitic, spherulitic, and flow-structure, the identity in chemical composition as indicated by a bulk analysis, the occurrence of the same minerals, associated together in about the same proportion,—all these characters form such a strong bond of union between certain crystalline rocks and lavas that it is not broken by the alteration of some of the minerals, the substitution of stony for glassy texture, and the other comparatively unimportant changes to which attention has just been called.

Association.—Further, they are associated with intrusive masses of similar composition, and interbedded with ashes, agglomerates, and tuffs, or with volcanic conglomerates and fossiliferous ashes in such a way that the connexion cannot be denied. It is under these circumstances that some crystalline rocks are stratified. Ancient ash-beds and lava-like sheets of crystalline rock are found to become thicker when traced in one direction, and they are there associated with a larger proportion of intrusive rocks, as though we were nearing the vent of a volcano; thus it is sometimes possible to rebuild in imagination the cone from which they were ejected (see p. 295). Indeed in many cases the actual vent itself, filled with a mass of agglomerate, and seamed with dykes which radiate out in all directions into the tuffs and lavas, has been discovered.

This, however, cannot often be expected, and as cones are rapidly denuded away, we have sometimes to be contented with a mere dyke or pipe filled with crystalline rock, which will be the last relic of the volcano to survive (see Fig. 109, p. 156).

Definition of Volcanic Rocks

Acid Rocks.—*Rhyolite*[1] usually contains porphyritic crystals of quartz and a glassy-looking form of orthoclase known as sanidine, with a little plagioclase felspar. The ground-mass consists chiefly of minute needles of felspar, sometimes with quartz, and occasionally hornblende or mica, embedded in glass, which often shows flow-structure (see Fig. 116). It is found in the form of intrusive masses, and probably also as lavas, near Tardree, in the north of Ireland.

Obsidian is a brown, black, or red glass, transparent in thin splinters, and sometimes containing porphyritic crystals of sanidine or quartz. In a frothy, scoriaceous state it is called *Pumice* (see Fig. 103, p. 152). When somewhat altered by water it loses its glassy lustre, and, becoming waxy or pitch-like in appearance, it is called *Pitchstone* (see Fig. 119). This occurs as dykes and lavas in Arran, Mull, and Eigg, off the west Scottish coast, where it sometimes contains porphyritic felspar (see Fig. 114). Microscopic sections of the pitchstone of Arran show innumerable tiny microlites of hornblende embedded in the glass (see Fig. 114).

Intermediate Rocks.—*Trachyte*[2] is a grey rock, rough to the touch, usually porphyritic, with crystals of orthoclase and plagioclase, which are embedded in a fine-grained ground-mass consisting of small crystals of felspar, with mica, hornblende, or augite, embedded in glass. Slightly altered trachytes occur as dykes and lavas amongst the Carboniferous volcanic rocks of the Garlton Hills and elsewhere in South Scotland.

Andesite is a trachyte-like rock, somewhat darker in colour, and with plagioclase felspar dominating over the orthoclase. Porphyritic crystals of felspar, hornblende, or augite are common, embedded in a fine ground-mass of plagioclase felspar with hornblende and augite in a brown glass. It occurs commonly as a lava in the volcanoes of the Andes, from

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[1] Gr. *rheo* = to flow.

[2] Gr. *trachys* = rough.

which it was named; but in a slightly altered form it is found as lavas in North Wales, Shropshire, and the Cheviots.

Basic Rocks.—*Basalt* is a black, dense rock, usually very compact, but sometimes showing porphyritic crystals of plagioclase felspar, augite, or olivine, embedded in a fine-grained ground-mass of felspar, augite, and glass (see Fig. 113). It is the lava of Etna and Vesuvius, and it occurs commonly in England, Wales, and Scotland as lavas and dykes of Tertiary age, and as intrusive masses in Carboniferous rocks. The quickly-cooled, glassy form, *Tachylyte*,[1] is rare.

Altered Forms of Volcanic Rocks.—The altered forms of these rocks are more common in Britain than the unaltered form. Thus rhyolite is represented by quartz-porphyry[2] and quartz-felsite (see Fig. 115), and trachyte by felsite.[3] These differ from rhyolite and trachyte chiefly in the fact that the glassy ground-mass has become obscurely crystalline. Similarly, andesites and basalts with their minerals altered to chlorite, calcite, epidote, etc., are more common in Britain than the fresh forms of the rocks.

Internal Heat of the Earth

Proofs.—The existence of volcanoes proves that the earth crust is very hot at certain places, and as volcanoes have at one time or other been active nearly all over the world, this heat must have been widespread. The occurrence of geysers and hot springs points to a similar conclusion, and in all deep borings, wells, and mines it is well known that the temperature gradually rises as we descend. On an average the rate of rise is about 1° (Fahrenheit) for every 60 feet of descent. If this rate is continuous, starting from about 50° at the surface, water would boil at a less depth than two miles; silver would melt at less than 20 miles; and everything known on the earth's surface would melt at a depth of 50 miles. The immediate conclusion from this would be that the interior of the earth is liquid; but there are many arguments against this view, and it is probable that the crust is kept solid to a much greater depth than this by the enormous pressure of the outside on the inside.

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[1] Gr. *tachys* = quick, *luo* = to fuse.

[2] Gr. *porphyreos* = purple.

[3] Ger. *fels* = a rock.

Effects.—The present internal heat is probably an indication that the earth was once an intensely hot body like the sun, and that it is slowly cooling down. Cooling would be accompanied by shrinking, and as the interior would continue to cool after the outside had become hard, stable, and cold, it would shrink away from the crust, leaving the latter to support itself. This it is unable to do, and so it would crush and crumple like the skin of a withering apple. The lateral force thus developed in the crust may be sufficient to tilt and contort rocks, and to cause jointing, faulting, and cleavage. Volcanoes would be associated with the bending and crumpling of the crust, and so would be likely to occur, as in fact they do. near the *great mountain-chains*, and on the lines of weakness at the *borders* of the *continents and oceans.*

RECAPITULATION

Lavas possess many characters not seen in sediments; some, such as the crystalline and glassy textures and the joints known as columnar, spheroidal, and perlitic, are the result of cooling from a state of fusion; others, such as *flow-structure* and streaking, are caused by the movement of the fluid mass.

Although in chemical and mineralogical composition they correspond closely with some varieties of crystalline rocks, there are certain differences due chiefly to the lapse of time, such as the *consolidation*, deposition of *new minerals*, *alteration* of unstable minerals, and loss of *glassy texture*, which mark a distinction from many of the crystalline rocks. These differences can be accounted for without difficulty when the events in the later history of volcanic cones are taken into consideration.

When this is done it is possible to speak of crystalline rocks and volcanic lavas in the *same terms*, and to recognise the former as recording past volcanic history in regions where there may now be no sign of active or extinct volcanoes, nor even any trace of the old cones.

Volcanic rocks are best classified according to their *mineral composition*, the *felspars* being most useful in this respect, and after them quartz, hornblende, augite, and olivine. Further subdivision according to *texture* is useful, as this gives an insight into the exact history of the rock and the circumstances of its intrusion or extrusion.

The internal heat of the earth provides the energy required for volcanic action. The shrinkage of the interior in cooling is partly responsible for the folding and faulting, and other changes in rocks connected with lateral pressure.

QUESTIONS ON CHAPTER XIII

1. Mention the chief differences between aqueous and igneous rocks. (1878.)

2. Mention the broad general characters by which igneous rocks may be distinguished from sedimentary strata. (1884.)

3. How is it possible to distinguish an intrusive from an interbedded (or contemporaneous) volcanic rock? (O and C.)

4. Mention the principal minerals which enter into the composition of the commonest and most important eruptive rocks. (1884.)

5. (*a*) State the characters which distinguish basalt.
   (*b*) How can it be shown that basalt is made up of several different minerals?
   (*c*) Give the names of the minerals found in basalt.
   (*d*) How has basalt been formed? (1898.)

6. Describe the structure of—
   (*a*) Dykes.
   (*b*) Veins.
   (*c*) Intrusive sheets [or sills].
   (*d*) Contemporaneous lava-flows. (1897.)

7. State some of the proofs of the existence of the so-called central heat in the earth. (1882.)

8. What reasons are there for believing that a source of heat exists in the interior of the earth? (O and C.)

CHAPTER XIV

PLUTONIC ROCKS

Origin of Plutonic Rocks

Definition.—Amongst the crystalline rocks there are several kinds, such as the *granite* we considered in Chapter II., which we cannot compare closely with the lavas poured out from volcanoes. These rocks differ markedly from lavas and dykes which have cooled near the surface. In granite *everything is crystalline*—mica, felspar, and quartz; sometimes the felspar crystals, and even the mica, may be two or three inches long (see Fig. 5). Crystals found in lavas are not usually more than a fraction of an inch in length, and those which solidify after the lava has been poured out are often very small indeed. Again, the scoriaceous aspect is not seen in such rocks as granite, glassy matter is altogether absent, and even the stony groundmass of some thick or altered lavas is not present in typical granites. Now most of these characters are such as we should expect to be related to slow cooling. A more perfect stony structure, with larger crystals, is found in the centre than at the top or bottom of a lava, and in a thick than a thin lava: And this is also evident in dykes; the bigger the dykes are, and the farther from the surface they have consolidated, the coarser the crystalline structure is.

Slow Cooling.—But there are also two parts of a volcano we have not yet been able to study—that which is far below the ground and near to the reservoir which supplies the lava, and the reservoir itself. What is likely to be the character of the rock that would result from lava solidifying here? It would cool and hence crystallise with extreme deliberateness, as the loss of heat would be slow. The effect of slow crystallisation may be studied by experiments on carbonate of soda. It will be found that if the water is evaporated quickly, the crystals are very small; but if it is allowed to evaporate very slowly in warm air, the crystals grow much larger, and it is possible to grow just one single large crystal out of the solution with proper care.

Occurrence.—Many granites are found in the centre of areas of lava and ash-beds, whose chemical composition the rock closely resembles. The chemical composition of the Cheviot granite is practically identical with that of the surrounding lavas, although its texture is altogether different. Its position in the middle of them suggests that granite-like rocks may actually result from the cooling deep down of the same material which flowed out as lava-streams (Fig. 121).

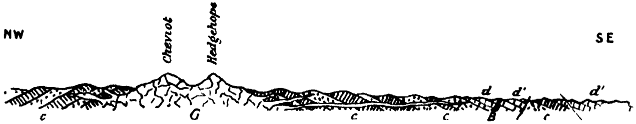

FIG. 121.—Section across the Cheviots. G = granite, sending out veins and dykes of granite, quartz-porphyry, etc., *c* = tuffs, ashes, and sandstones of the Old Red Sandstone age; *d* = lower Carboniferous rocks; B = basalt dykes.

Such lava would cool with extreme slowness. Sometimes lava-streams have taken centuries to cool down, and the thicker the pile of non-conducting material over them, the more slowly will the process go on; deep down in a volcanic focus it may be prolonged for thousands of years. Crystals will have ample time to grow to a great size, and as there will be no hurried cooling there will be no formation of glass, but one by one the minerals will sort themselves out, each one building up the most perfect crystals that are possible in the space allowed it. The heavy pressure on the top of the liquid will not allow steam to expand and escape, and no bubbles will be formed. On the other hand, what water is mixed with the melted rocks will be left shut up in it, and it can be detected in the millions and millions of infinitely tiny cavities which can be seen with a powerful microscope inside the quartz of granite. There will be no necessary association with ash-beds, for the whole cone may be quite denuded away, and we may only see that part of the pipe which traversed non-volcanic rocks, the foundations on which the volcano was built. Indeed the lava may have solidified on the way up from the inside of the earth, and may never have reached the surface or produced an active volcano, so that volcanic surface-products may never have been formed (Fig. 122).

Gradation towards Volcanic Rocks.—But if these rocks are really the roots of volcanoes, we ought to find every transition from them to the volcanic rocks. This is, in fact, the case, for granites themselves vary in grain from coarse to fine, and from porphyritic to very compact types. They give off dykes and the more irregular protrusions called veins, which, as they are traced nearer the surface and away from the main granite-mass, become finer in grain and sometimes take on a stony texture (Fig. 123). At times their edges and ends are even glassy or vesicular, and thus the transition from granite through dyke-rocks to volcanic rocks is quite complete and gradual. A mass of intrusive rock may shrink in cooling, and parts of the uncooled magma may be intruded into that which has been already solidified. Thus veins will be formed which may have a slightly different composition from that of the part first soldified. Granite in chemical and mineralogical composition—

FIG. 122.—Dyke of granite, Brazil Wood, Leicestershire. G=granite; S=metamorphosed shales.

felspar, quartz, and sometimes hornblende—corresponds with the lava-rock rhyolite; but there are also rocks corresponding to the other volcanic products. The whole group is called Plutonic,[1] from the circumstance of its deep-seated origin.

FIG. 123.—Veins of granite (G) piercing slates (S) of Tremadoc age, and enclosing patches of them; Tan-y-Grisiau, Carnarvonshire. (From a photograph by Mr. Griffith Williams: copyright.)

Thus there are acid, intermediate, and basic plutonic rocks which correspond, species for species, with the volcanic rocks, and the table on page 168 may be extended as follows:—

CLASSIFICATION OF IGNEOUS ROCKS

		ACID.	INTERMEDIATE.		BASIC.
		ORTHOCLASE.		PLAGIOCLASE.	
		With Quartz.	Without Quartz.	Hornblende or Augite.	Augite with Olivine.
Glassy	Volcanic	Obsidian, Pitchstone	Trachyte-glass	Andesite glass	Tachylyte
Partly Crystalline		Rhyolite, Quartz-porphyry	Trachyte, Felsite	Andesite Porphyrite	Basalt
Coarsely Crystalline	Plutonic	Granite	Syenite	Diorite	Dolerite, Gabbro

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[1] Pluto = god of the lower regions.

Dykes, Sills, and Laccolites.—These rocks occur in dykes and sills, like those already defined (see pp. 158, 159).

FIG. 124.—Ideal section of a laccolith, showing cover (*c*), sole (*s*), feeder (*f*), and easement dykes and sills (*e*).

FIG. 125.—Section of a laccolith in which the feeder is along a fault-plane, to which the asymmetry of the mass is due. Lettering as in Fig. 124.

They also occur in great masses of irregular outline, which are called bosses or *stocks* (see Fig. 129, p. 187), and occupy many square miles in area at their outcrop, like the Dartmoor and Cornish masses. There is another curious manner in which plutonic and volcanic rocks occur that demands a few words of explanation. These are called *Laccoliths*.[1] If the rock is

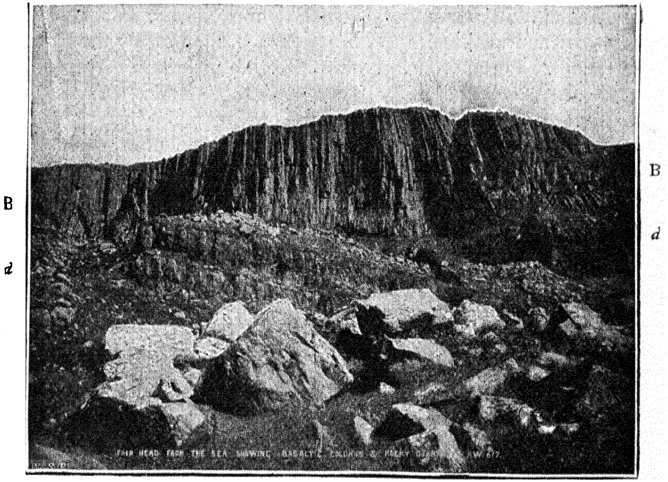

FIG. 126.—Fair Head, Antrim. An intrusive mass (laccolite) of dolerite (B), 250 feet high, intrusive into Carboniferous rocks (*d*). (From a photograph by Mr. R. Welch.)

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[1] Gr. *laccos* = a cistern, *lithos* = a stone.

intruded amongst strata while they are being folded they will tend to occupy any hollows or regions of low pressure due to the folding. During the making of an anticline the arching of the higher strata relieves the lower from part of their weight. When hard beds rest on softer ones the hard beds tend to arch, while the softer crumple. Into the core of such an arch lava will be intruded, and solidify as a cake (Figs. 124, 125). This type of intrusion will be seen to have a distinct connexion with sills, but the intrusion obeys the stratigraphy of the area as a whole. Fair Head (Fig. 126) is an excellent example of a laccolith. Other movement planes, such as fault- and joint-planes, may also become injected with the molten magma, and many dykes take this position.

Contact Alteration.—Plutonic rocks produce much change in the rocks into which they are intruded. The rocks are baked, and new minerals, such as mica and andalusite, are often formed in them. The fragments broken off by the force of the intrusion and enclosed in the molten magma become still more intensely altered. In some cases included fragments are partly or wholly melted, their constituents mingling with the enclosing rock and effecting considerable changes in its composition. Sometimes single crystals survive and remain enclosed as porphyritic crystals. These changes will be discussed in more detail in the ensuing chapter (see p. 187).

Age.—The age of a plutonic rock is very difficult to ascertain, unless it is associated with volcanic surface-products, the age of which can be made out with certainty. The first thing is to find out the age of the latest rocks into which it intrudes; the intrusive rock will always be newer than that which it penetrates. If it has been subject to denudation we can next ascertain the oldest rocks which contain pebbles or other fragments derived from it. But if it is connected with the folding and faulting of a definite period, and the age of this movement can be ascertained, we can then approach more nearly the age of the intrusion. Even then it is difficult to ascertain whether it is linked with the beginning, middle, or end of the movement. The granite of Dartmoor is intrusive into folds in the Carboniferous rocks, so that its age is probably post-Carboniferous; this is confirmed by the fact that the Permian breccias contain fragments derived from the granite.

As plutonic rocks are formed deep down, a great amount of material must be denuded before they are exposed to day, and this takes a great deal of time. Sufficient time has not usually elapsed to expose the plutonic products of volcanoes recently active, and the newest plutonic rocks we are acquainted with in Britain are the Tertiary granites and gabbros of Mull and Skye. For this reason the older plutonic rocks are much more commonly exposed than more recent ones

Igneous Rocks.—The word igneous[1] is used to include both plutonic and volcanic rocks.

Description of Plutonic Rocks

Texture and Structure.—Like volcanic rocks the granites and their associates may be porphyritic, large felspars being frequent in occurrence, while micas, hornblende, augite, and olivine are all to be found in a porphyritic state in the different members of the family. The other crystals are often large enough to be recognised by the naked eye or pocket-lens. In the acid rocks quartz is often the last mineral to form, and it moulds itself upon the previously-formed crystals of felspar and mica. Occasionally quartz and felspar crystallise simultaneously, when the quartz is deposited along the cleavage planes of the felspar, so that on a cross-fracture it looks somewhat like Hebrew writing ; this is called *graphic*[2] or pegmatitic texture. Often two or three minerals have crystallised so nearly simultaneously that none of the crystals are perfect, and then the structure is said to be *granular.*[3] In the basic rocks plagioclase felspar often crystallises first, and becomes enclosed in large plates and crystals of hornblende or augite ; this texture is called *ophitic* (see Fig. 9, p. 13). Plutonic rocks are sometimes columnar, but more usually cuboidal or platy in their jointing, and spheroidal structure is not uncommon, particularly in the basic types.

Acid Rocks.—*Granite*[3] consists of orthoclase felspar, quartz, and mica, both black and white mica being present in the typical rock (see Fig. 5). Sometimes only one is present ; white mica alone somewhat rarely, brown mica commonly.

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[1] Lat. *ignis* = fire.

[2] Gr. *grapho* = I write.

[3] Lat. *granum* = a grain.

The latter may be more or less replaced by hornblende, when the rock is called a hornblendic granite. Usually a certain amount of plagioclase is present, and often minute minerals such as apatite, zircon, and rutile. The chemical composition is distinctly acid, there being from 65 to 75 per cent of silica. There is little iron, lime, or magnesia, but a considerable proportion of potash or soda. Plagioclase is generally the first mineral to solidify; then mica, then orthoclase, and lastly quartz (see Fig. 8).

The quartz contains minute cavities usually filled with water. The specific gravity of the rock is about 2.5. It usually occurs towards the centre of mountain ranges, in huge intrusive masses (see Figs. 121, 122, 129). British examples occur in Cornwall, Dartmoor, Skiddaw, Mount Sorrel, and the Cheviots.

Intermediate Rocks.—*Syenite*[1] is a rather rare rock. It is practically a granite without quartz, but the mica is usually replaced by hornblende, and more plagioclase is usually present than in granites. Chemical composition: silica only 65 to 60 per cent; potash and soda about equal; and lime, iron, and magnesia a little more abundant than in granite.

Diorite[2] is a syenite in which plagioclase felspar is present in larger quantity than orthoclase: hornblende is usually present; and quartz may occasionally be found in it. Diorite occurs at Nuneaton, in the Malverns and North Wales, and in Ireland and Scotland. Chemically it does not differ much from syenite, but there is more lime and soda and less potash. The silica percentage varies from 60 to 55.

Basic Rocks.—*Dolerite*[3] *and Gabbro*[4] are not very sharply-defined terms, and we may deal with both rocks together. The chief minerals are plagioclase, usually a soda-lime or lime-felspar, with augite, magnetite, and sometimes olivine. Generally the felspar is embedded in great crystals of augite, which have evidently developed last of all. The composition of these rocks shows from 45 to 55 per cent of silica and a large proportion of lime and magnesia—the lime in the felspar, the magnesia in the augite and olivine when it is present; the proportion of alkalies is small. There are gabbro areas in Cornwall, in Ayrshire, and in Mull and Skye, and it occurs

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[1] After Syene = a place in Egypt.

[2] Gr. *dioros* = a clear distinction.

[3] Gr. *doleros* = deceitful.

[4] An Italian name for the rock.

usually in a somewhat central position, surrounded by masses of basic lava, such as basalt. The term *Gabbro* may be used for coarsely crystalline rocks with granular structure, and *Dolerite* for those with ophitic structure (see Fig. 9). Dolerites occur as intrusions in the Ordovician rocks of Wales, in the Carboniferous rocks of the Midlands and Scotland, and amongst the Tertiary volcanoes of North-east Ireland and Western Scotland.

Relationship of Different Types.—There are no absolutely hard and fast lines between the different groups of crystalline rocks, and one type constantly shades into another.

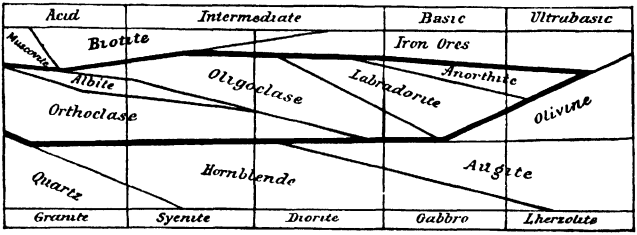

FIG. 127.—Scheme to show the relationships and mineralogical affinities of the plutonic rocks. The centre of each vertical column gives the average composition of the rock; to the right are its more basic, and to the left its more acid varieties, graduating into the neighbouring species. The felspars are within the thick line.

This is roughly expressed by the diagram (Fig. 127), which represents the chief variations in composition of each of the five great groups of plutonic rocks, and also the more usual way in which each graduates into its more acid or more basic neighbour. Thus while the most common minerals in granite are quartz, orthoclase, and mica, it is very rarely that albite is absent, and both oligoclase and hornblende are common constituents. By diminution of quartz and increase of hornblende, granite shades into syenites and diorites, but varieties of both these rocks contain mica. As the felspar becomes more basic, and oligoclase gives way to labradorite, mica usually disappears, augite replaces hornblende, and magnetite steadily increases. Then olivine and anorthite come in, until we have rocks consisting of olivine, augite, and iron ores, with very little felspar, that being of the most basic type, or none at all.

RECAPITULATION

That part of the lava of a volcano which does not reach the vent but *cools deep down*, will acquire characters never found in surface lavas. The crystals will he *larger*, the texture completely *crystalline*, the rock *compact* and not scoriaceous, while the steam will be shut up in the crystals instead of escaping. The fused rock will burrow among the sedimentary rocks in the form of *veins*, *dykes*, *sills*, *laccoliths*, and *stocks*.

Such characters it is which mark the difference between the *granites*, and other rocks related to them, and the surface volcanic products, the lavas which pour out as streams from volcanoes or make the more superficial dykes.

Granite, syenite, diorite, gabbro, and dolerite are all related in the characters just enumerated, and as a class they are spoken of as *plutonic rocks*. They represent the *roots of volcanic districts* or the molten rock which strove to reach the surface from below, whether with or without success.

They are connected with volcanic rocks by a graded series of *transitional forms* found at different depths in old dissected volcanic districts, such as the Cheviots. But sometimes, indeed generally, any surface products which may have existed have been long ago swept away by denudation. In consequence it is not easy to determine the *age* of the plutonic rocks, and this is only to be done by the tests of intrusion, contained fragments, and correlation with periods of earth-movement.

QUESTIONS ON CHAPTER XIV

1. Give a definition of each of the two classes (plutonic and volcanic) into which igneous rocks have been divided. Name two examples of each class. (1879.)

2. What is meant by the term "plutonic rocks"? How do such rocks usually occur, and what are their chief characteristics? (O and C.)

3. Describe the mineral structure of granite (including any varieties known to you). Give an account of the denudation of granite, and mention the rocks which are formed from its waste. (O and C.)

4. Describe the following rocks, and indicate their origin: basalt, granite, clay slate. (O and C.)

5. State what you know on the following points :—
    (*a*) The chemical composition of the rhyolites.
    (*b*) The minerals which occur in rhyolites.
    (*c*) The differences between rhyolites and granites.
    (*a*) The differences between rhyolites and andesites. (1896.)

6. Mention four of the most common kinds of igneous rocks, and state their mineral composition. (1880.)

7. Define and classify the following rocks: pitchstone, trachyte, tuff, lapilli, diorite, dolerite, pumice. (XII.)

8. Briefly describe the minerals which go to form granite or basalt. (1886.)

9. Mention the chief districts where granite is found in the British Islands, and give one instance where the geological age of the rock can be determined. (1889.)

10. Compare granite and basalt as regards (1) chemical and mineralogical composition; (2) structure and texture; (3) mode of occurrence; and (4) origin. Name two British localities for each of these rocks. (O and C.)

11. (*a*) In what respects do veins and dykes differ from one another?
    (*b*) What kinds of rocks are found forming veins and dykes respectively?
    (*c*) What effects are produced by dykes on the rocks through which they pass?
    (*d*) What effects are produced when dykes and the enclosing rocks are subjected to denudation? (1886.)

12. Describe the mode of formation of dykes and the appearances which they usually present. Name and briefly describe the kinds of rocks of which dykes are composed. (O and C.)

CHAPTER XV

FOLIATED ROCKS

WE have hitherto ignored one whole class of crystalline rocks. These are more or less perfectly crystalline, in some cases as completely so as granite itself, but the minerals are arranged in plates, giving to the rocks the aspect of lamination. This structure is spoken of as *foliation*[1] and the rocks as *foliated.* The association together of foliated rocks of different kinds also simulates stratification, bands of one character resting on those of a different type. The crystalline texture, associated with foliation and with the simulation of bedding, suggests that these rocks are either sediments which have become crystalline or igneous rocks which have become banded. It is even possible that both causes may have been in operation.

Thermometamorphism

By Volcanic Rocks.—We can study the alteration of sediments where they are intruded upon by igneous rocks. Every kind of igneous rock produces a certain amount of effect, but that due to dykes which have solidified near the surface is slight, and amounts to little more than the baking of clays or shales and the slight hardening of other rocks. The coarser the crystalline texture of the intrusive rock the longer it has taken to cool, and the greater, as a rule, are

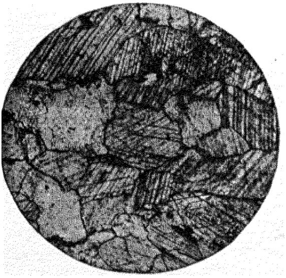

FIG. 128.—Microscopic section of crystalline limestone, Argyll; granular calcite (about $\frac{8}{1}$).

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[1] Lat. *folia* = leaves.

its effects on the rocks upon which it intrudes. Coals are coked or burnt, clays are baked into an impure porcelain known as *porcellanite* or lydite, in which a development of small crystals can be seen, limestones pass into a mass of calcite crystals sometimes interlocked firmly enough to produce a *marble* (Fig. 128), and sandstones and grits pass into *quartzite*, in which the grains are closely cemented together with silica, so that the rock looks like loaf-sugar. These changes have been imitated by the action of heat alone. Porcelain is baked or burnt clay. Powdered limestone, shut up in a strong iron box and submitted to a low red heat for several days, is not burnt into lime as would be the case in a lime-kiln, but converted into a marble or saccharoidal[1] limestone made of crystalline calcite; while the sandstone used for lining blast-furnaces, and left for months in contact with molten iron, becomes transformed into a rock very much like quartzite. All these changes are in the direction of crystallisation.

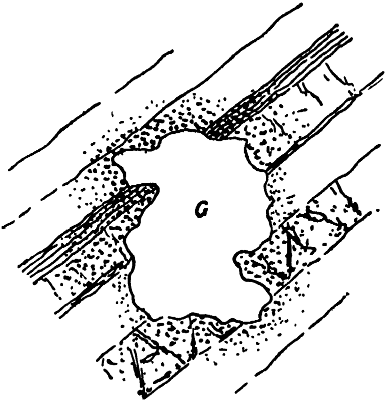

FIG. 129.—Plan of an intrusive mass of granite to show the "aureole" of contact-metamorphism round it. The metamorphic action extends farther in some rocks than in others.

By Granites.—On the borders of granite masses, however, much greater changes can be seen. The alteration can be observed to begin sometimes a mile away from where the granite is exposed at the surface (Fig. 129). Slates in this position are merely hardened. A little nearer the granite spots begin to appear, and on tracing them towards the granite, the spots gradually pass into crystals of *chiastolite* (Fig. 130). Nearer again come rocks with *andalusite*, which is often associated with mica; and quite

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[1] Gr. *saccharon* = sugar, *eidos* = form.

near the granite we have a true mica-schist made of crystalline quartz arranged in layers, which are separated from one another by folia of crystalline brown mica. Other minerals developed under these circumstances are white mica (see Fig. 122), staurolite, sillimanite, and cyanite. Volcanic ashes and lavas undergo changes which vary according to their composition; the new minerals developed being hornblende, brown mica, felspars, epidote, quartz, tourmaline, etc. Limestones when pure pass into crystalline limestones or marbles, but if impure the extraneous substances build up new minerals, crystals of which are to be seen embedded in the marble: Idocrase, augite, garnet, and scapolite are formed thus. Traces of fossils and of structures such as lamination are sometimes utterly destroyed in these rocks, many of which become mere masses of crystals. In some cases, however, the signs of lamination remain after the rock has become foliated, and roughly parallel lines of small inclusions traverse the crystals however the latter may be situated, making it quite clear that the crystals have grown on the spot in which they are found.

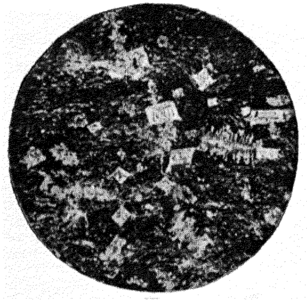

FIG. 130.—Microscopic section of chiastolite schist. The chiastolite crystals contain inside them some of the impurities of the rock, arranged more or less parallel to their outlines (about $\frac{8}{1}$).

Heat and Water.—In these great changes produced by *contact-metamorphism*,[1] as the action is called, probably heat is not the only agency brought into play. Water at a high temperature, often loaded with mineral matter in solution, steam, and other vapours given off by the plutonic mass, certainly do their share in producing the changes. Experiments with water were tried by Daubrée, who enclosed clay and other substances in glass tubes with plain water. The tubes were then placed in strong iron jackets and submitted to high temperatures for weeks or even months. The glass of the tube was found to be acted upon by the water and

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[1] Gr. *meta*, signifying change, *morphe*=form.

crystalline quartz formed, while the action of water on clay produced crystalline quartz and mica. When waters containing alkalies in solution were substituted for plain water crystals of felspar were made out of the clay.

High temperatures do not seem to be absolutely necessary for such changes. The structure and contents of a Roman aqueduct built to carry warm mineral water to supply baths at Plombières, in East France, were found by Daubrée to have been converted into crystalline rocks full of silicates and other minerals, formed from the reaction of the mineral water of the spring upon the materials of the bricks and mortar, and upon coins. Thus, if sufficient time be allowed, important mineral changes occur even where the temperatures are far below the boiling point.

The action of steam and vapours may be seen on Monte Somma. In the old lavas and tuffs of this part of the ancient cone of Vesuvius, a great number of different minerals are found to be produced in the limestones, clays, and volcanic substances which make up the agglomerates. Serpentine, micas, idocrase, scapolite, augite, meionite, and wollastonite are examples.

When all these agencies—heat, steam at high temperatures and pressures, and water laden with mineral matter in solution—are brought to bear for the very long periods during which a mass of plutonic rock is slowly cooling down, the great change effected is easily accounted for.

Regional Metamorphism

But foliated crystalline rocks occur not only in direct association with great plutonic masses, and in graded belts round them: They are found covering vast areas of the earth's crust, sometimes entirely unconnected with any normal plutonic rocks whatever, and they cannot all be accounted for by contact with hidden igneous masses. This is the case in nearly all mountain chains, whether comparatively modern like the Alps, or deeply denuded like the North-west Highlands of Scotland and Ireland, or worn to stumps like Anglesey. The bulk of the rocks exhibit foliation, that is, the arrangement of fairly perfect crystals in a platy fashion, so as to give a grain to the rock. It must not be confused with bedding, in which detrital materials—not perfect crystals—are arranged in sheets; nor with cleavage, due to the arrangement of the elongated particles of the rocks in one direction so as to give rise to a grain that determines the direction of splitting. Here we have the rock made up of successive plates of which one will consist chiefly of felspar, another chiefly of quartz, and another of some other mineral, perhaps mica or hornblende. If the rock splits up into thin plates parallel to the foliation, the structure is spoken of as schistosity, a structure generally exhibited by the schists.

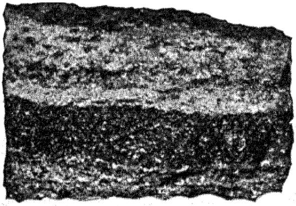

FIG. 131.—A piece of hornblendic gneiss, Aberdeenshire, showing foliation (about ⅓). (From the collection of H.M. Geological Survey.)

Definition of Rocks.—*Gneiss*[1] is practically identical in mineral composition with granite, but the minerals are arranged in folia, alternately layers of quartz and felspar with mica, either white or brown or both (Fig. 131). Layers of a single pure mineral are uncommon; more usually the folia are richer or poorer in particular minerals such as felspar, mica, or hornblende. A gneiss may contain porphyritic felspars, or it may possess other minerals in substitution for those enumerated, microcline or plagioclase in the place of orthoclase, hornblende in substitution for mica. While typical gneisses correspond in chemical composition with granite, others can be found which correspond with syenites, diorites, and even gabbros, the last being basic hornblendic gneisses of a type common in the North-west Highlands of Scotland. Foliation may be on a small scale and in thin leaves, or it may be so massive that it is not seen in a hand specimen, but can only be detected by a study of the rock in the field. *Augen-gneiss*[2] has its porphyritic crystals rounded at the ends with mica or hornblende bending round them, so as to look like eyebrows over an eye; hence the name. Garnet, andalusite, and sillmanite are sometimes present in gneisses.

Granulites[3] usually show a banding like gneisses in hand

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[1] German miners' term.

[2] Ger. *auge* = an eye.

[3] From granular.

specimens and the field, but when microscopically examined they are found to be made not of complete crystals, but of a number of irregular crystalline grains of approximately even size interlocking together (Fig. 132). They are found to be produced when many rocks, particularly gneiss rocks, are submitted to sufficiently great strain to cause them to yield and "flow" without being melted. The different kinds of granulites compare in composition with varieties of gneiss.

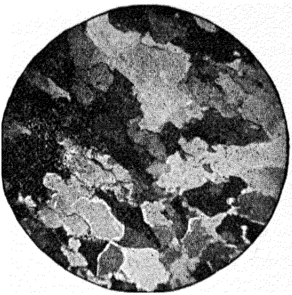

FIG. 132.—Microscopic section of granulite, to show the interlocking of the grains of quartz and felspar; taken with polarised light (about $\frac{8}{1}$).

Schists[1] are finely foliated rocks of very various composition, named generally after the chief minerals which they contain. *Mica-schist* (see Fig. 133), which may be taken as a type, is composed of leaves of white or brown mica alternating with layers of crystalline quartz, felspar being as a rule absent.

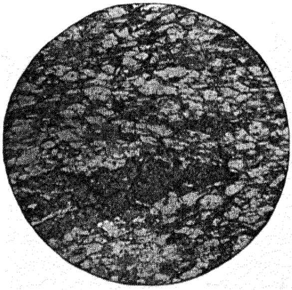

FIG. 133.—Microscopic section of mica-schist, showing foliation. The quartz is white, the mica slightly shaded, and the hornblende dark (about $\frac{8}{1}$).

FIG. 134.—Microscopic section of hornblende-schist. The felspar is white, and the hornblende tinted (about $\frac{8}{1}$).

Hornblende-schist is more basic in composition and consists of elongated hornblende foliated with plagioclase felspar (Fig. 134).

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[1] Gr. *schizo* = to split.

Chlorite-schist consists of chlorite with some felspar; talc-schist, chiefly of talc, sometimes with minerals related to hornblende; calc-chlorite- and calc-sericite-schists contain calcite with chlorite or sericite (a white hydrated mica).

Schists and gneisses are often contorted, faulted, and disturbed (see Fig. 73), and their outcrop can be mapped out like bands of sediments.

Mylonites[1] are compact, banded, shale-like rocks, produced by the crushing down of other rocks, generally at thrust-planes. They contain microscopic particles (augen) of rock still uncrushed, embedded in a ground mass which has been crushed to powder and more or less recrystallized.

Although not, strictly speaking, foliated rocks, those included in the following class must be described here, as they are so often interbedded and associated with foliated rocks.

Quartzites have originally been sandstones in which the quartz-grains have grown larger since they were deposited, new quartz being deposited on the surfaces as though with a definite intention to build up a complete crystal. Adjacent grains have grown till they met and the incipient crystals have become interlocked. Under polarised light we have a mosaic of irregular, interlocking, quartz-grains, but without it the microscope enables us to identify the outline of the old grains inside the new quartz. The original grains may be recognised in the middle of Fig. 135 inside the irregular quartz masses.

FIG. 135. — Microscopic section of quartzite from Little Caradoc, Shropshire. The original grains (slightly tinted) are to be seen inside the new growth of quartz at their edges (about $\frac{4}{1}$).

Metamorphosed conglomerates and coarse grits are occasionally met with. In them the nature of the original grit-grains or pebbles is sometimes recognisable, although altered to granulite or collections of minerals; the matrix is generally altered into such minerals as mica, chlorite, and calcite.

Phyllites[2] look like glossy slates, but under the microscope they are seen to be wholly made up of tiny flakes of white mica arranged in parallel folia so minute as only to be made out

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[1] Gr. *mylon* = a mill.

[2] Gr. *phyllon* = a leaf.

when magnified. They appear to have been produced by the alteration of fine slates.

Marbles and crystalline limestones consist of crystalline grains of calcite arranged to interlock like those of quartzite, but all trace of original structure is obliterated (see Fig. 128). Other minerals such as garnets, idocrase, augite, and hornblende are sometimes found in them.

The presence occasionally of rocks belonging to the group last described amongst complexes of gneisses and schists proves that altered sediments occur amongst the foliated rocks. But the bulk of the gneisses, granulites, and some of the schists, cannot be thus accounted for.

Flow-Structure.—On the borders of many granites, and other plutonic masses, undoubtedly intrusive in character, the flowing of the igneous rock in the final stages of consolidation has produced a flow-structure indistinguishable from foliation. Many granites are as much foliated as gneisses, and some gneisses have originated in this fashion.

Injection Structure.—Again, during the injection of an igneous rock into a sediment we have seen that it sometimes splits open the bedding planes and forms sills. This occurs also on a smaller scale, and small tongues and veins find their way between the planes of lamination. The thin sheets of sediment become intensely metamorphosed and are filled with new crystalline minerals, so there is produced a rock which is an intimate mixture of gneiss of igneous origin and schist of sedimentary origin.

Earth-Movement and Crystalline Rocks.—Further, it occasionally happens that an indubitable dyke of igneous rock can be traced into a region where earth-movement has been very severe. It is then found to become sheared, and its minerals to undergo change ; new minerals being developed in folia parallel to the planes of shear. Dolerite is thus found to pass into hornblende-schist, the decomposed felspar growing again as a new water-clear felspar, the augite passing into hornblende, and the iron ores helping to form new minerals. The same thing is observable in still more basic rocks which pass into talcose and chlorite schists, and in more acid and intermediate rocks which pass into ortho-gneisses and granulites. Porphyritic crystals sometimes survive this process while all else is changed, and augen-gneisses and schists are the result.

Earth-Movement and Sediments.—If igneous rocks may undergo this *dynamic*[1] *metamorphism*, as it is called, when consolidated and hardened, we should expect that sediments would undergo a like change when submitted to great crushing pressure, and to the action of water, and possibly heat; especially when the composition of the rock was not unlike that of an igneous rock, being made up of fragments of such minerals as felspar, quartz, and augite, hornblende, or mica. Gneissic rocks (paragneisses) and schists may be formed out of sediments under such circumstances.

Complexity of Origin.—Thus foliated rocks may be made by contact-metamorphism, by flow-structure produced in igneous rocks injected under pressure, by leaf-by-leaf injection into sediments, and by dynamic metamorphism of igneous rocks or sediments. All these agencies may not be in operation at any one spot, but probably most of them were in action in the typical areas of crystalline schists. Now most of these areas occur in mountain-chains, or in places, like Anglesey and the Highlands of Scotland, which are the stumps of mountain-chains worn down by denudation. In forming mountains the rocks become intensely compressed, cleaved, folded, and faulted. Volcanic activity is, as a rule, rife during the period of their elevation, and intrusion of igneous material goes on side by side with the uplift and contortion. Igneous intrusion will take place along lines of weakness, faulting, and folding, and parallel to planes of bedding and cleavage, the igneous rock acquiring flow-structure owing to the state of intense pressure existing as it is squeezed into the sediments; leaf by leaf injection will also occur, accompanied by the severe alteration of the sedimentary leaves; aureoles of metamorphism will be formed round each greater mass of plutonic rock; and further earth-movement when the igneous rocks have consolidated, accompanied by intense heat and the percolation of heated and mineral-bearing waters, will bring about still greater changes in the consolidated, massive, igneous rocks and in the associated sediments.

Foliated crystalline rocks are therefore, in all probability,

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[1] Gr. *dynamis* = strength, force

the result of the reaction of the interior of the earth on the exterior, brought about chiefly at the plane of contact of the two under the strain and stress of earth-movement. The product will consist partly of the matter from the interior acquiring a peculiar character from the circumstances of its intrusion, partly of an intimate mixture of the internal with the external material, partly of external matter acted upon by that from the interior, and partly of the result of the reaction upon both classes of rock of the great dynamical and chemical forces brought into play along this remarkable zone of contact.

As these rocks are highly complex in origin and have undergone such serious disturbance, it is evident that the surfaces of junction of different types must not be interpreted as bedding planes, nor must the apparent succession of the rocks be read as though they were unchanged sediments.

RECAPITULATION

The rocks of a great group, hitherto passed over, are *crystalline* in texture, but the crystals are arranged in layers which are called *folia*. These are the *foliated crystalline rocks*. Different types of these rocks are *interbanded* together, as though they bore some relationship to stratified rocks.

While it was at one time thought that they were the results of precipitation from a primæval and heated ocean, and later that they were *metamorphosed sediments*, it is now believed that they are *complex* in the mode of their origin.

Structures and textures such as are found in these rocks occur where sediments have been *altered* by *contact* with great intrusive masses like granites; where igneous rocks have been *intruded* under *great strain*; where igneous rocks have been injected *leaf by leaf* into sediments; where either sediments or crystalline rocks have been subjected to the *dynamical* effects of great *earth-movement* in the formation of mountain-chains; and where a mass of rock has at a great depth and pressure been subjected to the percolation of *heated waters*.

In the great *regions of metamorphism* probably many of the agencies just enumerated have been at work together, compelling the rocks to take on new *structures* and new *mineralogical* and *crystalline* textures under the *directing influence of earth-movement*. Whatever were the prominent planes in the rock when the change took place, whether of *bedding*, *cleavage*, *thrust*, *contact*, or other directions of movement and *weakness*, they would be emphasised by the metamorphosing agencies, and along such planes the new mineral development would take place.

QUESTIONS ON CHAPTER XV

1. What effects are produced by igneous rocks on sedimentary strata? (1879.)

2. State concisely the characters by which you can distinguish an aqueous from an igneous and from a metamorphic rock. (O and C.)

3. What is meant by metamorphic rock? Give an example. (1882.)

4. What is metamorphism? State the several kinds of metamorphic rocks and their several uses. (O and C.)

5. State the distinction between lamination, foliation, and cleavage. (1885.)

6. What is the difference between sandstone, quartz, and quartzite? (1888.)

7. In what respects does sandstone differ from quartzite, shale from schist, and granite from gneiss? Give some explanation of the difference in each case. (O and C.)

8. Explain what is meant by—
   (*a*) Contact-metamorphism.
   (*b*) Regional or general metamorphism.
Give the names of three rocks which are formed by—
   (*c*) Contact-metamorphism.
And of three rocks formed by—
   (*d*) Regional metamorphism. (1897.)

9. (*a*) How does gneiss differ from granite?
   (*b*) How does a slate differ from a shale?
   (*c*) Name three minerals commonly found in rocks altered by contact-metamorphism.
   (*d*) Name the chief varieties of schist. (1896.)

10. Define the following rocks, and state how you believe them to have been formed—gneiss, mica-schist, slate, granulite. (XII.)

11. Describe the following rocks—granite, gneiss, mica-schist, clay slate—and give a short account of their chemical composition and mode of formation. (O and C.)

CHAPTER XVI

FOSSILS

Occurrence and Preservation

IN most sedimentary rocks fossils are to be found. These are traces of the remains of organisms, usually bones, shells, and teeth of animals ; bark, wood, leaves or seeds of plants ; footprints or tracks ; and much more rarely the moulds of soft parts of animals or plants. When well-preserved examples of these are collected from the rocks in sufficient numbers much use may be made of the study of them.

Preservation.—In many clays and recent deposits the hard parts of the objects themselves are preserved, with the mere loss of the organic matter which fills the interstices of the solid framework or shell (p. 293). More usually a cast is taken or a substitute formed. When shells lie on the soft sea-bed they may impress their shape upon it, particularly when compressed by the deposit of other sediment on the top. If the shell is afterwards dissolved away the shape of the *mould* or *external cast* alone may remain, and it is necessary to take a cast of it in wax or plaster to see the shape of the organism (Fig. 84). Sometimes Nature does this herself by the deposit of mud from suspension or mineral matter from solution, in the mould, taking a perfect *cast* (Fig. 51). Again, a cast of the interior of a hollow structure (an *internal cast*), such as a shell (Fig. 214), may be taken, and if this remains after the shell is dissolved a natural cast may be made in the space between the outer mould and the internal cast, which will reproduce both the inside and outside of the shell so far as its outer and inner markings are concerned ; this is called a *hollow cast.* This kind of cast, and indeed all casts and moulds, will preserve only the markings of the surfaces and not the internal structure or the material of the shell.

When *replacement* occurs the shell, bone, or vegetable fragment is dissolved and removed particle by particle, and as each one is removed a particle of some substitute is deposited out of solution in its place (pp. 253, 276). This is done with such exactness that the old structure is preserved in the new substance with absolute perfection, so that every detail of its internal character is preserved (Fig. 145). Fossil wood replaced by opal or silica shows the microscopic character of the cellular structure as well as a modern bit of wood; and the same is true of shells, and even, but very rarely, of dead animal matter. Carbonate of lime is sometimes replaced by carbonate of iron, silica, pyrites, and occasionally galena. Another kind of substitution occasionally takes place—that of one *form* of a mineral for another. Thus shells originally made of the form of carbonate of lime called aragonite may be replaced by the more permanent crystalline form called calcite.

Nature of Fossils.—In marine deposits the bulk of the fossils will be such as live in the sea, either at the top or in the middle of the water, or on the bed of the sea; but occasionally organisms will be drifted from a distance, even from the shores of the sea and the rivers that flow into it. Shells which live in mud may be buried where they lived, and when found they will be embedded in the position in which they grew. Such fossils are useful as showing that the process of deposition has been slow and gradual. In coral deposits, too, the corals may make up the mass of limestone in the position in which they grew. But the majority of fossils will be the relics of dead organisms, whole or broken, and dropped amongst the other deposited matter.

Derived Fossils.—In a pebbly deposit some of the pebbles may contain fossils, or the fossils may be weathered out whole and deposited in newer sediments. These are obviously not of the age of the bed in which they are found, but have been derived from an older deposit; so they are spoken of as *derived fossils.* They will show signs of wear and tear owing to transportation, and they must be carefully distinguished from the indigenous fossils of the rock. They are often preserved in material of different composition from the indigenous fossils (see Fig. 96).

Classification

Most fossils can be recognised as being somewhat like such animals or plants as are still living, but cases of exact resemblance are comparatively rare and confined to the newer deposits. Still most of these forms admit of being inserted into the usual classification of the animal and vegetable kingdoms, so that it is necessary to have some knowledge of living forms and their classification.

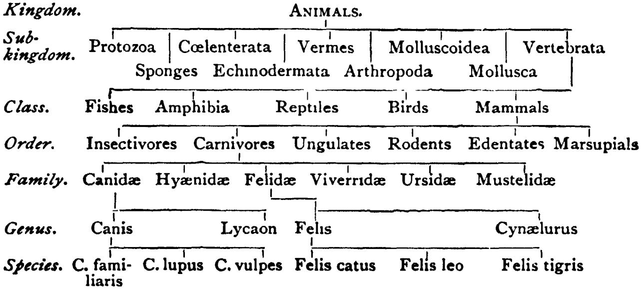
Species and Genera.—In classifying human beings we begin with the individual. A number of *individuals* will be found to be closely related together and to belong to the same *family*. Again, a number of related families will form a *tribe*, and several tribes or states living in proximity to one another may become united into a single *nation*.

So with animals or plants, we may begin by assorting together all those individuals which are alike in all their essential characteristics, such as general shape, proportion of parts, habits of life, colour, and bodily structure. These when linked together may be spoken of collectively as a *Species*. All domestic cats would belong to one species, tigers to another, and lions to a third. When typical examples of one species are compared with typical examples of another there may be found certain important characters which link several species together and separate them from other groups of species. Thus the general outline, the shape of the head, the 30 teeth, and the power of drawing in the claws, are characters which, on the one hand, bind together the lions, tigers, and cats, and on the other separate them from the dogs, wolves, and foxes, which possess 42 teeth, non-retractile claws, 5 toes on the fore-foot and 4 on the hind-foot. So all species of true cats are grouped in one *Genus*, the cat genus (*Felis*), which will include such species as the domestic cat (*Felis catus*), the tiger (*Felis tigris*), and the lion (*Felis leo*). Similarly all the dog-like species are placed in another genus (*Canis*), which includes the domestic dog (*Canis familiaris*), the fox (*Canis vulpes*), the wolf (*Canis lupus*), and some others.

Families.—But there are other dog-like animals, such as the Cape hunting dog (*Lycaon*), which has 4 toes on each foot, and these differ too much from ordinary dogs to be included in the genus *Canis*. Similarly there are cat-like forms, such as the cheetah (*Cynælurus*), with non-retractile claws, which do not belong to the genus *Felis*. But all the dog-like genera may be united into a dog *Family* (*Canidæ*), and the cat-like genera into a cat *Family* (*Felidæ*).

Orders.—All dogs agree with all cats in the fact that they are flesh-eaters, provided with claws and canine teeth to catch and hold live prey, and sharp molars to eat it, while their toes are all separate and provided with claws. They are thus united into a great group, sharply separated from the vegetable-feeding, hoofed group to which the horse and cow belong, and from the group of animals without canines, but with incisor teeth much developed for gnawing hard substances, to which the mice and rats belong. These greater groups are called *Orders;* and we have the rat and mouse order (*Rodentia*, gnawers), hoofed animals (*Ungulata*), and flesh-eaters (*Carnivora*).

Classes and Sub-Kingdoms.—Finally, the rodents, carnivores, and ungulates are all warm-blooded animals which bring forth their young alive, so they may be grouped together as mammals, one of the *Classes* of the back-boned animals or vertebrata; and the vertebrata form one of the nine great *Sub-kingdoms* into which the whole animal *Kingdom* is subdivided. This classification may be illustrated by the following table, which is merely intended to show the species, genus, family, order, etc., to which the domestic cat and dog respectively belong, and what are their near relatives at each stage of the grouping :—



Description of Fossils

There are nine great subdivisions of the animal kingdom, each of which is of importance to the geologist, so it will be necessary to say a few words about all of them and their principal divisions.

Animals

Protozoa.[1]—In this, the lowest division of the animal kingdom, the body consists of a single mass of jelly-like flesh, in which there are no definite organs, and no parts of the body told off for particular functions. Only those forms which cover themselves with a case of stony matter are preserved in a fossil state.

In the class called *Foraminifera* the covering is made of carbonate of lime, shaped like a globe or flask, or like several globes or flasks united together. They are called *foraminifera*, from the fact that slender, thread-like processes of the body, called pseudopodia, push out through the open mouth of the case or through holes (Lat. *foramina*) pierced in it.

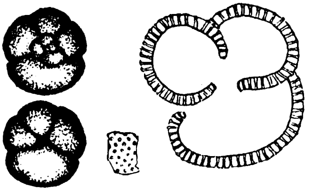


FIG. 136.—*Globigerina*, a Foraminifer (about $\frac{10-20}{1}$). (Z.)

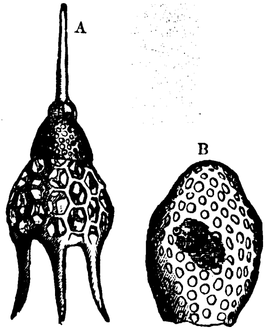


FIG. 137.—Radiolaria (about $\frac{100}{1}$). (Z.)

In the *radiolaria*[2] the case is a geometrical framework of ica. This framework, though exceedingly minute, is often great complexity and beauty, as will be seen from the illustran (Fig. 137).

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[1] Gr. *protos* = first, *zoon* = an animal.

[2] Lat. *radius* = a ray.

Porifera.—In this sub-kingdom, which includes the *sponges*, the body is a little more complex, and its outer layer consists of cells, which are different from those of the interior. The body is traversed by tubes or canals (hence the name *porifera* or pore-bearers), through which water continually circulates, bearing food to the organism (Fig. 138). The body is generally supported by a framework made of horny fibres, as in the bath sponge, or a network made out of needles or spicules of silica or carbonate of lime put together according to a complex pattern. Some of the commoner spicules are shown in Fig. 139.

FIG. 138.—A fossil sponge, *Siphonia* (about $\frac{1}{4}$). (Z after Sowerby.)

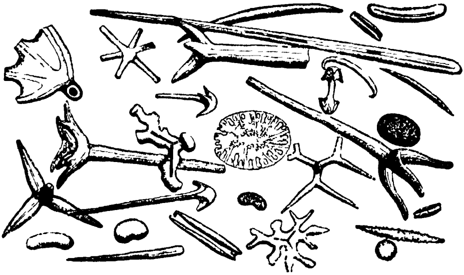

FIG. 139.
Spicules of sponges (about $\frac{15}{1}$) (Z)

Cœlenterata.[1]—The next higher sub-kingdom is so called because it has a definite internal cavity which serves for digestive purposes, and communicates with the exterior by means of a mouth which is surrounded by a ring of "arms" or tentacles. The first division of the Cœlenterata is called the *Hydrozoa*, in which the reproductive organs are external.

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[1] Gr. *koilos* = hollow, *enteron* = intestine.

Graptolites are the most important fossil hydrozoa. A number of similar individual animals are connected together in a series, each one being supported in a little horny cup, and all the cups connected together in a series by a horny skeleton, so that the general appearance of the composite animal is like a quill-pen; hence the name (Gr. *grapho*, I write). Examples are shown in Fig. 140.

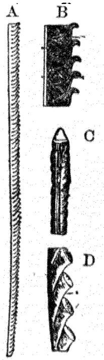

FIG. 140.—*Monograptus*, showing the character of the fossil (A), a portion magnified (B), back view (C), and magnified portion of another species (D) with differently shaped cups. (Z.)

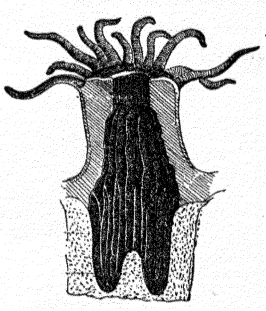

FIG. 141.—Section of a coral, showing soft parts with tentacles, mouth, œsophagus, body-cavity with mesenteries; and solid cup of carbonate of lime with septa and columella. (Z. after Lacaze-Duthiers.)

The second division of the Cœlenterata is known as *Actinozoa*,[1] of which the *Corals* form the most important group. Here the reproductive organs are internal, and in the bulk of fossil forms the soft body is supported by a cup made of carbonate of lime, in which are placed a number of radiating partitions. Sometimes the cups are single, but more usually a large number are united together into a complex mass or corallum. A single coral is illustrated in Fig. 141. The older types of corals belong either to the Rugose or the Tabulate order (see Fig. 199). In the former, the radiating partitions are in multiples of four; in the latter there are partitions or tabulæ bridging the cup (see Fig. 185, p. 243), and the radiating partitions are often wanting. Sex-radiate types were common in Mesozoic times (see Fig. 232).

[1] Gr. *aktis* = a ray, *zoon* = an animal.

Echinodermata,[1] or thorny skins, come next. They present a decided advance in the possession of a nervous system and of a series of internal canals through which water circulates, in addition to a definite digestive canal. The animals are usually symmetrical in outline, and their parts radiate out from a central point, usually in five directions. They are generally protected by an armour of plates or spines made of carbonate of lime. The sub-kingdom includes the star-fishes (Asteroidea[2] and Ophiuroidea[3]), the sea-urchins (Echinoidea[4]), and the "sea-lilies" (Crinoidea[5]).

The *Star-fishes* consist of a central disc with five arms radiating out from it ; the animals are free-swimming.

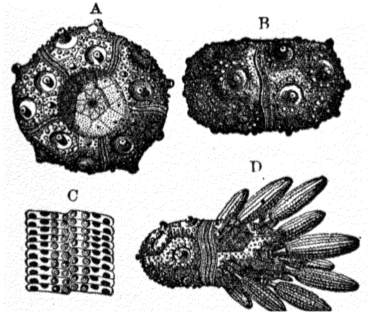

FIG. 142.—*Cidaris*, a sea-urchin (Oolitic). A=top view; B=side view, showing tubercles for attachment of spines; C=ambulacra perforated for the tube-feet; D=spines in position on part of the test, ½. (Z.)

The *Sea-urchins* are enclosed in a heart-shaped, discoidal, or globular case, which is made of five- or six-sided plates of carbonate of lime fitted together. Some of the plates are provided with spines, also made of carbonate of lime, and five sets of these plates, which are arranged in pentagonal fashion, are penetrated by little tubes through which pass the *tube-feet*, by means of which the animal moves (Fig. 142, C).

The *Crinoidea* are like star-fishes attached to a long stalk, and with the rays prolonged into appendages, which may be

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[1] Gr. *echinos*=a hedgehog, *derma*=skin.

[2] Gr. *aster*=a star, *eidos*=form.

[3] Gr. *ophis*=a snake, and *eidos*.

[4] Gr. *echinos*=an urchin, and *eidos*.

[5] Gr. *krinon*=a lily.

again and again subdivided. The main portion of the body is enclosed in a calcareous test, from which the arms (at first five in number) are given off. Crinoids are usually attached to the sea-bed by a jointed calcareous stalk. Broken stems and arms of crinoids are often so common as to build up whole masses of limestone.

Vermes.[1]—This sub-kingdom comprises the worms, in which there is a jointed body with a nervous system, a digestive canal, and a complicated set of vessels and other organs. They only occur as fossils when they are protected by a calcareous tube, or when they burrow into sand and mud and the traces of their burrows and casts are to be found.

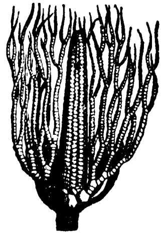

FIG. 143.—Head of crinoid, showing stem, arms, and proboscis, ½. (Z. after Schulze.)

Arthropoda.[2]—In this sub-kingdom the animal is also divided into a number of segments, placed one behind another, and each segment bears a pair of limbs which are often jointed. The animal has complex nervous, digestive, and circulatory systems. The sub-kingdom includes the Crustacea, such as crabs and lobsters, as well as the Spiders, Insects, and Scorpions.

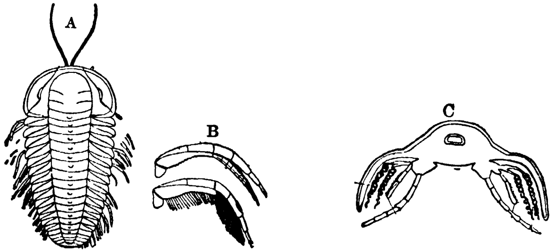

FIG. 144.—A, a Trilobite (*Triarthrus Becki*), showing head, thorax, and tail, each with its trilobation; on the head are the eyes, facial suture, and antennæ; on the thorax and tail are the limbs (Z. after Beecher). B shows detached limbs. C is a cross-section of the thorax in another trilobite showing the limbs in place with spiral gills attached to them (Z. after Walcott).

The most important forms of the older crustacea are known

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[1] Lat. *vermis* = a worm. [2] Gr. *arthron* = a joint, *pous*, *podos* = a foot.

as the *Trilobites*,[1] the name referring to the fact that each of the successive segments is divided into three portions, a central and two outer parts, so that the animal as a whole is trilobed. The front segments are usually united together as a forward portion called the head, which bears the eyes when they are present, the antennæ, and the appendages of the jaws. The succeeding group of segments, known as the thorax, are free, and the hinder set are again united together to form the tail-piece. The number of segments in the thorax varies from two to twenty. The thoracic and tail segments have feet adapted for swimming and gills for breathing, just as is the case with a lobster (see Fig. 144).

Large crustacea known as *Merostomata*[2] occur in rocks of Silurian and Devonian date (see Fig. 195), but they are succeeded by smaller representatives of the group, the King-crabs, from Carboniferous time to the present day.

Decapoda.[3]—This is the order which includes the crabs and lobsters—a group more common at the present day than in past time.

The *Entomostraca*[4] include the water-fleas or ostracoda, which have minute bodies enclosed in a bivalved shell. They are common in Palæozoic rocks, and continue to the present day.

Molluscoidea[5] are soft-bodied animals without segmented bodies, protected by a calcareous or horny coating. In the group known as the Polyzoa[6] the animals are minute, each being enclosed in a separate sac, but many sacs are united to form a colony, as in the "sea-mat" of our shores. In the case of a very important fossil class, the *Brachiopoda*,[7] the covering consists of a double shell, made up of a lower and larger half or valve, in which the animal is contained, and an upper valve which serves as a cover. The two valves are usually unlike one another; but each one is equilateral, that is, it is symmetrical about a line (Fig. 146), down the middle of the valve.

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[1] Gr. *treis* = three, *lobos* = a lobe.

[2] Gr. *mēros* = thigh, *stoma* = a mouth.

[3] Gr. *deka* = ten, *pous* = foot.

[4] Gr. *entomo-* = insects, *ostrakon* = a shell.

[5] Lat. *mollis* = soft.

[6] Gr. *polys* = many, *zoon* = an animal.

[7] Gr. *brachion* = arm, *pous* = foot.

The mouth of the animal is provided with arms, whose function it is to bring food, and most shells contain a curved (Fig. 146, *a*) or spiral attachment for supporting them (Fig. 145). The attachments are, as a rule, more complex in the older brachiopods than in more recent forms. The shells are extremely common as fossils in Palæozoic and Mesozoic rocks, and the *Terebratula* or lamp-shell, so called from its resemblance to a Roman lamp, is a living example. This shell has an attachment for the arms which is something like a carriage spring (Fig. 146, *a*).

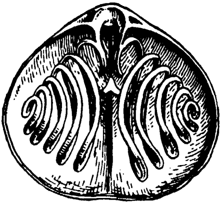

FIG. 145.—A brachiopod (*Nucleospira*) with spiral attachments for the support of the arms. (Z.)

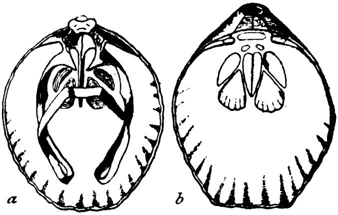

FIG. 146.—*Terebratula* (*Waldheimia*), showing the equilateral shell, foramen (*b*), and the "carriage-spring" apparatus for support of the arms (*a*) ½. (Z. after Davidson.)

Mollusca.—This sub-kingdom includes the shell-fish proper, which may be considered under the head of three great classes. The nervous system is elaborate and the heart well developed.

The *Lamellibranchiata*[1] are headless, and the body is protected by a shell made of two pieces or valves, which, being placed on the right and left sides of the body, are usually similar and symmetrical one to the other. The cockle and mussel are good examples.

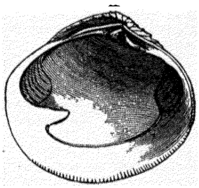

FIG. 147.—One valve of a lamellibranch shell (*Venus*), showing muscular scars, mantle line, and hinge teeth (½). (Z.)

The *Gastropoda*[2] possess a distinct head provided with eyes, and the animal is covered with a single conical shell which may be a simple cone as in limpets or coiled in a spiral as in the snails and whelks. The shell varies very much in shape, as will be seen in Figs.

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[1] Lat. *lamella* = a little plate, *branchiæ* = gills.

[2] Gr. *gaster* = a belly, *pous*, *podos* = a foot.

189, 238, 263, and 268, but as a rule the older examples have the mouth of the shell "entire," and not broken by "canals," indicating that they were generally vegetable feeders, while the newer ones are mostly carnivorous.

FIG 148.—Shell of a gastropod (*Mitra*) cut open to show the internal shape (about ⅓). (Z.)

The *Cephalopoda*[1] are represented at the present day by cuttle-fish and nautili. The animal possesses a head with a mouth surrounded by tentacles; the latter bear suckers or hooks. The Nautilus possesses two pairs of gills, and the animal is protected by a shell divided into chambers. The earlier genera were related to the *Nautilus*,[2] a genus which has survived to the present day. The genera more common in Mesozoic times, which, with forms related to them, have all become extinct, are the *Ammonites*.[3] The two-gilled family, to which the modern cuttle-fish belongs, became common in Mesozoic times, and in rocks of that age it is represented by the guards of cuttle-fish known as *Belemnites*.[4]

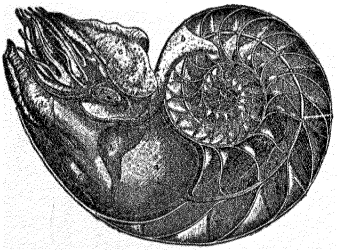

FIG. 149.—Shell of pearly nautilus, cut open to show the position of the animal, and the chambers separated by septa which are pierced by the siphuncle. (Z.)

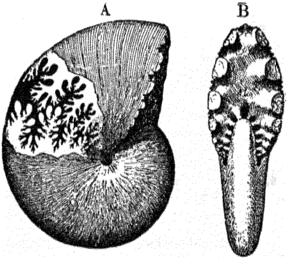

FIG. 150.—Two views of an ammonite shell showing (A) external marking, portion of the external shell removed to display the pearly interior marked with the line (sutural line or suture) where a septum meets the shell; (B) the profile of the shell with the shape of one of the septa; this is bent about at the edges so as to give the crenated line of contact seen in A (¼). (Z. after Owen.)

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[1] Gr. *kephale* = the head, *pous* = a foot.

[2] Gr. *nautilos* = a sailor.

[3] After Jupiter Ammon.

[4] Gr. *belemnon* = a dart.

Vertebrata. — This sub-kingdom includes the animals with an internal skeleton usually consisting of a backbone or vertebra and four limbs, which are turned away from that part of the body in which the backbone is situated. There are five classes: *Fish*, which live in water and breathe by means of gills; *Amphibia*,[1] which breathe by gills during the earlier part of their life; *Reptiles*, which do not pass through a water-living stage; *Birds*, as a rule provided with feathers and beaks; and *Mammals*, to which all the ordinary land quadrupeds belong. At the head of this Class stands Man.

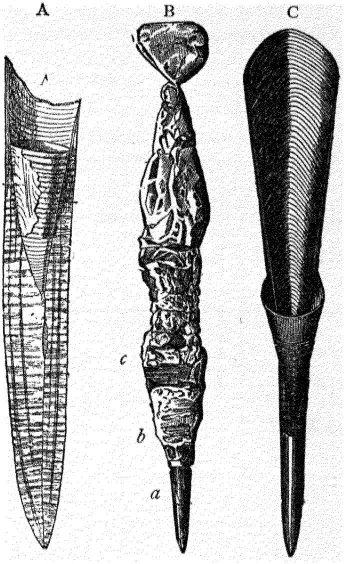

FIG. 151.—Belemnite. A, section of "guard," showing hollow containing chambered phragmacone in upper part; C, restoration; B, fossil, found with guard (*a*), phragmacone (*b*), ink-bag (*c*), and other parts in position, on which the restoration is founded. (Z. after Huxley.)

Plants

Plants are divided into two great groups — those which bear flowers and seeds by means of which they reproduce themselves, the *Phanerogams*,[2] and the flowerless plants or *Cryptogams*.[3] The former division includes all the flowers of the gardens and hedgerows; the latter the ferns, mosses, fungi, and seaweeds. In the older rocks fossil cryptogams are found alone, but in newer rocks fossil flowering-plants are found as well.

The Phanerogams are again divided into two groups: the Gymnosperms, with a naked seed,[4] which includes the pines and cycads; and the Angiosperms,[5] including palms, lilies,

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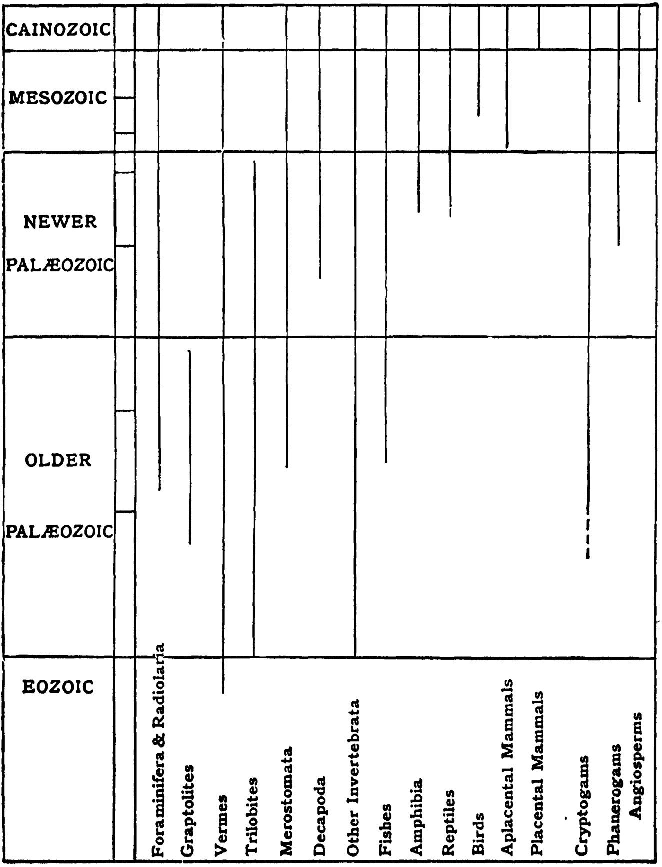
[1] Gr. *amphi* = both, *bios* = life. [2] Gr. *phaneros* = evident, *gamos* = marriage. [3] Gr. *kryptos* = concealed, *gamos*. [4] Gr. *gymnos* = naked, *sperma* = seed. [5] Gr. *angeion* = vessel.

primroses, and violets, and most of the common garden plants and forest trees, in which the seed is enclosed in a seed vessel. The latter group did not appear till Cretaceous times.

Distribution in Time

The table, drawn approximately to scale, will show the distribution of the principal animals and plants in time:



Uses of Fossils

Physical Conditions.—The most obvious use of fossils is to give evidence of the condition of things existing at the time the rocks containing them were formed. Thus land-shells are easily distinguished from fresh-water, and these again from marine shells; and the presence or absence of any of these types will be a guide as to whether a given deposit was laid down on land, in fresh water, or in the sea.

The following table indicates the habitat of a few living genera which illustrate this point:—

	Terrestrial.	Fresh-water.	Frequently found in Brackish Water.	Marine.
Gastropods	*Helix* (snail) *Bulimus* *Succinea*	*Planorbis* *Limnæa* *Paludina*	*Melania* *Melanopsis* *Neritina* *Potamides*	*Litorina* (periwinkle) *Buccinum* (whelk)
Lamellibranchs		*Unio* *Cyclas*	*Cyrena*	Oysters Cockles Mussels

Then again in the sea, free-swimming, surface-living (pelagic[1]) organisms are distinct from those living on the sea-bed, while of those living on the bed of the sea we may distinguish between those which flourish between tide-marks, those living down to 100 fathoms, and those living at greater depths. Thus it may sometimes be possible by means of the fossils to estimate the approximate depth of water under which a deposit was formed.

Climates.—Again, certain animals are confined to arctic, temperate, or tropical climates, and their remains may sometimes give an insight into the *temperature* and climate of the period. As all great ocean depths are cold it is only surface and shallow water organisms which are of much use in this

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[1] Gr. *pelagos* = the sea.

connexion, together with plants—the latter being of especial utility.

Extinct Organisms.—Both these lines of research are, however, hampered by one important fact. The farther we go back in time the more do the organisms differ from those of the present time. First we find species which are not like any living (that is, they are extinct); then we come to extinct genera; farther back we meet with whole families and even orders which have become extinct. Hence the difficulty of ascertaining the conditions under which these creatures lived. All that can be done is to make the utmost use of such species, genera, and orders as still survive; to compare the extinct ones with their nearest living relatives; to judge by *faunas* and *floras*, *i.e.* groups of animals or plants considered as a whole, rather than by isolated genera or species; and to learn as much as possible of the habits of the creatures from their structure. Considering that reef-building corals at the present day all live in the sea, in low latitudes, only in warm water, and at no greater depth than 20 fathoms, it is unlikely that the continuous succession of these creatures met with in the past, although belonging to separate species, genera, and families, should have lived in fresh-water lakes, at great ocean depths, or in cold climates.

Time Registers.—But the use of fossils which is of most interest to the geologist is that they enable him to ascertain the age of strata when other tests of age are difficult to apply. It has been shown (p. 84) that the age of stratified rocks can be ascertained by their position with regard to one another. If the age of a series of successive strata is carefully ascertained by this method, and fossils are then collected from each bed of rock, it is found that though some species of fossils may be found in two or even more sets of strata, yet there are invariably some which occur solely in one particular set of beds, and do not occur above or below them. When the succession of organisms has been ascertained in this manner, fossils may be collected from any other bed of rock whose age, owing to faulting or denudation, cannot be ascertained by superposition, and compared with those whose age is known. The age of the disconnected rock can then be ascertained with tolerable accuracy. Fossils are as useful in the study of rocks as dated medals and coins are in the study of history. Here again, however, in places several miles apart, it is better to judge by the entire fauna or flora than by single species common to the two localities only.

Evolution.—When the order of succession of all known rocks had been carefully ascertained, it was found that in a general way there was a gradual advance in the succession of organisms—the most lowly appearing first, and being succeeded in order by higher and higher forms. Thus, although representatives of eight of the nine sub-kingdoms of animals are known as fossils in the Cambrian Rocks, and of many of the Classes and even Orders of these Sub-kingdoms, yet each of them is represented by its most rudimentary Genera. It is not until the Ordovician Rocks are reached that fishes are found ; amphibia and reptiles appear in Carboniferous time ; birds and mammals are only known from the Neozoic rocks. Again, the Mesozoic mammals are all aplacental, and only in Tertiary time do our modern genera of placental mammals make their appearance. Further, linking forms are not infrequently found as fossils. There are reptile-like birds and bird-like reptiles ; amphibia with affinities to the fish, and fish with affinities to the amphibia ; tapirs having affinities with horses, and forms intermediate between camels and llamas (see also p. 298).

Distribution in Space.—The study of the faunas and floras of past epochs reveals another important fact. We do not meet with the same animals and plants all over the earth at the present time. The fauna of South America is vastly different from that of the northern part of the continent ; the flora of Australia differs widely from those of Africa, Asia, and South America ; and the shells of the Atlantic are unlike those of the Pacific across the Isthmus of Panama. Fossil faunas and floras show that a distribution of this kind existed in time past, sometimes conforming to the present method of distribution, but often differing widely from it, proving that provinces once severed are now joined, like North and South Africa, and that others now severed were once joined, like Northern America and Northern Asia, or Britain and the continent of Europe. This causes a difficulty in correlating the fossils of widely-separated localities ; and correlation of strata by their organic remains should always be effected stage by stage; in advancing from one point to a distant one the fossils of deposits in the intervening area should be studied, and correlation be carried step by step across the intervening area.

False Fossils. — Occasionally inorganic markings or structures have been mistaken for fossils (pseudo-fossils!). Deposits of oxide of manganese imitate fern- or moss-like markings; concretions of carbonate of lime simulate massive corals; concretions of clay-ironstone and carbonate of lime are sometimes like fruits; concretions of flint imitate bones, and many other shapes; structures produced by cleavage and faulting have been mistaken for trilobites and graptolites; and slickensides produced by faulting sometimes imitate fossil trees. It is necessary to avoid carefully these resemblances in drawing deductions from fossils. On the other hand, many markings in rocks hitherto unexplained are doubtless due to organisms, but in some cases to extinct forms so widely different from existing forms that it has not yet been found possible to ascertain their true nature.

Destruction of Fossils. — The crushing, cleavage, and metamorphism of rocks may utterly destroy all traces of organisms contained in them; or distort them so much that their shapes are very misleading, and this must be allowed for (see Fig. 84, p. 112). This is especially true in ancient rocks. Again, the percolation of water through rocks may entirely dissolve away all traces of fossils. It is therefore necessary to be cautious in concluding that a deposit was formed under conditions inimical to life because we do not now find fossils in it. Such deposits, however, do undoubtedly occur.

RECAPITULATION

Fossils are the remains of once-living organisms, either animals or plants, now found buried in the rocks. They may be preserved in many different ways, the gradual replacement of their substance by mineral matter giving us often a very exact copy of the original in shape or structure or both.

Although many fossil forms belong to *extinct* types, they can be inserted in their place in the classifications of modern animals and plants. Such classifications divide the whole animal kingdom into nine great *sub-kingdoms*, called the Protozoa, Porifera, Cœlenterata, Echinodermata, Vermes, Arthropoda, Molluscoidea, Mollusca, and Vertebrata. The plants are divided primarily into the flowerless or cryptogamic, and flowering or phanerogamic divisions.

The collection and study of fossils, although many of them belong to extinct kinds, give us a clue to the physical conditions and geography at the time the rocks containing them were being deposited, the climate, depth, and nature of the sea, and the position of shallow-water and land areas. They enable us to ascertain the age of the rocks, to group them into convenient divisions, and to trace out the gradual evolution of plant and animal life on the globe.

QUESTIONS ON CHAPTER XVI

1. What are fossils, and what do we learn from them? (1877.)

2. What are fossils? Of what practical use are they in geology? (1884.)

3. On what evidence should we infer that a fossil found in a certain rock has been derived from an older formation? (1890.)

4. Explain what is meant by—
    (*a*) Hollow casts.
    (*b*) Internal casts.
    (*c*) External casts.
    (*d*) Derived fossils.

And refer to an example of each of these kinds of fossils found in British rocks. (1897.)

5. In what rocks do the Cephalopoda, Crustacea, Vertebrata, Land-plants, Corals, and Brachiopoda first appear? (1880.)

6. Briefly state the broad general facts as to the distribution of the Mollusca in time. (1885.)

7. Enumerate the genera of Mollusca by means of which you would be able to distinguish deposits formed in fresh water from those formed in salt-water. (1888.)

8. Arrange the following groups in the order of their appearance on the earth, viz. Brachiopoda, Cephalopoda, Exogens, Foraminifera, Mammalia, Reptilia. (1878.)

9. What is meant by the word fossil? Explain how fossils are useful in determining former changes (1) in climate, (2) in geography; and also their use in the classification of rocks. (O and C.)

10. What is the value of organic remains (fossils) in showing the slow formation of stratified rocks? Mention any modern observations of the process of deposit still going on. (O and C.)

11. Fossil shells are scarce in sandstones. Why is this? (1893)

CHAPTER XVII

PRINCIPLES OF HISTORICAL GEOLOGY

IN the preceding chapters it has been shown that it is possible to ascertain the way in which each kind of rock was formed, and, by combining the information derived from different portions of the same rock-mass, to get a clear idea of the physical geography of the region in which the rock was forming. If the different rocks can be arranged in order of their age, it must be possible to go a step farther, and to determine the successive changes through which the physical geography of the area has passed. The fossils contained in the rocks give an idea of the animals and plants living at the date of formation of a rock, and in the same manner the changes in the life-history of the world can be made out. This branch of the science is known as *Historical Geology*.

Tests of Age.—It has been shown (p 84) that of a set of strata the oldest is that at the bottom and the newest that at the top, unless inversion by folding or faulting has occurred. Then the order can only be made out by unravelling the folds and putting the strata back in imagination in the position in which they were formed. The age of igneous rocks is ascertained also by *order of superposition* with regard to rocks poured out at the surface, but by *order of intrusion* when thrust in from below. A second test for bedded rocks is that of *included fragments*. A rock is necessarily newer than that which has furnished the pebbles, sand-grains, or mud of which it is built up. A third test has been only referred to inferentially—*mineral composition*. Strata of marked mineral composition like the Chalk, the Coal-measures, and the Old Red Sandstone, can be traced for long distances by their mineralogical character, and their age at one place ascertained from their position in the sequence elsewhere. Only certain sediments, however, such as clays and limestones, can be expected, from their mode of formation, to extend over wide areas. Even these are found to change their composition to some extent from point to point, and must have been at one time bordered by sandstones and conglomerates formed contemporaneously. This caution is especially necessary in working out the age of coarser-grained deposits, and in all cases due allowance must be made for the change in character which sediment undergoes, according to the part of the lake or sea-bed in which it was laid down (see p. 84).

The determination of age by *fossils* has also been alluded to, and the cautions given in Chapter XVI. should be noted. The primary guide must be the *order of superposition*, and that must be obtained, however much complicated by the folding, faulting, and inversion of the strata. These must be put back in imagination into their original position in the sequence. In this unravelling it is essential that rock-bands should be individually recognisable, and here the fossils they contain supplement the lithological characters of the strata.

Division of the Record.—When the order of deposit of all known rocks is ascertained we must next divide the long history thus revealed into convenient epochs or chapters, so that they may be easily described and referred to. At the outset, however, it must be clearly understood that this cannot be done in the same terms as are used for written history. The difficulty of ascertaining the rate of deposit in present times, the uncertainty of applying this estimate to time past, the unknown value of lost chapters in the history,—all render it impossible to express the lapse of geological time in years. But although we have to give up the idea of using years as a unit, we may take another hint from written history. The whole written history of the world may be divided into periods according to the supremacy of different peoples at different epochs. Thus we may speak of the great period of Egypt, the time when China was the most highly civilised nation, the age of Greece, the epoch of Roman empire, and so on. Each of these great periods may be divided according to the reign of particular dynasties. The Normans, the Plantagenets, the Houses of York and Lancaster, the Tudors, Stuarts, and the House of Hanover. The period embraced by any of these dynasties is again divided into those of the successive sovereigns, these again into epochs marked by great wars, important legislative enactments, or social reforms. Any two of these periods may not be precisely comparable as to lapse of time or even in relative importance, but they form a convenient system of links in the chain of historic time.

Geological Divisions.—Similarly may geological time be subdivided. The geological history of the earth may be divided into three great *Eras*. The life existing during the earliest of these is not yet fully known, but that of each of the two later ones differs in a striking fashion from that of the other. These three Eras are named the Eozoic, dawn of life (Gr. *eōs*, dawn, and *zoe* = life); Palæozoic, ancient life (Gr. *palaios*, ancient); Neozoic, new life (Gr. *neos* = new), after the dominant character of the life-forms of the Era as expressed by the fossils. Each great rock-mass which contains the physical and life history of an Era is spoken of as a *Group* of strata. But both physical geography and life usually underwent many important changes during the lapse of an Era, and such changes are used to break the time-record of the Era into successive *Periods*. The rocks of each Period are called a *System*. Thus the Neozoic Era is in Britain divided into the Triassic (salt-lake) Period, the Jurassic (mediterranean-sea) Period, and the Cretaceous (wide-sea) Period, and into five later Periods.

Many geographical changes of less moment, generally accompanied by corresponding life-changes, took place during each Period, and each of these may be used to indicate the limits of an *Epoch*. Thus the Cretaceous wide-sea Period began with a delta Epoch called the Wealden Epoch; that was succeeded by green-sands formed in the open sea, the Greensand Epoch; and that by the wide spread of the ocean in which the chalk was formed, the Chalk Epoch. The Chalk, Greensand, and Wealden Rocks may each be denoted as a *Series* of rocks. The greater subdivisions of each Epoch of time are known as *Ages*, and the corresponding divisions of the rocks as *Stages*. Finally, when the progress of life during an Age is studied, it is seen that certain assemblages of life-forms gradually succeed one another in orderly succession; the time during which any one assemblage existed is named a *Hemera*, and the thin sets of strata in which the fossils of each assemblage are found are designated as *Zones*. The analogy with human history may be gathered from the following summary:—

Human History.	Geological Time.	Strata.	Examples.
Nation	Era	Group	Neozoic Group
Dynasty	Period	System	Cretaceous System
Reign	Epoch	Series	Chalk
Important Events	Age	Stage	Upper Chalk
Lesser Events	Hemera	Zone	Zone of *Belemnitella plena*

Classification of Strata

The application of these terms to the whole of Geological History is summarised in the accompanying table, in which only the Groups, Systems, and Series of *rocks* and their equivalent Eras, Periods, and Epochs of *time* are recognised. The whole are placed in historical and descending order, with the youngest at the top.

Group (Era).		System (Period).		Series (Epoch).
Neozoic	Cainozoic[1] or Tertiary	Post-pliocene		Recent Strata Glacial Beds
		Pliocene		Forest Bed Norwich Crag Red Crag Coralline Crag
		Miocene		
		Oligocene		Hamstead Beds Bembridge Beds Osborne Beds Headon Beds
		Eocene	Upper	Barton Clay Bracklesham Beds Lower Bagshot Sands
			Lower	London Clay Woolwich Beds Thanet Sands
	Mesozoic[2] or Secondary	Cretaceous		Upper Cretaceous Lower Cretaceous
		Jurassic		Upper Oolites Middle Oolites Lower Oolites Lias
		Triassic		Keuper Bunter

[1] Gr. *kainos* = new, *zoe* = life.

[2] Gr. *mesos* = middle, *zoe* = life.

Group (Era).		System (Period).	Series (Epoch).
Palæozoic or "Primary"	Newer Palæozoic.	Permian	Upper Permian Lower Permian
		Carboniferous	Coal-measures Millstone Grit Yoredale Beds Carboniferous Limestone
		Devonian	Upper Devonian Middle Devonian Lower Devonian
	Older Palæozoic.	Silurian	Ludlow Wenlock Llandovery
		Ordovician	Bala Llandeilo Arenig
		Cambrian	Olenus Beds Paradoxides Beds Olenellus Beds
Eozoic		Archæan	

To give an idea of the enormous lapse of geological time it must be remembered that the rocks of the older Systems are far thicker than those of the later ones, and that the whole of *written human history*, from the earliest Egyptian and Babylonian records to the present day, forms but a *part* of the "*Recent Epoch.*"

In the establishment of these divisions regard is had to two prominent classes of change: those which affect the physical aspects of the earth's surface, and those which affect its inhabitants.

Physical Changes

Conformity.—When the surfaces of successive strata lie parallel to one another they are said to be *conformable* (Figs. 86, 65, 67, 78). Each *lamina* of rock indicates some slight physical change such as the source of sediment, or a pause in its supply. Each *bed* indicates a still greater change like that from shallow to deep water, or *vice versa.* More conspicuous changes still are marked by the encroachment of the sea over areas previously occupied by lakes, by the drying or filling up of seas, or by the outbreak of great volcanoes.

Unconformity.—But the most stupendous changes accompany great epochs of *earth-movement* and *mountain-building* when vast areas of sea-bed or flat land are ridged up into lofty ranges and summits. Such an epoch is marked in the rock sequence by what is known as an unconformity or *physical break* in the rocks. The phenomenon receives this name because the stratification of a newer set of rocks is not in the same direction or at the same angle as that of the older, or, in other words, the two sets do not conform to one another.

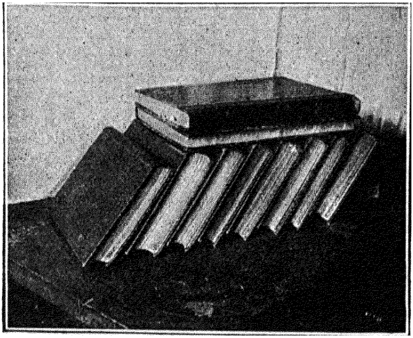

FIG. 152.—Model to illustrate unconformity.

An unconformity is illustrated in Fig. 153. There is clearly a great break in history between the set of rocks marked *a* and those marked *b*. The earlier set must have been laid down in horizontal sheets under the sea, then folded, and denuded, and part at least of the denudation must have taken place above sea-level, as the surface is irregular and cut into hills and valleys. Then the irregular surface must have been

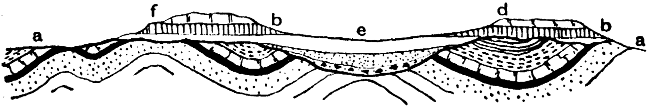

FIG. 153.—Unconformity of set of rocks *b* on set *a*; deceptive at *d*, *e*, and *f*, flagrant elsewhere.

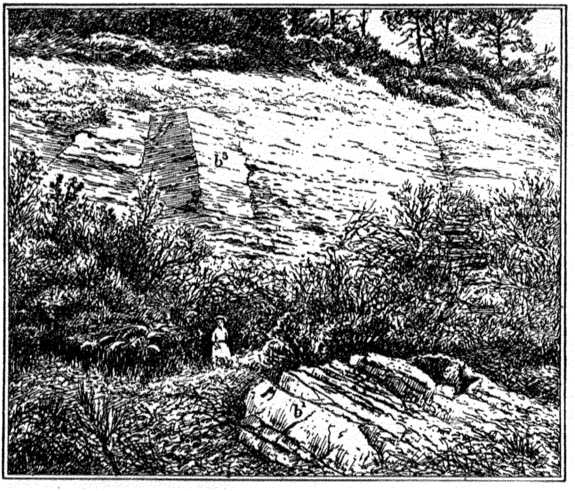

FIG. 154.—Unconformable junction of Upper Llandovery rocks (b^5) on tilted Arenig ashes (b^1), Hope, Shropshire.

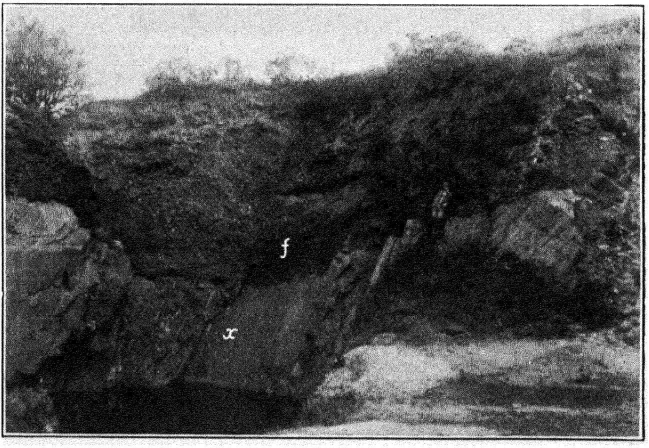

FIG. 155.—Section in Charnwood Forest, showing unconformable junction of Triassic marl (f), resting in an old valley excavated through the ancient (pre-Cambrian) slates (x).

let down beneath the sea again, and new deposits were formed which filled up the hollows, and eventually built up horizontal sheets over the whole. The photograph (Fig. 154) gives the appearance of an unconformity seen in a road section, and that in Fig. 155, a quarry in Charnwood Forest, in Leicestershire, shows a valley excavated in ancient slates, and filled up by the deposit of red marl and sandstone. The period of history which is lost in this case between the strata *x* and *f* is much longer than at first appears; for the older rocks have not only been folded and denuded into a system of hills and valleys, but they have been intensely indurated, cleaved, jointed, faulted, and intruded upon by dykes and masses of igneous rock of three distinct ages, long before the red marls were deposited.

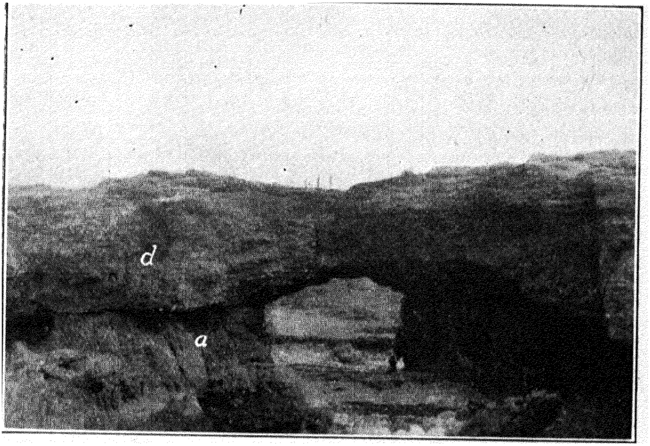

FIG. 156.—Section in the south of the Isle of Man, showing the unconformable junction of Carboniferous Conglomerate (*d*) on Manx Slates (*a*) An arch has been excavated by the sea along the junction plane.

The existence of unconformity is detected in the first place by the discordance in the stratification, which may, however, not be equally marked everywhere, for at the points *d*, *e*, and *f* in Fig. 153 there is apparent concordance in the strata. But the study of the junction for a few hundreds of yards or a few miles usually reveals the fact of the discordance (see Fig. 18, p. 23, and Fig. 177, p. 240). In the second place, as the rocks *a* were exposed to denudation, pebbles and fragments derived from *a* will generally be found in *b* (see Fig. 96).

History of Land Surfaces.—The significance of unconformities is great, and their value in geological chronology correspondingly important. Rock strata give the history of the sea-bed or other area of *deposition*, and if conformable, the deposition has been continuous or broken only by slight physical movements. But an unconformity indicates a break in the sequence due to the formation of a land area, a mountain-chain, or other area of *denudation* (see Figs. 166, 177, 212). Conformable strata give the history of the sea; unconformities of the land. They fix for us the dates of periods of earth-movement, of mountain uplift, and physical change; and frequently they enable us to map the outline and even the contour of continents and mountains, of sea-margins and plateaus. Great and widespread unconformities usually occur between each pair of the great rock *Groups* and often between the *Systems*, while smaller ones of local consequence are at times met with between rock *Series*. They always indicate breaks in time and lost chapters in the record, which can only be filled in if some other area can be found in which deposition was continuous during the lost interval. This is the only way in which the lost interval can be restored; for the mere appearance and structure of the unconformity may be such as to give no clue to the length of time elapsing between two sets of rocks. It must be remembered that, as no movement is world-wide, and as the sea must always have existed somewhere in the neighbourhood of the land-masses, a physical break will not be always found between the same sets of strata in distant localities; thus Systems and Series separated by unconformities at one place may be quite conformable to one another elsewhere. The higher members of a conformable series may *overlap* the lower ones (d^5 over d^4 and d^2, Fig. 212), and may *overstep* or *transgress* on to different members (*c*, *b*, *a*) of an underlying, unconformable, series. Examples of unconformity may be studied in Figs. 177, 197, and 216.

In Chapter XXIV. the physical structure of Britain is linked up with the geographical changes to which geology bears witness.

Life-changes and Breaks

In studying the life-changes exhibited in the rock sequence, it is sometimes found that the same types persist through considerable thicknesses of rock, as though the sediment had been accumulated rapidly. At other times changes in the fauna occur in every few feet of rock, clearly indicating that the rate of deposit was slow in comparison with the change in organic life. Very slowly-deposited sediments, such as certain cherts and many very fine-grained shales, exhibit the latter character, and they were in all probability laid down in deep waters far from land. Considerable changes in geography are sometimes not accompanied by great life-change, but as a rule they bring about important and rapid changes in fauna and flora, while, in certain cases, great life-breaks occur without any stratal or physical break corresponding with them. The persistence of an important fauna for a considerable period, or a series of such faunas linked together, is one of the most valuable of facts for individualising a marked Period of time or a System of rocks, especially when the types have a wide geographical range. Thus it is necessary in classifying the geological succession to interpret as far as possible the exact meaning of physical and organic changes, and to be guided by the general advance in both when constructing a classification. It is upon both series of facts that the classification above given is founded.

RECAPITULATION

The first thing necessary in constructing a geological chronology is to find out the relative ages of rocks. This is done by means of one or more of the following classes of evidence: order of *superposition* and deposit, contained *fragments*, *mineral* character, *fossil* contents.

In dividing the record into convenient chapters and epochs for reference, a study is made of the changes in life and geography revealed by the rock succession. Such groups of rocks as yield evidence of long-continued geographical stability, slow and steadfast change, regular succession and evolution of life-forms, are grouped together in *Stages*, *Series*, and *Systems*.

Important *geographical revolutions*, such as the conversion of continental areas into marine areas or *vice versa*, and periods of great earth-movement and mountain-making, are used as divisional lines. Unconformities in the bedding of the strata reveal this type of change, so they are of the utmost value in separating Period from Period and Era from Era.

Similarly, *great* or rapid *changes* in the *plant* or *animal* population of a given area are of the utmost consequence, and they must be made use of as dividing lines in classification.

The division of the geological record is effected by laying due stress on *both* these classes of evidence.

QUESTIONS ON CHAPTER XVII

1. On what principles are the relative ages of stratified rocks determined? (1884.)
2. In what ways may the relative ages of stratified rocks be determined without reference to fossils? (1881.)
3. What are the tests on which you would rely for judging of the age of sedimentary rocks? (1887.)
4. What is commonly understood in geology by the term stratum or bed, as distinguished from formation or series? (1882.)
5. Draw a section showing fault, outlier, synclinal, unconformity, inlier. (1888.)
6. Define the terms—basin, overlap, thrust-plane, unconformity. Give sketches to illustrate your answer. (1894.)
7. What is meant by unconformity? What does it imply? (1879.)
8. Define the terms—cleavage, denudation, conformity, and give examples of their application. (O and C.)
9. Illustrate the meaning of the following geological terms—dyke, fault, outlier, overlap, syncline, unconformity. (O and C.)
10. Show by diagrams the difference between overlap and unconformity. What can be inferred from these appearances concerning the geological history of the strata exhibiting them? (O and C.)
11. What are the various tests by which the relative ages of the stratified rocks are determined? How is it possible to ascertain the relative ages of igneous and metamorphic rocks? (O and C.)
12. What do you understand by the following geological terms, and what does each phenomenon tell us concerning the physical history of the district where it occurs—false-bedding, outlier, overthrust fault, raised beach, and unconformity? (O and C.)

CHAPTER XVIII

THE EOZOIC AND OLDER PALÆOZOIC GROUPS

THE EOZOIC GROUP

Eozoic Group.—We may employ this term as a correlative of the other group-names to signify the rocks which occur below those of the Cambrian System. These rocks contain the earliest life-forms known, the dawn of life.[1] They are also known as Archæan [2] or Pre-Cambrian Rocks.

Occurrence.—These, the oldest known rocks in Britain, are in most places concealed by newer deposits, and they only appear in a few regions where they at one time formed very high land, or where they have been exposed by great faulting or extensive denudation. Consequently they often occur in a series of isolated exposures, and the task of correlation is very difficult, not only on account of the extreme rarity of organic remains and their unsatisfactory character, but from the isolation and incomplete exposure of the rocks and the great disturbance the rocks have undergone. Rocks which are placed in this Group occur beneath the Cambrian strata in Shropshire, Warwickshire, and Worcestershire, and others, of about the same age, occur in a similar position in North and South Wales, and in Anglesey; while at Charnwood Forest, in Leicestershire, Pre-Cambrian Rocks rest unconformably beneath a cover of Trias (see Fig. 155). In the Highlands of Scotland, beneath the fossiliferous Cambrian Rocks, massive Torridon Sandstone, containing shales and conglomerates, rests with very strong unconformity on the denuded mountainous masses of the " Fundamental " or "Lewisian" Gneisses.

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[1] Gr. *eos* = dawn, *zoe* = life.

[2] Gr. *archaios* = ancient.

The latter are plutonic in origin and therefore intrusive into something, and possibly the altered sediments associated with the gneisses at Loch Maree may be the older rocks intruded upon. The "Dalradian" schists of the Grampians and the "Moine" schists of the North-West are probably Archæan rocks, in age between Lewisian and Torridonian. They are, however, separated from the Lewisian area by lines of intense disturbance, and are very much metamorphosed and otherwise affected by earth-movement. In Shropshire there exists in the Longmynd a thick mass of sandstones, conglomerates, and shales, in which obscure traces referred to worm-tracks and trilobites have been found (see Fig. 166, p. 236). The lower series is grey and green, the upper red and purple, and the latter are probably equivalent to the Torridon Sandstone. In this area there is a volcanic group, best developed at the Wrekin, and named, after the Roman city near, the Uriconian System (see Figs. 166 and 177). These rocks appear to be older than the Longmyndian, and are mainly acid lavas, which have been proved to be altered rhyolites, banded with tuffs, ashes, and breccias; with these are associated intrusive basic rocks. This volcanic series is in character like that met with under the Cambrian Rocks near Nuneaton, in Warwickshire, and certain volcanic rocks described by Dr. Hicks, Professor Bonney, and others, similarly situated in Carnarvonshire and Pembrokeshire. The ashes, breccias, etc., of the latter district were called by Dr. Hicks the Pebidian System, and they are associated, both here and in Carnarvonshire, with acid lavas, and intruded upon by granitic rocks. In Anglesey and the Malverns there are masses of gneiss and schist, in part modified plutonic rocks, which are Pre-Cambrian, as fragments from them are contained in the associated Cambrian Rocks. These are followed in Anglesey by four or five great Series of volcanic and sedimentary rocks. The rocks of Charnwood Forest are chiefly volcanic agglomerates connected with lava flows and intrusions, followed by conglomerates, quartzites, and slates, all probably of Lower (grey) Longmyndian age.

The following table shows the general arrangement of types :—

	GNEISS AND SCHIST.	VOLCANIC AND PLUTONIC ROCKS.	SEDIMENTS.	COVERED BY
Highlands	Fundamental Gneiss, Dalradian, and Moine Rocks		Torridon Sandstone	Cambrian
Anglesey Malvern Shropshire	Gneisses and Schists ?	Granitoid and Volcanic Rocks	Sediments Longmyndian	Ordovician Cambrian
Lickey Nuneaton		Barnt Green and Caldecote Rocks		
Charnwood		Charnian Rocks	Quartzite and Slate	Trias
Carnarvon Pembroke		Granitoid and Volcanic Rocks		Cambrian

This table is not to be taken as implying any correlation of these different types, but only as showing at a glance the characters which these fundamental rocks present in different places.

Gneisses and schists occupy large areas in Finland and Scandinavia, in Canada and elsewhere, and the rocks of the latter region are interesting because they contain beds of limestone in which what was called *Eozoon*[1] *canadense* is found. This was formerly supposed to be a fossil foraminifer, but it has now been proved that it is of inorganic origin. Seams of graphite and limestone, however, occur, which are not unlikely to have been formed by organic agency. The rocks of this Group yield vast supplies of gold, silver, iron, nickel, and copper in North America.

Structure.—In North Scotland the structures and metamorphism exhibited by the Pre-Cambrian rocks are very remarkable. The "Fundamental Complex" consists of gneisses and schists which are crystalline throughout and foliated. Many of the dykes which penetrated them before the Torridon strata were laid down have been sheared and converted into schists along their edges or throughout. Other great movements which took place after the Cambrian Period, probably the first part of the *Caledonian* movement (p. 240), broke up the whole sequence of Gneisses, Schists, Torridon

[1] Gr. *eos* = dawn, *zoon* = an animal.

Rocks, and the Cambrian Quartzites and Limestones into slices along over-faults or major thrust-planes, and again into innumerable smaller slices along minor thrusts. The effect of the two types of thrust is seen in Fig. 157, where an apparent ascending sequence, extending in some cases for miles, is really made up of the repetition of the same beds again and again by thrust-planes. The gneiss and other rocks have often been driven many miles along the thrust-planes, and in consequence they have not only undergone much metamorphism themselves, but have also produced great changes in the rocks over which they have ridden, crushing and contorting them, and often converting them into mylonites, granulites, and crystalline schists with new structures and features.

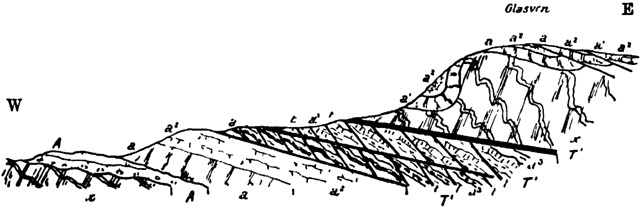

FIG. 157.—Section of the face of Glasven in the N.W. Highlands of Scotland, showing the Archæan Gneiss (x) covered by Torridon Sandstone (A), and that by Cambrian Quartzite (a^1) and "Fucoid Beds" (a^2). On the right of the section, however, the gneiss is over-thrust by a major thrust (T'). In the middle of the section the various members of the Cambrian succession, including the Fucoid Beds (a) and the Limestone (a^3), are repeated many times over by minor thrusts (t), and the same thing occurs above the gneiss to the right. (After Peach and Horne.)

THE PALÆOZOIC GROUP—THE ERA OF INVERTEBRATES

This great Group of rocks comprises no less than six rock Systems which are of vast thickness. They consist of sediments to which volcanic débris has largely contributed, and volcanoes burst out in the area of Britain at least half a dozen times during the Period, forming huge piles of lava and other ejecta. The life of the Era is marked not only by extinct species and genera, but by extinct Families and Orders. The trilobites are confined to Palæozoic rocks and the graptolites to the lower part of the Group. The corals, star-fish, sea-urchins, crinoids, merostomata, and fish, belong to Families, Orders, or Suborders which either die out in the Era, or, if not, live on only in much diminished numbers. On the other hand, many Neozoic types of animals, such as birds and mammals, do not seem to have made their appearance in Palæozoic times.

The Older Palæozoic Division

The three lower Systems of the Group contain the evidence of Britain's *first* great *marine phase.* They are well marked off from the succeeding Newer Palæozoic Sub-Group. The division is noted as the time of the free development of the trilobites, and the graptolites do not survive it except in the form of the one genus *Dictyonema.* Certain of the brachiopoda like *Orthis*, *Strophomena*, *Pentamerus*, at this time attain a great development, while there is an abundance of cephalopoda allied to *Nautilus*, the only genus of the Class which survives to the present time. Plant remains are not abundant, and seem to be confined to the cryptogamous division.

The Cambrian System

Subdivision.—The rocks of this division are found in North Wales, and the System has hence been named Cambrian. They rest unconformably on the Pre-Cambrian Rocks, and consist mainly of greywackes, flagstones, and slates; they admit of division, according to their fossils, into the following Series, given in descending order :—

SERIES	LOCAL DIVISIONS
4. *Shumardia* Beds	Tremadoc Slates.
3. *Olenus* Beds	Lingula Flags.
2. *Paradoxides* Beds 1. *Olenellus* Beds	The Menevian Beds. The Lower Cambrian Rocks of St. Davids, Harlech, Shropshire, and Nuneaton.

The type trilobites of the *lowest division* have not been at present found except in Mid-England and North Scotland, but fragments referred to them have been discovered at St. Davids. Fossils of Lower Cambrian age including *Olenellus* and *Hyolithus* have been found in Shropshire, at Nuneaton, and at Malvern; and beds which have hitherto yielded few or no fossils occupy a position below the Menevian Beds at Harlech. The rocks of the Midlands are usually quartzites (see Fig. 135) passing up into green sandstones, containing thin and impure beds of limestone in which fossils occur (see Fig. 177). Elsewhere they are conglomerates, grits, greywackes, and slates (Fig. 158) Probably on this horizon or the next must be placed the great mass of slates worked for roofing purposes at the Penrhyn and Llanberis quarries in North Wales.

The *Paradoxides* Beds include the Menevian flags and shales of North and South Wales, together with certain grits and slates below them. In Shropshire there are beds of limestone and sandstone, and at Nuneaton shales, containing *Paradoxides*, above the Lower Cambrian limestone.

The *Lingula Flags* are typically exposed around the great dome of Lower Cambrian Rocks near Harlech in North Wales, but they also occur in South Wales and Nuneaton. The two earlier Stages are shallow-water sandstones and flags, yielding trilobites such as *Olenus*,[1] and the characteristic brachiopod *Lingulella davisi.* Above these come intensely black deep-water shales (the Dolgelly Stage) recognisable over wide areas, and yielding a well-marked series of trilobites and brachiopods. Lingula Flags are known and fossiliferous in Pembrokeshire, but in Shropshire they are poorly represented, possibly as the result of faulting. (See Figs. 166 and 177.)

The *Tremadoc Slates*, named after a small town in Carnarvonshire, are slates and grits generally well cleaved, but too rough to afford very good roofing slate (see Fig. 158). They are typically developed in succession to the Lingula Flags in North Wales, and yield fairly numerous fossils. They occur as uncleaved shales in the Shropshire (see Figs. 166, 177), Malvern, and Nuneaton districts. Typical trilobites are *Asaphellus* and *Shumardia*, and the lower beds yield *Dictyonema.* Some geologists place these rocks in the Ordovician System.

Volcanic Rocks.—Intrusive volcanic rocks occur in all

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[1] Olenus = a son of Vulcan, who was turned into stone.

members of the Cambrian System, and the diorites, typically seen at Nuneaton, but present elsewhere, may be taken as examples.

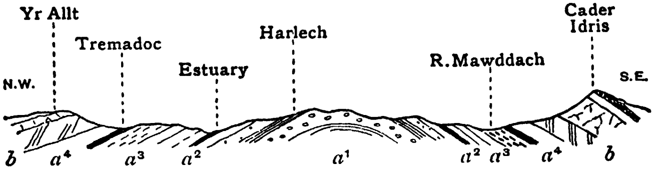

FIG. 158.—Section across the Harlech anticline from Tremadoc to Cader Idris. a^1 = Harlech Rocks (*Olenellus and Paradoxides beds*); a^2 = Menevian Rocks (*Paradoxides beds*), a^3 = Lingula Flags (*Olenus beds*); a^4 = Tremadoc Beds (*Dictyonema and Shumardia beds*); *b*, Ordovician Rocks.

Fossils.—The fossils of the System are chiefly trilobites, of which the type-forms, *Olenellus*[1] (Fig. 159), *Paradoxides*[2] (Fig. 160), *Olenus* (Fig. 161), and *Shumardia* are the most characteristic; but *Agnostus*[3] (Fig. 162, *a*, *b*) and *Angelina*[4] are also important forms. Among the brachiopods *Lingulella*[5] *Davisi* (Fig. 163) may be mentioned, for it is very little different from the *Lingula* found in the sea at the present day.

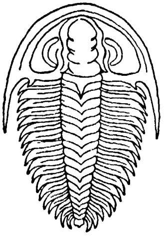

FIG. 159.—*Olenellus.* Lower Cambrian, $\frac{3}{8}$. (After Lapworth.)

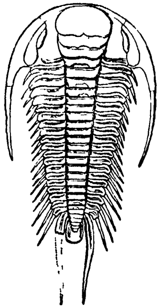

FIG. 160.—*Paradoxides.* Middle Cambrian, $\frac{1}{4}$. (Z.)

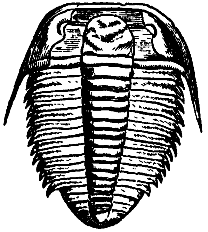

FIG. 161.—*Olenus.* Upper Cambrian, $\frac{1}{1}$. (Z. after Angelin.)

[1] Diminutive of *Olenus*.

[2] Gr. *paradoxos* = marvel, *eidos* = form.

[3] Gr. *agnostos* = unknown.

[4] After Angelin the Swedish geologist.

[5] Diminutive of Lat. *lingula* = a tongue.

Kutorgina,[1] *Orthis*,[2] *Obolus*,[3] and *Obolella* are other brachiopods. Lamellibranchiata and gastropoda are rare, but cephalopods related to *Orthoceras*[4] occur. *Hyolithus*,[5] probably a pteropod mollusc, is found throughout. In addition to this we have sponges, worm-tracks, *Hymenocaris*[6] (Fig. 164), star-fish, crinoids: The curious branching fossil called *Oldhamia*[7] (Fig. 165), is from the Cambrian rocks of Ireland.

FIG. 162, *a*, *b*.—*Agnostus*. Cambrian and Ordovician. (Z.)

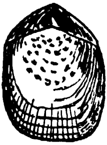

FIG. 163.—*Lingulella Davisi*. Lingula Flags and Tremadoc Slates, ½.

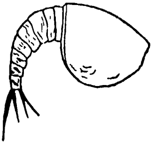

FIG 164.—*Hymenocaris*. Cambrian, ⅓. (Z. after Salter.)

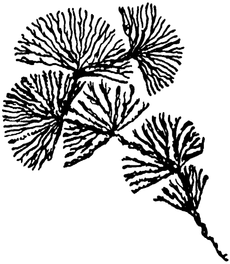

FIG. 165.—*Oldhamia*. Cambrian, ½.

Landscape and Economics.—Where they occupy a large area, as near Harlech, the rocks give rise to craggy hills, but where, as is more usually the case, they occur only in narrow strips, they have little effect on the landscape. About Nuneaton and in the Harlech district they yield deposits of manganese, and the Nuneaton quartzites and the associated diorites afford a valuable and much-used road metal. The perfect cleavage of the Cambrian rocks of North Wales renders them a valuable source for the supply of thin, light slates of excellent quality. Gold occurs in Merioneth.

Conditions of Formation.—The rocks appear to have formed under varying circumstances; the sea-water was shallow

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[1] From Kutorga, a Russian geologist. [2] Gr. *orthos* = straight.
[3] Gr. *obolos* = a small coin. [4] Gr. *orthos* = straight, *keras* = a horn.
[5] Gr. *hyalos* = glassy. [6] Gr. *hymen* = a membrane, *karis* = a shrimp.
[7] After Oldham the Irish geologist.

at first when the quartzites were forming, but much more open in the Menevian Epoch; shallower again while the lower and middle Lingula Flags were forming, very deep at the close of that Epoch; then shallower during the Tremadoc Epoch. We cannot yet, however, define closely the outlines of the sea and land of the Period.

The Ordovician System

Name.—These rocks were called the Lower Silurian System in the maps and memoirs of the Geological Survey during the nineteenth century. They were named by Sedgwick the Upper Cambrian Rocks. They are now termed Ordovician. The typical development of these rocks is in East Wales and Shropshire, the country once inhabited by the Ordovices, after whom they have been named. The rocks probably rest unconformably on those of the Cambrian System, but evidence of unconformity is concealed.

Subdivision.—Beginning usually with grits or quartzites, the bulk of the rocks are flagstones, shales, or slates, interbedded with grits, which are often washed volcanic ashes, tuffs, and lavas; limestones occur at one or two horizons, and the upper beds are in places sandstones. The typical succession is the following, and the Series is fairly well established in Shropshire and in North and South Wales:—

3. *Bala Beds* (*Caradocian* and *Ashgillian*). Grits and shales with volcanic débris locally, and one or two beds of limestone.
2. *Llandeilo Flags* (*Llanvirnian* and *Llandeilian*). Black flags or slates and limestone, with a group of volcanic rocks at the base.
1. *Arenig Rocks* (*Skiddavian*). Dark flags, with usually coarse grits and a quartzite at the base.

The *Arenig Rocks*, named after the mountains of that name near Bala Lake, are fine dark flagstones. They are cleaved in North and South Wales, and yield slates, particularly in Pembrokeshire and about Blaenau Ffestiniog in North Wales. There are interbedded volcanic rocks in some localities. Fossils are not very common, and are confined to particular zones. They consist of trilobites, graptolites, and some pelagic shells.

The *Llanvirnian Series.*—A huge and wide-spread volcanic outburst marked the close of the Arenig Epoch. To the thick sheets of andesitic and rhyolitic ashes and lavas are due the great mountain masses of the Arans, Arenigs, Cader Idris (Fig. 158), and the Shelve district in Shropshire (Fig. 166). The Lakeland mountains, such as Scawfell and Helvellyn, built of the Borrowdale volcanic rocks, belong to the same time. The volcanoes were often submarine, as is shown by the occurrence of marine fossils in some of the beds of ash.

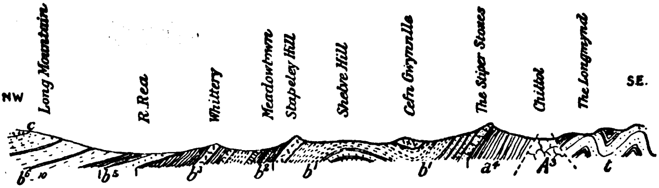

FIG. 166.—Section from the Longmynd to the Long Mountain in Shropshire. t= Longmyndian Rocks; A^3= Uriconian Rocks; a^4= Cambrian Rocks, Tremadoc Rocks (Shineton Shales); b^1= Arenig Quartzite, Flags, and Ashes; b^2= Llandeilo Flags and Limestone; b^3= Bala Ashes and Shales; b^5= Upper Llandovery Sandstones; b^{6-10}= Wenlock and Ludlow Mudstones; c= Old Red Sandstone.

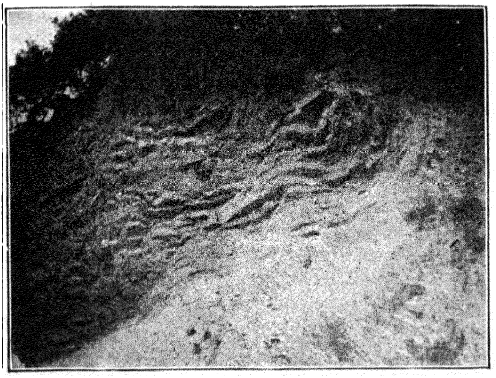

FIG. 167.—Contorted Arenig ashes, Hope, Salop.

The *Llandeilian Series* contains an important bed of limestone, richly fossiliferous, and yielding trilobites and shells, while the fine black flags contain graptolites. They are seen about Builth and Llandeilo, and at Meadowtown in Shropshire. There are occasional volcanic rocks in this Series.

The *Bala Rocks* are named after the lake of that name, where limestones which yield abundant fossils are to be found; sandstones, shales, and calcareous beds of this age also occur in the neighbourhood of Caer Caradoc in Shropshire, and the Series is thus often named the *Caradocian.* The rocks are usually of somewhat shallower water type than the preceding. The main Snowdonian lavas, and equivalent rocks in Lakeland, the Berwyns, and West Shropshire are Caradocian; and there was some vulcanicity in Ashgillian time

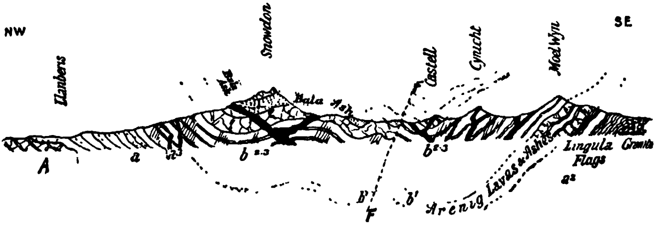

FIG. 168.—Section across Snowdon from Llanberis to Tan-y-Grisiau. A = felsite (Pre-Cambrian); a = Lower and Middle Cambrian Rocks; a^2, a^3 = Upper Cambrian; b^1 = Arenig Rocks; $b^{2\,3}$ = Llandeilo and Bala Rocks, including the ashes of Snowdon. Black masses = dykes of dolerite; F = faults.

Volcanic Rocks.—The Ordovician Period was one of earth-movement and great volcanic activity, and the physical geography may have resembled that of Alaska and the Kurile Islands at the present day, with steep shores and sharp slopes leading down to profound ocean depths and with volcanoes overlooking them. Black shales bearing graptolites are indicative of deep water, and where the Ordovician Rocks are thinnest in South Scotland there occurs a most interesting radiolarian chert, which may well be a deep-sea deposit, like the radiolarian oozes of the present day. In confirmation of this it may be mentioned that the thousands of feet of these rocks in North Wales and Shropshire are represented by a deposit less than a tenth part of that thickness in the Moffat area of South Scotland.

Fossils.—The chief fossils are graptolites, beginning with much-branched forms like *Dichograptus*.[1] Then we have four- and two-branched kinds, *Tetragraptus*,[2] *Didymograptus*[3] (Fig. 169), and *Nemagraptus*[5] (Fig. 170), followed by double-pen genera like *Diplograptus*[6] (Fig. 171). Trilobites also occur, chiefly forms like *Ogygia*[7] (Fig. 172), *Asaphus*,[8] *Illænus*[9]

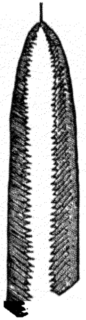
FIG. 169.[4]—*Didymograptus*, 1/1. (Z.)

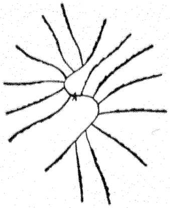
FIG. 170. *Nemagraptus*. Much reduced (after Lapworth).


FIG. 171.—*Diplograptus*. Ordovician and Silurian, 1/1. (Z.)

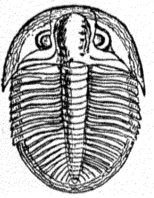
FIG. 172.—*Ogygia*. Upper Cambrian and Ordovician (about ½).

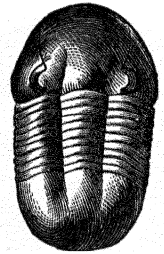
FIG. 173.—*Illænus*. Ordovician and Silurian, 1/1. (Z. after Holm.)

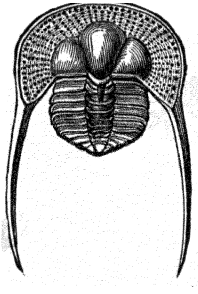
FIG. 174. — *Trinucleus* (natural size). (Z.)

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[1] Gr. *dichos* = double, *grapho* = I write (pen). [2] Gr. *tetra* = four.

[3] Gr. *didymos* = twin.

[4] Where the range of a fossil is not indicated under a figure it may be taken that the *genus* is confined to the *System* under description.

[5] Gr. *nema* = thread. [6] Gr. *diplous* = double.

[7] Gr. *Ogyges*, a king of Thebes, in whose reign there was a deluge.

[8] Gr. *asaphes* = obscure. [9] Gr. *illos* = squinting.

(Fig. 173), *Trinucleus*[1] (Fig. 174), and *Ampyx*.[2] The brachiopod *Orthis* (Fig. 175) is abundant in the Bala rocks, and occasional lamellibranchs, gastropods, crinoids, and pteropods (Fig. 176) are to be found.

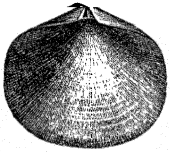

FIG. 175 *a.*—*Orthis.* Cambrian to Carboniferous, $\frac{1}{1}$. (Z.)

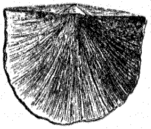

FIG. 175 *b.*—*Strophomena.* Ordovician to Carboniferous, $\frac{1}{2}$.

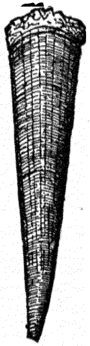

FIG. 176.—*Hyolithus.* Cambrian to Permian, $\frac{2}{3}$. (Z.)

Economics and Landscape.—The slates are the chief economic deposits worked about Blaenau Ffestiniog, Corris, and South Wales, but phosphatic rocks occur in association with the Bala Limestone. The intrusive rocks and some of the sediments are used for paving setts and sometimes for road metal. Veins of lead, zinc, and barytes occur in Shropshire and North Wales. Some of the most beautiful mountain scenery in Britain is made up of these rocks: the great Snowdon and Arenig groups of mountains (see Frontispiece and Fig. 300), the Berwyns and the Lake Country mountains, are typical examples, and they owe their character and beauty to the occurrence among softer rocks of the hard and resisting sheets of volcanic ashes, lavas, and intrusive sills.

Conditions of Formation.—A deep-sea archipelago, the islands being chiefly volcanic, and somewhat like Alaska or the Kurile Islands, seems to have been the nature of the geography of Britain while these rocks were being laid down; deep-sea deposits were being formed and submarine volcanoes

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[1] Lat. *tres* = three, *nucleus* = a kernel.

[2] Gr. *ampyx* = a head-band or fillet.

occasionally rose sufficiently above the surface of the ocean to form islands which were extensively denuded. Some of the older rock-masses also stood up to form continental islands, such as the Longmynd of Shropshire, the Archæan masses of Charnwood, and perhaps some of the Cambrian and Pre-Cambrian areas in Wales and Anglesey. The early part of the *Caledonian* earth movement at the end of the Period built land masses and mountain ranges.

The Silurian System

Name.—This System is found in Shropshire, Central and South Wales, including the land inhabited in Roman times by the Silures; hence the name. Its strata were formerly mapped by the Geological Survey under the name Upper Silurian. They usually rest with a marked *unconformity* on the Ordovician Rocks (see Fig. 154) which had become consolidated, crumpled, and exposed to denudation locally before the Silurian Rocks were laid down (Figs. 166 and 177).

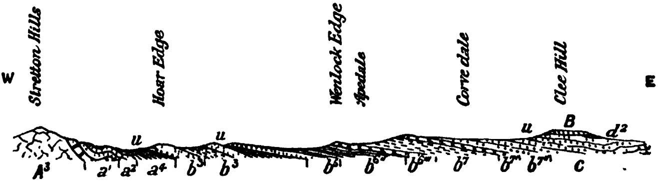

FIG. 177.—Section across Shropshire from Caradoc to the Clee Hill. A^3 = Uriconian Rocks; a^1 = Cambrian Quartzite; a^2 = *Olenellus* Limestone; a^4 = Shineton Shales (Tremadoc age); b^3 = Caradoc or Bala Sandstones and Shales; b^5 = Upper Llandovery Sandstone; $b^{6''}$ = Wenlock Shale; $b^{6'''}$ = Wenlock Limestone; b^7 = Lower Ludlow Mudstones; $b^{7'}$ = Aymestry Limestone; $b^{7''}$ = Upper Ludlow Sandstone; c = Old Red Sandstone; d^2 = Carboniferous Rocks; B = Dolerite; u = unconformities.

Subdivision.—This System begins with a set of conglomerates and sandstones, formed as beaches and sand-banks round the edges and over the land area (due to the first *Caledonian* movement) as it submerged. The predominating colour of the rocks is a bluish grey and the typical succession is as follows:—

SERIES.	STAGES.	CHARACTER OF ROCKS.
	Passage beds	Thin sandstones and flagstones
3. Ludlow Series	Upper Ludlow	Sandstones
	Aymestry Limestone	Fossiliferous limestone
	Lower Ludlow	Mudstones
2. Wenlock Series	Wenlock Limestone	Fossiliferous limestone
	Wenlock Shale	Grey shales
	Woolhope Limestone	Limestone
1. Llandovery Series	Tarannon Shale	Red and green shales
	Upper Llandovery	Limestone, sandstone, and conglomerate
	Lower Llandovery	Sandstone

The lower division, the *Llandovery* Series are found wrapping round the denuded irregularities of the Ordovician, Cambrian, and older rocks, and they include fragments, pebbles, and sometimes worn fossils derived from them. They are usually richly fossiliferous, but the fossils are often in a poor state of preservation. The brachiopods *Pentamerus* of two or three species are very characteristic of this Series. Trilobites, such as *Calymene* (Fig. 178) and *Phacops*[1] (Fig. 179), brachiopods like *Orthis*, *Atrypa*, *Strophomena*, and *Meristella*, and worm-tracks frequently occur. The upper division is the widespread *Tarannon Shale*, which sometimes contains graptolites. A few diplograptids survived through Lower Llandovery time, and monograptids then appeared for the first time.

A thick sheet of shale, the *Wenlock Shale*, rich in minute shells, succeeds, having sometimes a band of limestone (the *Woolhope Limestone*) at the base, and containing throughout its thickness beds and lumps of impure limestone (see Fig. 61), which become more and more common until they graduate into the *Wenlock Limestone* above (Figs. 177 and 180). This is often made up of crinoids and corals sometimes building actual coral-reefs. Other fossils, however, are common, such as trilobites, *Orthis*, *Leptœna*, *Atrypa*, *Meristella*, and other brachiopods, cephalopods, gastropods, and polyzoa.

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[1] Gr. *phacos* = a lentil, *ops* = an eye.

The *mudstones* of the *Lower Ludlow Stage* are rather more sandy than the Wenlock Shale, and work up so easily into mud as to deserve the local name. Fossils are fewer, and the beds pass up locally into a mass of limestone (the *Aymestry Limestone*), which reproduces the character of the Wenlock Limestone with variations in the fauna (see Fig. 177). Mudstones and sandstones succeed, and in these we have two or three remarkable deposits known as *bone-beds*, made up of the relics of fishes and crustacea.

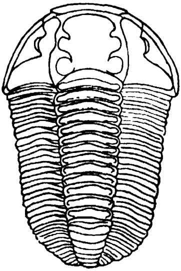

FIG 178.—*Calymene.* Ordovician and Silurian, ½. (After Salter.)

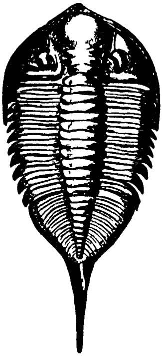

FIG. 179.—*Phacops.* Ordovician to Devonian, ½. (Z. after Hall.)

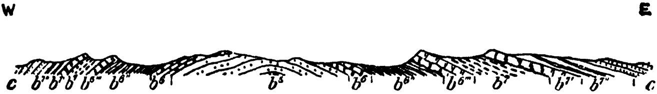

FIG 180.—Section across the anticline of Woolhope, Herefordshire. b^5 = Upper Llandovery Sandstone; b^6 = Woolhope Limestone; $b^{6''}$ = Wenlock Shale; $b^{6'''}$ = Wenlock Limestone; b^7 = Lower Ludlow Beds; $b^{7'}$ = Aymestry Limestone; $b^{7''}$ = Upper Ludlow Beds; c = Old Red Sandstone.

Volcanic activity all but ceased in Britain, and the beds were deposited tranquilly in not very deep waters. Towards the north and west they pass into shales in which the graptolites *Cyrtograptus* and *Monograptus* are found, and into sandstones, indicating that a shore-line was in this direction. The upper rocks turn yellow and red in colour, become less fossiliferous, and gradually pass into the yellow and red sandstones of the overlying System of rocks.

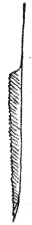

FIG. 181.—*Monograptus*, ½. (Z. after Lapworth.)

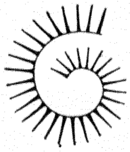

FIG. 182.—*Rastrites*, ½. (Z. after Barrande.)

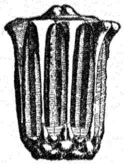

FIG. 183.—*Eucalyptocrinus*. Silurian and Devonian (about ½). (Z.)

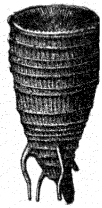

FIG. 184.—*Omphyma*. Ordovician and Silurian (about ¼). (Z.)

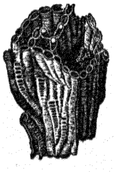

FIG. 185.—*Halysites*, the "Chain Coral." Ordovician and Silurian, ½ (Z.)

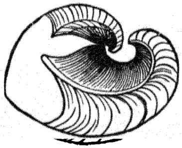

FIG. 186.—*Pentamerus*. Silurian and Devonian, showing the internal plates, ½. (Z.)

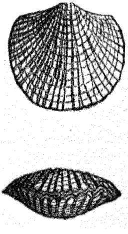

FIG. 187.—*Atrypa reticularis*. Silurian and Devonian, 1/1. (Z.)

Fossils.—The earliest traces of land-plants have been described from Silurian Rocks, and the earliest British fishes from the Lower Ludlow Beds. The Diplograptidæ are found for the last time in the Llandovery rocks; they are accompanied and eventually replaced by *Monograptus* (Figs. 181 and 140), *Cyrtograptus*, and *Rastrites* (Fig. 182), all of which die out, in or before Aymestry time. Crinoids like *Eucalyptocrinus*[2] (Fig. 183) are very common. Trilobites of the genera *Phacops*, *Encrinurus*,[1] and *Calymene*[2] are not uncommon, and

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[1] Encrinite-like, and Gr. *oura* = a tail.

[2] Gr. *calypto* (*kekalymmenos*) = concealed, or protected by a covering.

they are often found rolled up like wood-lice. Corals are abundant; *Favosites*,[1] *Heliolites*,[2] *Omphyma* (Fig. 184), and *Halysites*[3] (Fig. 185) being characteristic. *Pentamerus*[4] is a brachiopod; *P. oblongus* being characteristic of Llandovery, *P. galeatus* of Wenlock, and *P. Knighti* (Fig. 186) of Aymestry Rocks. *Orthis* is abundant, particularly the small species; and the genus *Atrypa*[5] (Fig. 187) is found in all rocks of the System. Cephalopods like *Orthoceras* (Fig. 188) and *Phragmoceras*[6] occur frequently; such gastropods as *Murchisonia*[7] and *Euomphalus*[8] (Fig. 189), a few lamellibranchs (*Cardiola*), and many polyzoa, occur. In the upper beds gigantic merostomatous crustacea known as *Eurypterus*[9] and *Pterygotus*,[10] called by Scotch quarrymen "seraphim," together with scorpions, have been found in the Silurian Rocks of South Scotland. (Fig. 195, p. 249.)

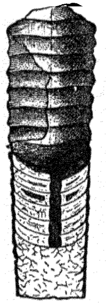

FIG. 188.—*Orthoceras.* Cambrian to Trias, about ½. (Z. after Barrande.)

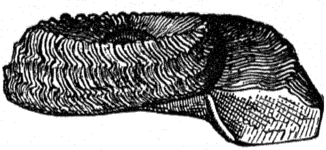

FIG. 189.—*Euomphalus* (*Omphalotrochus*). Silurian to Carboniferous, $\frac{1}{1}$. (Z. after Nicholson.)

Economics and Landscape.—The lime is the most valuable economic product, though slates are worked in North Wales and Lakeland. The scenery of Shropshire consists of tree-clad ridges situated on the limestones, with long, parallel,

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[1] Lat. *favus* = a honeycomb.

[2] Gr. *helios* = the sun, *lithos* = a stone.

[3] Gr. *halysis* = a chain.

[4] Gr. *pente* = five, *meros* = a part.

[5] Gr. *a* = not, *trype* = a hole.

[6] Gr. *phragmos* = a partition, *keras* = a horn.

[7] After Sir Roderick Murchison.

[8] Gr. *eu* = well (marked), *omphalos* = umbilicus.

[9] Gr. *eurys* = broad, *pteron* = wing or fin.

[10] Gr. *pteryx* = a wing, *ous* (*otos*) = an ear.

fertile valleys on the shales ; but where limestones are absent there are rolling uplands sometimes attaining a considerable altitude like those of North Wales and the Long Mountain (see Fig. 166), the south part of the Lake Country, and the Southern Uplands of Scotland.

Conditions of Deposit.—The physical conditions of the Period appear to have been open sea in Central England, probably extending from Shropshire eastward to Hertfordshire and Kent. Earth-movement during the Archæan Era and taken up again after Ordovician time (the *Caledonian Movement*) established a great northern continent extending from Scandinavia to North Scotland and Ireland, out an unknown distance into the Atlantic. This great mountainous land underwent continuous denudation, providing sediment for the succeeding Formations, as is especially well seen in the Silurian, the Old Red Sandstone, and the Carboniferous Systems. Its southern margin at first fell sharply downwards into a deep sea trough south of which was shallower water containing islands, some of them of continental character like the Longmynd, some of volcanic and evanescent nature built by Ordovician vulcanicity. The Post-Ordovician movement increased the area of the continent at the expense of the southern sea, but this sea gradually re-established itself during Silurian times, when the later sediments spread farther and farther northward, filling the deep trough and lapping round the cliffs and stacks at the margin of the continent and the adjacent islands. The upward movement started again in late Silurian times preparing the way for the great continental extension of the Old Red Sandstone Period and the mountain-making movement that occurred within that Period.

RECAPITULATION

The *Eozoic* rocks form the floor on which all the later rocks rest. They are in most places covered so deeply by newer sediments that it is only in a few isolated localities that they come to the surface.

They present three distinct aspects, but how far these represent successive periods it is not yet possible to say. There is the *Gneissic* aspect of the north-west of Scotland and Ireland, where all the rocks are foliated and have been much subjected to earth-movement and its accompanying metamorphism ; the *Plutonic* and *Volcanic* aspect of the English and Welsh Midlands and the Malverns ; and, lastly, the

Sedimentary aspect of the Longmynd Rocks and the Torridon Sandstone.

The *Cambrian* System admits of division according to its fossils and its petrological character. The thickness of rock is not very great, but the fauna is richer than we might expect from such ancient deposits. Graptolites, *trilobites*, *brachiopods*, and mollusca, are all present, though some of them show but *rudimentary forms*.

The *Ordovician* System is characterised by the prevalence of *volcanic* rocks which belong to the late Arenig, Llanvirn, and Bala time. The fossils indicate an advance in the higher forms of *graptolites* and *trilobites* which are present, while *brachiopods* and *corals* become abundant.

The *Silurian* Rocks were deposited in the Midlands in a muddy *sea* in the clearer parts of which *limestones* could form ; the sea was shallow at the beginning and end of the Period. The fossils are related to those of the Ordovician Rocks, but of more advanced organisation. *Fishes* and *land-plants* are found in Britain for the first time.

QUESTIONS ON CHAPTER XVIII

1. What is the general nature of the Archæan rocks? Account for the difficulty in correlating those of different districts.

2. Describe the variations found in the Cambrian rocks in different localities.

3. Give the general succession of the Ordovician rocks, and mention the chief horizons at which volcanic rocks occur.

4. Arrange the following formations in descending order, placing the newest at the top, and state to which of the great geological systems each belongs—Lingula Flags, Ludlow Beds, Caradoc Sandstone, Wenlock Limestone, Llandeilo Beds, Arenig Rocks. (XII.)

5. Describe briefly the structure of one or more districts in this country, chosen to illustrate the following geological characters—succession of varying deposits indicating varying conditions of deposition, folding, faulting, denudation. (O and C.)

6. Write the names of three genera of fossils which are of common occurrence in the Silurian rocks, stating the natural history division to which each genus belongs. (1882.)

7. What is a Trilobite? In what rocks are these fossils most abundant? Give the names of three genera. (1890.)

8. Name some genera of fossils still existing which occur in Palæozoic rocks. (1884.)

9. Of what groups of rocks are the following fossils especially characteristic, viz. Graptolites, Trilobites, Eurypterida? (XII.)

CHAPTER XIX

THE PALÆOZOIC GROUP (*continued*)

The Newer Palæozoic Division

THE Devonian, Carboniferous, and Permian Systems are united as the upper division of the Palæozoic Group, which is called the Newer Palæozoic Sub-Group. After the long-continued marine conditions of the former sub-era came a great earth-movement, uplifting a continental region in Northern Europe, on which lofty mountain-chains arose. This is the main *Caledonian* movement, originating the *second continental phase*, followed by the Carboniferous (2nd) *marine phase*, and that by the *third land phase* due to the *Pennine-Armorican* movement. Life underwent important changes; trilobites and the last graptolite died out, but there were hosts of fishes, amphibia, merostomata, crinoids, sea-urchins, corals, and cephalopods belonging to the Palæozoic types. The vegetation was made up chiefly of cryptogamous trees, but the earliest phanerogams, conifers allied to the pines and yews, made their first appearance.

The Devonian System

Name.—These rocks are found in Cornwall and Devonshire (whence their name), and also in South and Central Wales, the Cheviots, and many parts of Scotland; but those of the first two localities are chiefly of marine origin, and differ very widely from those found elsewhere in Great Britain and Ireland.

The Devonian Type.—The order of succession in Devonshire usually accepted is the following:—

SERIES	STAGES
3. Upper Devonian	Baggy, Marwood, and Lower Pilton Beds. Pickwell Down Sandstones. Morte Slates and U. Ilfracombe Limestones.
2. Middle Devonian	L. Ilfracombe Limestones and Calcareous Slates. Hangman Grits.
1. Lower Devonian	Lynton Slates. Foreland Sandstone.

The rocks consist of alternations of grits, sandstones, and beds of slate, with one principal limestone bed occurring in the *middle* and a less important one at the top of the System. Fossils occur in these calcareous beds and somewhat more sparingly in the slates. The strata are very much contorted, broken, faulted, and cleaved, so that it is most difficult to make out the succession, and certain of the rare fossils that occur on particular horizons, such as the Morte slates, have not as yet permitted of precise identification. On the whole the beds appear to have been formed in marine waters, but some of the unfossiliferous sandstones, like those of the Foreland and Pickwell Down, may possibly represent lacustrine or estuarine conditions like those of the Old Red Sandstone. The fossils include abundant corals, the limestone which contains them being quarried for ornamental marble near Torquay. Iron ore occurs in the Morte slates; but other deposits of economic value are rare. The rocks give rise to the far-famed and beautiful scenery of Exmoor and North Devon, an ancient plateau deeply cut into by steep-sided valleys. Volcanic rocks are interbedded with some of the strata in North Devon, and are of much more common occurrence in the south of the county.

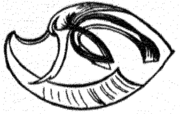

FIG. 190.—*Stringocephalus*. Silurian and Devonian, ¼. (Z.)

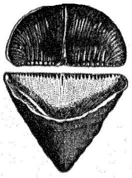

FIG. 191.—*Calceola*, ½. (Z.)

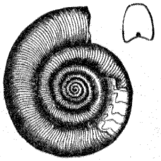

FIG. 192.—*Clymenia* (*Oxyclymenia*), showing septal line, ½. (Z.)

Fossils.—Amongst the fossils may be mentioned *Spirifer*[1] and *Stringocephalus*[2] (Fig. 190), belonging to the brachiopods; *Bronteus*,[3] a trilobite; *Favosites* and the remarkable *Calceola*[4] (Fig. 191) amongst the corals; and a curious nautiloid shell called *Clymenia*,[5] in which the septa or divisions between the adjacent chambers are gently waved, as shown in Fig. 192, and the siphuncle is internal.

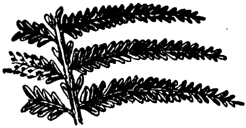

FIG. 193.—*Adiantites*, showing a fertile branch (about ⅛).

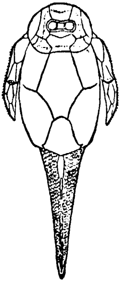

FIG. 194.—*Pterichthys* (about ⅓). (Z. after Traquair.)

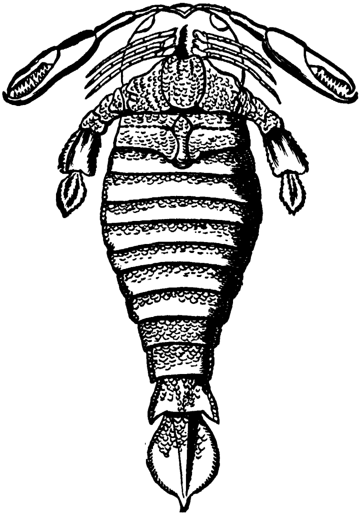

FIG. 195.—*Pterygotus*. Silurian and Devonian, ⅛. (Z. after Woodward.)

Old Red Sandstone Type.—In Herefordshire, South Wales, and Scotland (see Fig. 24), an entirely different set of rocks comes above the Silurian Rocks, but, like the Devonian, it is certain that their position is between the Silurian and the Carboniferous Systems (see Fig. 177). They consist of red, brown, chocolate, and white sandstones, seams of conglome-

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[1] Lat. *spira* = a coil, *fero* = I bear.

[2] Gr. *strinx* = an owl, *kephale* = the head.

[3] Brontes (thunder), one of the Cyclopes.

[4] Lat. *calceolus* = a small shoe.

[5] Clymene, a sea nymph.

rate, great thicknesses of red marl, and beds of impure limestone, called cornstones, which are poor in fossils. They are called the *Old* Red Sandstone System in contradistinction to the *New* Red Sandstone, because they underlie the coal-bearing rocks, while the other System overlies them. The predominant red colouring is due to the deposit of thin coats of iron oxide round the grains of quartz.

Fossils and Conditions of Deposit.—Fossils are very scarce, and include a few land-plants, such as ferns (Fig. 193), the remains of fish (Fig. 194), and some gigantic crustacea like *Pterygotus* (Fig. 195). No marine, but a few fresh-water shells, *Anodonta*[1] *Jukesi* (Fig. 196), have been found, and some of the fish are related to sharks and to the gar-pike of North American rivers. The great crustacea are like those which appear at the top of the Silurian rocks when the colour becomes red and marine fossils are no longer found. The fish, like *Coccosteus*[2] and *Pterichthys*[3] (Fig. 194), appear to have had a cartilaginous or imperfectly bony skeleton, but they were protected externally by an armour of bony plates; the back-bone was prolonged into the upper lobe of the tail, a character still possessed by the sharks and gar-pikes (see Fig. 215). So it has been concluded that the rocks were formed in great inland lakes, like Lake Superior of to-day. One lake occupied South Wales and the border counties, another the Cheviot region, a third the Central Valley of Scotland, and a fourth lay north of the Central Highlands of Scotland, and stretched probably to the Orkneys and Shetlands. The approximate boundaries of these lakes have been traced by Sir A. Geikie by means of the bands of breccia along their margins. These were derived from granitic and gneissose rocks in the vicinity, and are extremely massive, some of the fragments measuring over three feet across. The grey flagstones found in these rocks furnish the well-known Caithness flags, so much used for paving and renowned for yielding abundant remains of fossil fish. Indeed

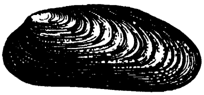

FIG. 196.—*Anodonta (Archanodon)* Devonian to present day, ¼. (After Baily.)

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[1] Gr. *a* = without, *odous* (*odontos*) = a tooth.

[2] Gr. *kokkos* = a berry, *osteon* = a bone.

[3] Gr. *pteron* = a fin or wing, *ichthys* = a fish.

the Old Red Sandstone Period is sometimes spoken of as the age of fishes.

Volcanoes and Earth-movement.—Volcanic rocks, mainly andesitic lavas and tuffs, occur in the Cheviots, where they surround a central plug of augitic granite (see Fig. 121). Volcanic rocks also occur in the Old Red Sandstone of Scotland. The lower and upper divisions of the System in Scotland, Wales, and Ireland, are often separated by an unconformity ; the lower division passes conformably down into the Silurian Rocks, and the upper graduates up to the Carboniferous. This means that while there was only a slight earth-movement and a gradual physical change at the end of the Silurian Period, a great deal of movement and considerable changes in physical geography took place after the formation of the Lower Old Red Sandstone. This movement is practically a renewal of that which began in post-Ordovician times, and, recurring at the end of Silurian times, converted the Silurian seas into lakes ; it then brought about the temporary drying of the lakes in the middle of the Period. It was this *Caledonian* movement as a whole which had vast consequences upon the scenery of Great Britain, for it elevated the mountain-chain of the Scottish Highlands, the Southern Uplands, and those of the Lake Country and North Wales.

Economics and Landscape.—Vast masses of granite were intruded during the Period, such as those of the Grampians, of the Southern Uplands about Criffel and the Cairnsmuir, Shap, Eskdale, and Skiddaw in the Lake Country, and the Cheviots (see Fig. 121). These seem to be connected with the volcanic eruptions of the time. In short this is essentially a *continental period*, during which the Atlantic continent extended southward in the British area, giving rise to large rivers and lakes among its mountain-chains, the formation of which was, as usual, accompanied by the outburst of vigorous volcanic action, the intrusion of plutonic rock, and the contortion, faulting, and metamorphism of rocks.

The Carboniferous System

Name and Subdivisions.—This System is named from the fact that it contains our principal deposits of coal, and hence it is of immense commercial value, and the precise knowledge of its character is of national importance. It consists of three principal members :—

SERIES	ROCKS
3. The Coal-measures	Sandstones, fire-clays, ironstones, and coals.
2. The Millstone Grit	Grits, sandstones, and shales.
1. The Yoredale Beds and Carboniferous Limestone	Limestones and shales.

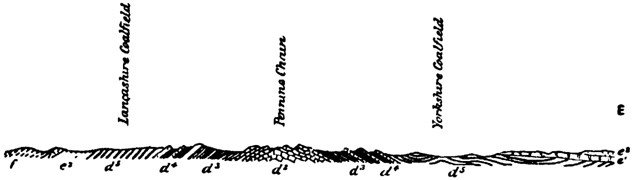

FIG. 197.—Section across the Pennine Chain and the Coal-fields of Lancashire and Yorkshire. d^2 = Carboniferous Limestone ; d^3 = Yoredale Rocks ; d^4 = Millstone Grit ; d^5 = Coal-measures ; e^1 = Permian Limestone ; e^2 = Permian Sandstone ; f = Trias

The greatest display of the rocks of the System is on the flanks of the Pennine Chain. They also occur in the Midlands, in South Wales, and in Devonshire. Where the Old Red Sandstone is present, as in the Cheviots and South Wales, the Carboniferous Rocks generally succeed it conformably, beginning with shales which pass up into the Limestone (see Fig. 121). Where that System is absent, a conglomerate or other basal rock below the Limestone rests unconformably on older rocks (see Figs. 156 and 111), and in some localities one or two of the lower Carboniferous divisions are wanting.

The Carboniferous Limestone, or Mountain Limestone, is typically developed as a vast mass of pure limestone (see Figs. 25, 66, 67, 287, 301), not less than 1600 feet thick, in Derbyshire, where it is splendidly exposed in the dales, and in the cuttings and quarries on the High Peak Railway.

Fossils.—It is made up largely of crinoid stems such as *Poteriocrinus*[1] (Fig. 198), and some varieties of this limestone are cut and polished for ornamental marble (Fig. 13). Corals are often present (*Michelinia*,[2] Fig. 199), and the compact portion of the limestone is often seen by the microscope to be made

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[1] Gr. *poterion* = a cup, *krinon* = a lily.

[2] Named after M. Michelin.

of foraminifera. Brachiopoda are also abundant, particularly *Productus*[1] (Fig. 200), *Spirifer* (Fig. 201), *Athyris*,[2] and *Terebratula*,[3] the last genus now beginning to be abundant. Cephalopoda like *Orthoceras*, gastropoda like *Euomphalus* (Fig. 202) and *Pleurotomaria*,[4] heteropoda like *Bellerophon*,[5] and the teeth and spines of fish, such as *Orodus*[6] and *Psammodus*,[7] are also abundant. The pearly *Nautilus*[8] (Fig.

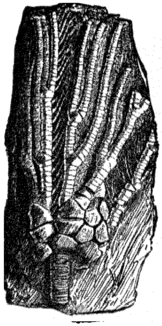

FIG. 198.—*Poteriocrinus.* Devonian to Carboniferous, ½. (Z.)

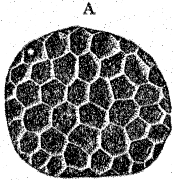

FIG. 199.—*Michelinia.* Devonian and Carboniferous, ⅓. (Z.)

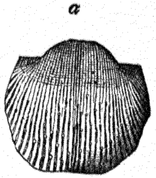

FIG. 200.—*Productus.* Devonian to Permian. ½. (Z.)

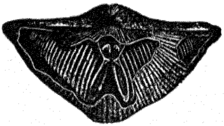

FIG. 201.—*Spirifer*, with internal spirals. Silurian to Lias, ⅜. (Z. after Davidson.)

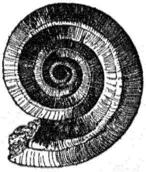

FIG. 202.—*Euomphalus.* Silurian to Carboniferous, ½. (Z.)

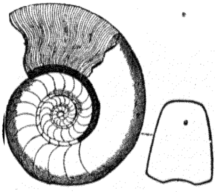

FIG. 203.—*Nautilus* (*Discites*). Ordovician to present day, ⅖. (Z. after de Koninck.)

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[1] Lat. *productus* = lengthened.

[2] Gr. *a* = not, *thyris* = door.

[3] Lat. *terebratus* = perforated.

[4] Gr. *pleuron* = a side, *tome* = a notch.

[5] Bellerophon, a mythic hero.

[6] Gr. *oraios* = beautiful, *odous* = tooth.

[7] Gr. *psammos* = sand.

[8] Gr. *nautilos* = a sailor.

203) is found as a fossil, but a more common form of cephalopod is known as *Goniatites*[1] (Fig. 204); in this the edges of the septa between the chambers are bent into zig-zag lines, while in *Nautilus* the lines are gently curved. The last trilobites known in Britain come from the Carboniferous Limestone, one of the common genera being *Phillipsia*[2] (Fig. 205).

Distribution.—When traced into North Derbyshire, Lancashire, Yorkshire, and Northumberland, the limestone becomes intercalated with bands of shale and sandstone, which steadily thicken to the north and enclose thin seams of coal. This indicates the approach to a shore-line in this direction. In Scotland this part of the System has a group of sandstones, the Calciferous Sandstone, at the base, followed by a series of thin limestones interbedded with shales, sandstones, and coal. Round the Midland coal-fields the limestone division is absent, or else very thin and unimportant, but it swells out again, and attains great consequence, in the Mendips and on the edge of the coal-fields of the Forest of Dean and South Wales.

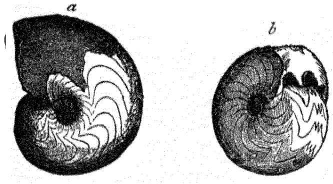

FIG. 204.—*Goniatites* (a, *Gephyroceras*; b, *Glyphioceras*). Silurian to Carboniferous, ½. (Z.)

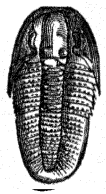

FIG. 205.—*Phillipsia*. Devonian to Permian, 1/1. (Z.)

The Millstone Grit, which succeeds, consists of very massive grits (see Fig. 296) and conglomerates, made up chiefly of granite débris such as quartz and felspar grains, interbedded with shales. Some of these grits are very thick and hard, standing out as the principal mountain-masses in the Peak District. Fossils are not very common, and consist chiefly of plant remains, but marine fossils like Goniatites occur in the shales. Thin seams of coal and a few ironstones also occur, and are at times sufficiently important to be worked in Derbyshire, Yorkshire, and Northumberland.

[1] Gr. *gonia* = an angle.

[2] After Professor Phillips.

The Millstone Grit is a marine deltaic deposit, comparing in many respects with the outer edge of the Mississippi delta.

The **Coal-measures** are a very varied set of deposits, chiefly sandstones (see Fig. 40), fire-clays, coal-seams (see Fig. 15), and beds of ironstone, with occasional thin limestones in the upper part of the Series. The coal-seams often have a roof of sandstone; they may rest upon seams of fire-clay or gannister, called by miners under-clay or seat-earth, sometimes penetrated by rootlets proceeding from the roots of fossil trees which occur in the coal-seams and in the sandstone "roofs" (see Figs. 99 and 209).

Ironstones occur as layers of lumps or concretions embedded in clay. Each lump generally includes a fossil inside it, such as a fern-leaf or a shell. The sandstones contain fossil plants or thin seams of coal. Sometimes they are so fine-grained and highly siliceous, that they can be employed as a lining for iron furnaces: they are then called gannister.

A microscopic examination of some coals shows traces of vegetable structure, such as portions of bark, the epidermis of leaves, and more frequently spores and spore-cases like those of ferns at the present day (see Fig. 98). The composition of coals varies very much, but as a general rule they are so pure that the only inorganic impurity found in them is not sand or muddy sediment, but just about the same in amount and composition as if the coal had been formed from wood. This extreme purity seems to show that coals are not ordinary sediments, but that they were formed from the growth of forests in the places where the seams are now found (see p. 140); a very good idea of such a forest is given by the one found near Glasgow, Fig. 206. This is borne out by the character of the fire-clay, a clay from which all the alkalies (potash and soda) have been removed as if by the growth of vegetation (see Figs. 99 and 209), and by the *Stigmaria* rootlets which penetrate it, just as rootlets penetrate a modern soil. Coals of this type soil the fingers, are bright and shiny, burn with a bright flame giving off gas, and are called house coals or bituminous coals. When coals of this class are traced in certain directions in the South Wales and other coal-fields, their character changes, and they pass first into steam-coal and then into anthracite.[1] These are hard shining coals, which do not

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[1] Gr. *anthrax* = carbon.

soil the fingers, burn without flame, give off little gas, and in composition resemble bituminous coals which have lost a large proportion of their gaseous constituents. In some cases it is possible that anthracites may be somewhat metamorphosed coals (see Table on p. 140), but in the South Wales coal-field the present character of steam-coals and anthracites appears to result from the character of the original deposit. Cannel coals are so rich in gases that splinters kindle easily. They result from the rotting of plant debris under water. This is proved by the fossil fishes they contain, their high content of inorganic matter which has the composition of clay and grit, and their gradual transition into bituminous shales, which are ordinary shales so loaded with coaly matter that oil may be distilled from them, at one time an important industry in the Scottish coal-fields.

FIG. 206.—Coal-measure forest, Partick, near Glasgow. (From a photograph by Mr. R. M'F. Mure: copyright.)

Fossils.—The fossils of the Coal-measures are chiefly the remains of plants, which often attain a great size. But these plants are not related to the large trees of our own forests:

they belong to the Cryptogams, a lower division of the plant kingdom.

A close comparison of these plants shows that while some are like the tree-ferns of New Zealand and tropical regions, others like *Neuropteris*,[1] *Alethopteris*,[2] *Pecopteris*,[3] *Odontopteris*[4] and *Sphenopteris*[5] (Fig. 207), are smaller, herbaceous forms. Some, such as *Lepidodendron*[6] (Fig. 208) and *Sigillaria*[7] (Fig. 209), are like club-mosses in shape, method of branching, their small scale-like leaves, and the method of bearing cones with spores: the roots of these plants are known as *Stigmaria*.[8] Others again (*Calamites*,[9] Fig. 210) are like the living but

FIG. 207 —*Sphenopteris*, ¼. Carboniferous to Jurassic.

FIG. 208.—*Lepidodendron*, ¼. Silurian to Permian.

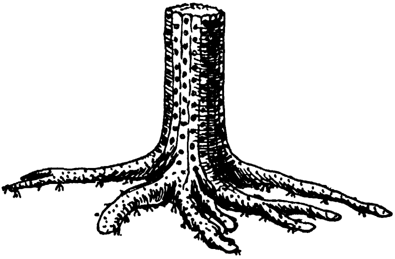

FIG. 209.—*Sigillaria* with its Stigmarian roots, ⅛. Devonian to Carboniferous.

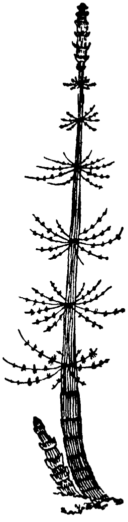

FIG. 210—*Calamites*, 1/80. Devonian to Trias.

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[1] Gr. *neuron* = nerve, *pteris* = fern.

[2] Gr. *alethes* = true.

[3] Gr. *peko* = I comb.

[4] Gr. *odous* (*odontos*) = a tooth.

[5] Gr. *sphen* = a wedge.

[6] Gr. *lepidotos* = scaly, *dendron* = a tree.

[7] Lat. *sigillum* = a seal.

[8] Gr. *stigma* = a puncture.

[9] Lat. *calamus* = a reed.

humbler *Equisetum*[1] or horsetail. These, however, instead of being small and lowly plants as they are nowadays, grew into great trees, some of which reached 50 or 60 feet in height. The oldest flowering plants, the conifers, belonging to the gymnosperms, make their appearance at this time. Associated with them there are generally found fresh-water or brackish-water shells, such as *Anthracosia*,[2] *Anthracomya*,[3] *Naiadites*,[4] and the annelide *Spirorbis*,[5] the latter at times forming beds of limestone. Air-breathing shell-fish like *Pupa*[6] (Fig. 211) and *Zonites*[7] have been found in America, amphibia such as *Lepterpeton*[8] in Ireland, and reptiles elsewhere. Occasionally marine seams are found which contain *Spirifer*, *Productus*, *Aviculopecten*,[9] and *Nautilus*, recalling in some degree the fossils of the Carboniferous Limestone below.

Economics.—The chief economic products of the Coal-measures are the coals and ironstones, the fire-clay for bricks and coarse pottery, the gannister sandstones for furnace linings, and the sandstones for building and flagging—the famous Yorkshire flags being derived from this formation. The Millstone Grits have been much used for making millstones, for which their rough texture and hard siliceous composition adapts them admirably. In the Carboniferous Limestone district of Yorkshire and Northumberland metalliferous veins are found, Lead and Zinc being the commonest, while the lime from that Formation is much used both for burning and smelting purposes. A point of great importance in this System is the occurrence of coal among other deposits of economic value, so that it is available for making bricks and pottery, for iron industries, and for burning lime, while it also provides for the cheap transport of these raw materials and the products manufactured from them.

FIG. 211.—*Pupa* (*Dendropupa*). A land-shell. Related to present day forms, $\frac{2}{1}$. (Z after Dawson.)

Landscape.—The beautiful scenery of the Peak District

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[1] Lat. *equus* = a horse, *seta* = bristle or hair.
[2] Gr. *anthrax* = carbon.
[3] Gr. *myax* = a mussel.
[4] Gr. *Naias* = a river nymph.
[5] Lat. *spira* = a coil, *orbis* = a circle.
[6] Lat. *pupa* = a girl.
[7] Gr. *zoné* = a girdle.
[8] Gr. *leptos* = slender, *herpeton* = a reptile.
[9] Avicula-like, Lat. *pecten* = a comb.

and the Yorkshire mountains near Ingleborough is due to the Carboniferous Limestone flanked by rough moorlands founded on Millstone Grit, while the Coal-measures formed at one time a beautiful rolling pastoral country, which has, however, now been disfigured by spoil-banks, and ruin due to mining operations.

Conditions of Deposit.—In the Midlands the lower parts of the Carboniferous System are absent, and first the Millstone Grit and then the Coal-measures rest directly against much older rocks. This is illustrated by the diagram (Fig. 212), which teaches a very useful lesson as to the means employed in ascertaining the physical geography of the Period. The physical conditions then existing are responsible for the character of the deposits. The Carboniferous Limestone of Derbyshire was deposited in an open and fairly deep sea, the chief bordering land-mass being towards the north, the sediments increasing in thickness and coarseness in that direction, while coal-seams occurring there indicate that this sediment at times filled up the water sufficiently to allow of forest growth taking place. This old land occupied what is now the North Atlantic, with the Scottish Highlands and their continuation at its south-eastern edge. Another bar of land stretched across the Midlands from Shropshire to Charnwood, and bits of this old land peer up through the coal-fields of Shropshire, South Staffordshire, Warwickshire, and Leicestershire. South of this, again, open sea occurred in South Wales, and this may have been at times deep in Devon-

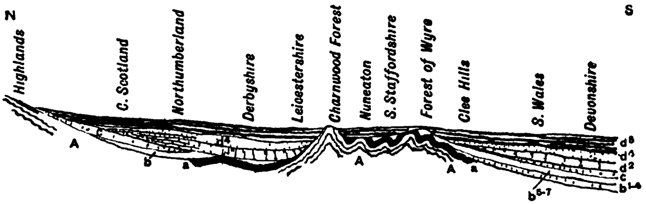

FIG. 212.—Section of England from north to south, when the whole of the Carboniferous Rocks had just been formed, showing the Midland ridge buried in Coal-measures. A = Archæan ; *a* = Cambrian ; b^{1-4} = Ordovician ; b^{5-7} = Silurian ; *b* = Ordovician and Silurian ; *c* = Old Red Sandstone and Devonian ; d^2 = Carboniferous Limestone ; d^4 = Millstone Grit ; a^5 = Coal-measures.

shire, where beds of radiolarian chert are found in the Lower Carboniferous Rocks underlying the shales and sandstone which form the upper part of this series.

The area on which the Carboniferous Limestone was accumulated gradually became overspread with the river-borne sediments of the Millstone Grit, filling up the sea and accumulating to so great a thickness that at certain spots forests began to grow and were buried by new sediments, which in their turn again supported vegetation. The condition of things during the Carboniferous Limestone Epoch recalls somewhat the condition of the Gulf of Mexico, in which the rich organic deposits of the Gulf Stream are being laid down. The Millstone Grit is like the encroachment on the Gulf of the mechanical deposits of the Mississippi delta, on which great forests are now growing, to be in their turn buried up to form coal-seams. The forests gradually spread southwards, and the most productive Coal-measures are progressively later in date as we proceed southward in Britain.

Volcanic Action.—There was a good deal of volcanic action in Britain, chiefly in early Carboniferous time. There are basaltic lavas and ashes in Derbyshire, and near Limerick, and in Scotland there were volcanoes which poured out masses of basic and intermediate lavas, such as basalts, andesites, phonolites, and trachytes. Basic lavas, dykes, and sills occur in association with late Carboniferous Rocks in the Midlands.

Earth-movement.—At the end of the Carboniferous Period great earth-movement supervened. The rocks were folded by an east-and-west force (the *Pennine Movement*), so that the axes of the folds and the strike of the rocks run north and south. This is the cause of the outcrop along the Pennine Chain. Another crushing movement came at right angles to this direction, and its folds run east and west, crossing the other set. The result is that the Carboniferous Rocks occur mainly in basins, the centre of which is occupied by the Coal-measures. Sheets of rock with coal-seams, once continuous across the Pennine Chain, have now been sundered by denudation, and separate coal-basins exist on the east and west sides of the chain. These basins are not usually exposed in their entirety, as newer rocks, especially the New Red Sandstones, frequently cover one lip or other of the basin (see Fig. 197, p. 252). The north-and-south folds are the most conspicuous in the North of England, and the east-and-west in the South (the *Armorican Movement*). The South Wales coal-basin and its borders, the Mendip Hills, and the strike of the rocks across Devonshire are the chief Armorican folds now visible in England, but they stretch away eastward, hidden under more recent deposits beneath the Weald of Kent and Surrey, and across France to the Ardennes.

The Permian System

Name and Subdivision.—Succeeding the Carboniferous Rocks unconformably is a mass of red sandstone, formerly called the New Red Sandstone. The lower part of it contains fossils which are related to those of the Carboniferous Rocks—both marine animals and, to a less extent, land plants—while the upper part is more closely connected with the overlying Jurassic Formation. So the line between the Palæozoic and Mesozoic Groups is drawn in the middle of the New Red Sandstone, the beds below being called the Permian System—after the province of Perm in Russia, where they are well developed,—those above, the Triassic System. The succession of Permian Rocks flanking the Pennine Chain is the following :—

SERIES.

4. Red Marl.
3. Magnesian Limestone.
2. "Marl Slate."
1. Red or Yellow Sandstone, with Breccias.

The lower part of the Permian in North-west England contains bands of breccia, largely made up of fragments of limestone and other older rocks exposed during the *Pennine* earth-movement. These breccias are often screes weathered by frost from the limestone cliffs, and consolidated by cement when buried under the succeeding sediments. In the Midlands breccia is associated with red sandstones containing conglomerates, while in the north-east of England there occurs a magnesian limestone or dolomite, a limestone consisting of carbonate of magnesia combined with carbonate of lime. This limestone is often crystalline in texture, and frequently carries concretions of crystalline carbonate of lime, while fossils are often scarce in it. Those which do occur are much stunted and dwarfed in appearance, like those fresh-water or marine forms which live under unfavourable conditions in brackish water. The more purely magnesian parts of this limestone are quite devoid of fossils, and the same is true of the sandstones, with the exception of land-plants. The upper beds are marls, with salt in Durham.

Conditions of Deposit.—These characters suggest that the deposit has been formed in inland salt lakes into which rivers and streams carry many saline substances in solution, and from which only the pure water is removed by evaporation. Under such circumstances the dissolved salts are separated out and sink to the bottom in the form of crystalline precipitates, among which mixed carbonates of lime and magnesia, dolomite, would be one of the first to fall, followed by sulphate of lime or gypsum.

FIG. 213.—*Productus*. Devonian to Permian (about ⅛). (Z.)

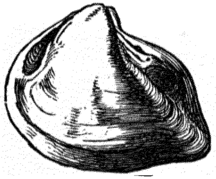

FIG. 214.—*Schizodus* (natural size). (Z. after King.) Internal cast.

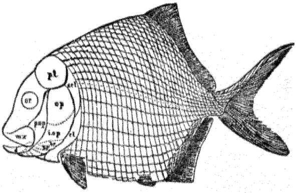

FIG. 215.—*Platysomus*, ⅛. (Z. after Traquair.)

One of the features of the deposit is its irregularity; false-bedding is common, and small unconformities due to irregular movement or method of accumulation are frequently seen. It was evidently, like the Old Red Sandstone, a *continental deposit*, formed by rivers and lakes, during the *third continental phase* the land and mountains of which resulted from the *Pennine-Armorican* movement of late Carboniferous and Permian date. Accompanying the movement was the upthrust of considerable masses of granite, including those of Dartmoor and the

Land's End; but the intrusion of this appears to have ceased before the Permian Rocks were deposited, as fragments of the granite are enclosed in the Permian breccias in Devonshire.

Fossils.—Fossils are monotonous[1] and not common. We have brachiopods like *Spirifer* and *Productus* (Fig. 213) allied to those in the Carboniferous Rocks; a large number of lamellibranchs, such as *Ambonychia*, *Schizodus*[2] (Fig. 214), and *Axinus*[3]; fish-remains (*Platysomus*,[4] Fig. 215), and land-plants, such as *Lepidodendron*, *Sigillaria*, cycads, and ferns.

Economics, etc.—The Permian Rocks are noted for their rich red soil; the magnesian limestone yields lime and a capital building stone, and it has been used for the preparation of magnesian salts; the red sandstones of Penrith and Dumfries are used for building purposes. In Scotland and Devonshire the deposit was accompanied by important volcanic action, basic lavas and tuffs being ejected.

RECAPITULATION

The second division of the Palæozoic Group consists of three Systems, the rocks in each of which are very thick, and cover a large area in Great Britain.

The *Devonian* System is represented by *marine* rocks in the south of England, but in the west and north, and in Scotland and Ireland, by *estuarine* or fresh-water rocks called the Old Red Sandstone. The fossils are remarkable for the predominance of *fish* remains belonging to those types which have an imperfect internal skeleton, but an outer armour of bony plates. The Period in Britain was one of essentially *continental* conditions, and there was much earth-movement and *vulcanicity* during the time.

The *Carboniferous* System furnishes us with our principal supply of coal. The lower rocks are of *marine* aspect and include a great thickness of limestone which, although present in North and South England, is absent from the Midland counties, or else is thin and unimportant. The higher rocks yield coal, ironstone, fire-clay, and building stone. While the lower rocks seem to have been deposited under conditions like those now prevailing in the Gulf of Mexico, the upper rocks recall a large *river delta* like that of the Mississippi or the Ganges. *Amphibia* and *reptiles* are the highest existing animals.

The *Permian* Rocks are red sandstones associated with *magnesian limestone*, apparently deposited in inland salt lakes like the Dead Sea.

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[1] Many individuals, few species.

[2] Gr. *schizo* = I cleave, *odous* = a tooth.

[3] Gr. *axine* = an axe.

[4] Gr. *platys* = broad, *soma* = a body.

This Period was likewise one of *great earth-movement*, and volcanoes occurred in parts of England and Scotland. *Amphibia* are becoming abundant.

QUESTIONS ON CHAPTER XIX

1. Describe briefly the rocks known as Old Red Sandstone. Where do they occur, and what is there especially interesting as to their fossils? (1886.)

2. Arrange the following formations in descending order, placing the newest at the top, and state to which of the great geological systems each belongs—Millstone Grit, Carboniferous Limestone, Devonian Beds, Old Red Sandstone, Ilfracombe Limestone, Coal-measures. (XII.)

3. Write a tabular list of the Palæozoic rocks, placing the newest at the top, and give the name of a fossil characteristic of each group. (1880.)

4. In what systems of rocks are the following genera found—*Olenus*, *Phacops*, *Calamites*, *Odontopteris*, *Orthoceras*, *Monograptus*? To what zoological classes do these genera respectively belong? and mention their nearest living relatives. (XII.)

5. What is Carboniferous Limestone? Name some of its valuable minerals, and the districts in which they chiefly occur. (1883.)

6. (*a*) What are the "Coal-measures," and to what great system of strata do they belong?
   (*b*) Name the chief varieties of sedimentary rocks usually found in the Coal-measures.
   (*c*) State the formations usually found respectively above and below the Coal-measures.
   (*d*) Do the Coal-measures sometimes lie on different formations? If this is the case how do you account for the fact? (1895.)

7. Give a general view of the circumstances under which the coal-beds were formed. (1879.)

8. From what has coal been formed? Give reasons for your answer. (1877.)

9. Name the chief coal-fields of England; draw a section through one of them. (1887.)

10. What are under-clays? In what strata do they occur? (1894.)

11. Write a short account of the Carboniferous formation. (O and C.)

12. Give a short account of the formations of the Carboniferous period, and state the relation of the Coal-measures to the other Carboniferous formations in any one locality in England or Wales. Name a few characteristic fossils. (O and C.)

CHAPTER XX

THE NEOZOIC GROUP—MESOZOIC DIVISION
THE ERA OF REPTILES

THIS Era introduces us to great alterations in the physical geography of Britain and to vast changes in the life. The graptolites and trilobites of the Palæozoic Era have died away, many forms of nautiloid cephalopods, brachiopods with complicated internal spirals, old forms of sea-urchins, and crinoids, the armour-plated fish of the Old Red Sandstone,—all are on the decline and shortly disappear. The new life of Neozoic time is in marked contrast to that which was dying away. Sea, air, and land begin to be tenanted by hosts of reptiles; birds and mammals soon appear; the seas are at first filled with ammonites and belemnites; later on gastropods and lamellibranchs develop in enormous numbers, and new forms of crinoids, sea-urchins, and fishes make their appearance. The ancient vegetation of gigantic cryptogams gradually disappears, being replaced first by cycads and conifers (gymnosperms), and later on by higher flowering plants. In fact both fauna and flora bridge over the gap between the ancient types of the Palæozoic Era and the modern types which exist on the earth to-day.

The Mesozoic Division

The older division of the Neozoic rocks, comprising three Systems, receives this name in contradistinction to the newer life of the Cainozoic division. The predominant life-features are the abundance of reptiles and cephalopoda, the earliest known birds, which have reptilian affinities, and the presence of aplacental mammals only. The vegetation presents no angiospermatous flowering plants until the Cretaceous Rocks have been reached.

The Triassic System

Name and Subdivision.—Although the Trias is in places separated from the Permian Rocks by an unconformity, the interval between the two Periods does not appear to have been a very long one, and the Triassic Rocks in their lithological character seem to be a continuation of the Permian Rocks. The dominant colour is red, as before, and the principal deposits are sandstones, conglomerates, and marls. The System was named from the threefold division of the rocks in Germany. The succession of rocks in England is as follows:—

SERIES	ROCKS
3. Rhætic Series . .	Shales and Limestones.
2. Keuper Series . . (mainly argillaceous)	New Red Marls. Waterstones.
1. Bunter[1] Series. . (mainly arenaceous)	Upper Mottled Sandstone. Pebble Beds. Lower Mottled Sandstone.

The *Lower and Upper Mottled Sandstones* are fine-grained beds, mottled in tints of orange or red with greyish green or white (see Fig. 17). The *Pebble Beds* are conglomerates made of pebbles, chiefly of purple quartzite, embedded in a matrix of sandstone, and not usually very much consolidated, so that the pebbles are easily taken out by denudation, and are ready, without further rounding, to form new conglomerates. The *Waterstones* are usually fine white sandstones with seams of marl that hold up the water with which the sandstones are usually filled. The *Keuper Marls* are red clays and marls with occasional bands of stone which are often beautifully ripple-

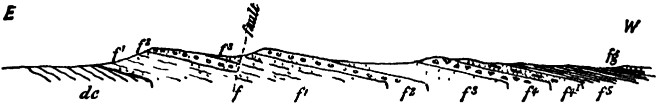

FIG. 216.—Section across the Triassic Rocks of Staffordshire. de = Carboniferous and Permian Rocks; f^1 = Lower Mottled Sandstone; f^2 = Bunter Pebble-beds; f^3 = Upper Mottled Sandstone; f^4 = Breccia, and $f^{4'}$ = Building-stone division of the Waterstones; f^5 = New Red Marl; fg = Rhætic Beds.

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[1] Ger. *bunt* = variegated.

marked and bear prints of rain-drops, sun-cracks (see Fig. 51), and moulds of salt-crystals. Beds of rock-salt and gypsum are by no means uncommon. The former give rise to brine springs in Cheshire and Worcestershire, where salt is obtained from the evaporation of the water. The water pumped from the Keuper usually carries sulphate of lime (gypsum) in solution, and this gives it great value for brewing purposes at Burton-on-Trent and other places.

Economics and Landscape.—Water and salt are the chief things of commercial value obtained from the Trias, but gypsum and alabaster are worked in Derbyshire and Notts. The fertile lands of the Central Plain of England and the Vale of York are situated upon Triassic rocks; but in North Staffordshire and a few other places, where rivers have cut down deeply through the Trias, there occur very picturesque, wooded valleys, with sandstone crags jutting out from their sides.

Fossils.—Fossils are rare in the rocks of this System, but a few marine shells and some fishes have been found in the upper Keuper of Shrewley, in Warwickshire. In some places the tracks of amphibia and reptiles are found impressed upon the surface of the sandstones (see Fig. 51). Portions of skeletons of amphibia like *Trematosaurus*[1] (Fig. 217), and of reptiles, like

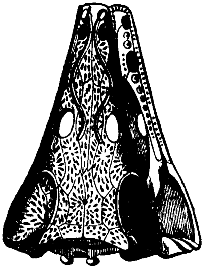

FIG. 217.—*Trematosaurus* (about $\frac{1}{8}$). (Z. after Burmeister.)

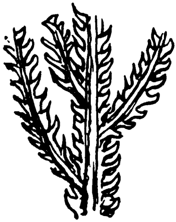

FIG. 218.—*Voltzia*, a conifer, $\frac{1}{2}$. (After Lyell.)

FIG. 219.—*Ceratodus*. A living species of a genus dating from Triassic times, $\frac{1}{12}$. (Z. after Gunther.)

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[1] Gr. *trematoeis* = porous, *sauros* = a reptile.

Telerpeton[1] and *Stagonolepis*,[2] have been found in a few localities, and the remains of land-plants, chiefly gymnosperms related to the cycads and conifers (Fig. 218), are not altogether uncommon. The most remarkable fossil fish is *Ceratodus*[3] (Fig. 219), related to the mud-fish of the Australian rivers, which has affinities with the amphibia in breathing by its swim-bladder as well as by gills. Beyond these, however, indigenous fossils are very rare in the British Trias, even more so than in the Permian. In the pebbles of the conglomerates derived fossils are not uncommon (see Fig. 96, p. 134). These show that the pebbles have been derived from Silurian, Ordovician, Carboniferous, and older rocks.

Conditions of Deposit.—This absence of fossils is probably to be accounted for by the conditions of deposit. The beds were certainly not formed in the open ocean, but in salt lakes. The red coloration on the sand-grains and the presence of gypsum and rock-salt are in favour of this conclusion. When sea-water is evaporated, a mixture of the carbonates of lime and magnesia would be deposited first, sulphate of lime next, and rock-salt or table-salt third. This is what is now occurring in the Great Salt Lake of Utah and the Dead Sea. Gypsum occurs mingled with marl in the deposits which occur on the old bed of the Dead Sea when it occupied a larger area, and deposits of rock-salt also occur there, and indeed are now forming in consequence of the intensely briny character of the water. The present condition of parts of the interior of Asia seems to be very like that in which the English Triassic deposits were laid down. The torrential streams debouching from the mountains on to the plain rapidly lose their velocity, drop their pebbles and coarse sand in the form of alluvial cones (see Fig. 53, p. 80), and spread out their finer sand in sheets over the plain. Both kinds of deposit creep out from the mountains, recalling the character of the Bunter Rocks. In other places the drifting sand forms deserts, fills up lakes, and buries up mountain chains; while, again, this is the site of inland drainage and of salt lakes in which calcareous and saline precipitates become mingled with marly

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[1] Gr. *teleos* = complete, and *herpeton* = a reptile.

[2] Gr. *stagon* = a drop, *lepis* = a scale.

[3] Gr. *keras* = horn, *odous* = tooth.

sediment. The latter conditions recall those of the Keuper Epoch. That deserts existed in Triassic times seems to be proved by the occurrence of the "Millet Seed Sandstone" in Cheshire and Lancashire, a finely-rounded sand in which the grains, even those as small as one-hundredth of an inch in diameter, are well rounded (see Fig. 23), like those in the Sahara. This could only be effected by wind-drift, for small grains would be buoyed up in water and escape erosion. The surfaces of the Mount Sorrel granite are wind-worn under a cover of Trias.

When the Triassic Rocks are traced into Germany there occurs in them a bed of limestone, the "Muschelkalk," which is full of marine fossils, and in the Alps we have a marine Trias with fossils which represent a great number of forms of life. The old Palæozoic types were fast dying out, and the new Mesozoic ones beginning to come in, and for a while the two sets of creatures lived together. The Palæozoic types died out before the formation of the succeeding rocks. One of the most remarkable of these fossils is *Ceratites*[1] (Fig. 220, *a*, *b*), in which the character of the edges of the septa is midway between the shapes seen in *Nautilus* and *Ammonites*. *Encrinus*[2] (Fig. 221) is a common crinoid.

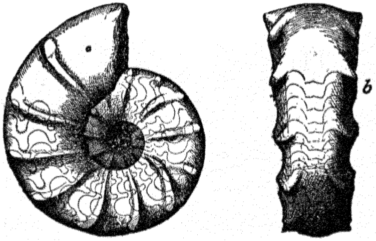

FIG. 220, *a*, *b*.—*Ceratites*, showing sutures of the septa slightly crenated, ⅙. (Z.)

FIG. 221.—*Encrinus* (about ½). (Z.)

Rhætic Rocks.—The end of the *third continental phase* is marked by the Rhætic Rocks, named after the Rhætian Alps. They are of interest, as they were clearly formed in the brackish water which resulted from the first invasion of the

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[1] Gr. *keras* = a horn.

[2] Gr. *krinon* = a lily.

Triassic lakes by the sea. Bone-beds give evidence of this. Brackish-water, fresh-water, and terrestrial organisms occur in the limestones and shales, and among the fossils are remains of shells (*Cardium*[1] *rhæticum*, Fig. 222, and *Avicula*[2] *contorta*, Fig. 223), ostracoda, insects ; and the earliest known mammal, *Microlestes*[3] (Fig. 244), possibly a marsupial related to the kangaroo-rats of Australia, has been found at the top of the Keuper or in the Rhætic Rocks.

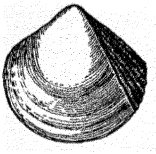
FIG. 222.—*Cardium rhæticum* (Rhætic rocks), $\frac{1}{1}$.

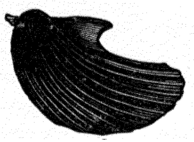
FIG. 223.—*Avicula contorta* (Rhætic rocks), $\frac{1}{1}$. (Z.)

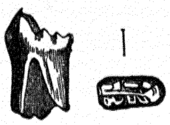
FIG. 224.—Teeth of *Microlestes*, $\frac{3}{1}$. (Z.)

The Jurassic System

Name and Subdivision.—This System of rocks is well developed in the Jura mountains, parallel to the Alps to the north and west. Hence they are conveniently called Jurassic **Rocks.** They mark the beginning of the *third marine phase* and bridge over the period from the submergence of the Triassic lake under the sea which occupied North-West Europe, until the re-emergence at the end of the Period.

The main subdivisions are indicated in the vertical section (Fig. 225), which shows what would be seen if a shaft were sunk through the rocks of the System where they were all present. This succession may be briefly described as an alternation of beds of clay with beds of limestone, sometimes associated with beds of sand.

The Lias.—The base of this Series is a great group of clays, which vary from dark blue to black, with seams of concretionary limestone. In the middle, beds of limestone and ironstone, known as the Marlstone, are interbedded with the clays. The

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[1] Gr. *cardia* = a heart.
[2] Lat. *avis* = a [little] bird.
[3] Gr. *micros* = small, *lestes* = beast of prey.

whole Lias deposit is rich in fossils, so that it can be divided into zones, each of which is characterised by a special fauna. In the Middle Lias a bed of ironstone is largely worked in the Cleveland district in Yorkshire and in the Midland Counties, *e.g.* near Banbury. This appears to have been formerly an oolitic limestone, which has been converted into an ironstone by the agency of percolating water, bearing salts of iron in solution. The Upper Lias clays yield jet, and the shales were much used at one time for the preparation of alum, the decomposition of the sulphide of iron of the pyrites in the clays furnishing sulphuric acid, which reacted upon the clay, giving rise to sulphate of alumina.

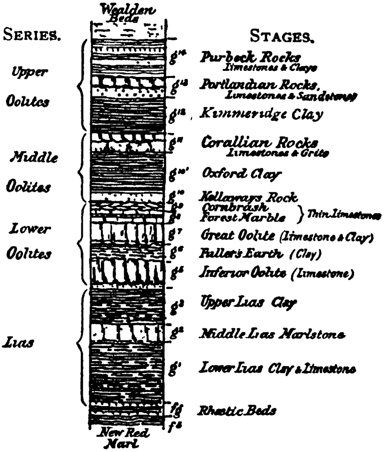

FIG. 225.—Vertical section to show the succession of the Jurassic rocks.

The Oolites.[1]—Following the Lias occur beds of *oolitic limestone* of a type which is markedly characteristic of this Period. These stretch across the country as escarpments or edge-like hills from Gloucestershire, where they form the Cotteswolds, to Yorkshire, where they form the Moors. A few seams of clay intervene, the chief being the Fuller's Earth. The limestones

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[1] Gr. *oon*=an egg, *lithos*=a stone.

are richly fossiliferous, and, like the Lias, may be divided into zones, each named after a characteristic ammonite. Ammonites, brachiopoda, and corals are of frequent occurrence with a vast number of other shells. The egg-like structure which gives these limestones their name of *oolite* or roe-stones, from their resemblance to the roe of a fish, is a remarkable one. The grains consist of crystalline calcite, and in them can be observed both a radial and a concentric structure, arranged usually round a grain of sand, a fragment of a shell, or some foreign body (Fig. 226). By some this is supposed to have resulted from the deposit of carbonate of lime from solution in water round grains of sand and shell fragments drifting about between tide-marks; by others the growth of calcite is supposed to be due to the action of a small organism which builds minute tubes of carbonate of lime. The similar but larger grains which occur in the *pisolite* or pea-grit of the Inferior Oolite were undoubtedly formed by the growth of such an organism. Oolitic limestones not only occur in the Lower Oolites, but in the *Corallian Rocks* and in the *Portland Stone*, so famous for building massive structures in classical styles, like St. Paul's Cathedral. The Inferior and Great Oolites also yield splendid building stones in Somerset, Gloucestershire, and Lincolnshire, which are much used for Gothic architecture.

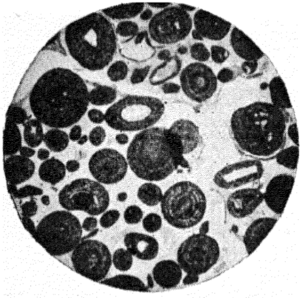

FIG. 226. — Microscopic section of oolitic limestone. The concentric and radial arrangement of the calcite in the grains can be seen, and the nuclei of some of them (about $\frac{8}{1}$).

The great masses of clay known as the *Oxford and Kimmeridge Clays* reach their highest development about Oxford and on the south coast. The Oxford Clay is a greenish grey clay and grey or purple shale, the Kimmeridge Clay is a dark shale, but the two clays can best be distinguished by their fossils. The Kellaways Rock, the Oxford Clay, and Corallian Rocks of Yorkshire are shown in Figs. 60 and 227. The *Portland Rocks* contain sandstones as well as limestones, and the *Purbeck*

Rocks are a fresh-water and lacustrine or estuarine series, the limestones and clays containing fresh-water pond snails and other shells, with crustacea, fishes, and the remains of land-mammalia, of which several species have been found.

Conditions of Formation.—The Liassic rocks present much the same character over a good deal of England, and the same is true of the great Jurassic clays, but the limestones are apt to die out and become replaced by other deposits. The Purbeck Beds are not represented as far north as Oxford, the Portland Beds disappear a little farther north; the Corallian Rocks die out locally and are replaced by clays; but the most remarkable changes are seen in the Lower Oolites which—traced into Northamptonshire and Lincolnshire—are partially replaced by estuarine deposits, and these, in the latter county, contain an important limestone called the Lincolnshire Limestone, an equivalent of the lower part of the Inferior Oolite. The Northamptonshire iron-ore is a representative of part of the Inferior Oolite in that area. Farther north, again,

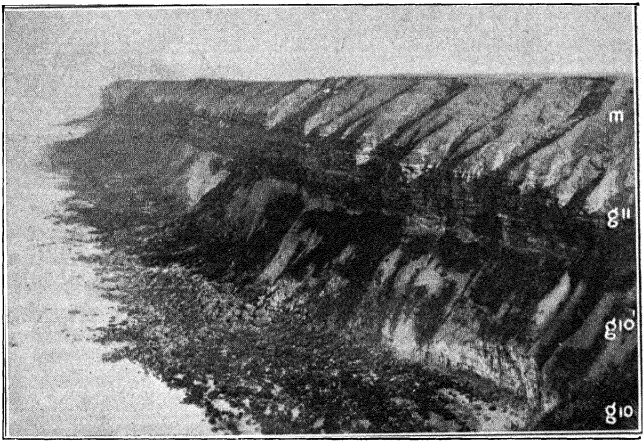

FIG. 227.—Gristhorpe Cliff, near Scarborough. Boulder-clay (*m*) resting on Corallian Rocks (g^{11}), those on Oxford Clay ($g^{10'}$), and that on Kellaways Rock (g^{10}). (From a photograph by Mr. G. Bingley: copyright.)

in Yorkshire, the whole of the Lower Oolites except the Cornbrash pass into sandstones and shales, sometimes containing seams of lignite, and amongst them two or three marine limestones are recognisable. This suggests that the limestones themselves could not have been deposited in very deep water, and that land occurred in the Eastern Midlands of England, and probably in the Pennine Chain and West Yorkshire, which oscillated in level, being submerged when clays were being deposited, and re-elevated when the limestones, which pass so rapidly into sandstones and shales, were being formed. No volcanic action occurred during this Period in Britain, and the land was made of the relics of the old post-Carboniferous mountain-chains which had previously formed the shores of the Triassic lakes. After numerous oscillations, an upward movement was in progress when the Portland Rocks

FIG. 228.—*Belemnites.* Jurassic and Cretaceous, ¼. (Z.)

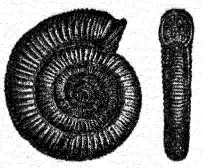

FIG. 229. — *Ammonites* (*Dactylioceras*) *communis.* —Upper Lias (about ⅓). (Z.)

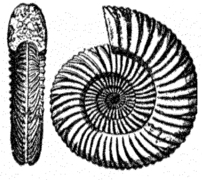

FIG. 230. — *Ammonites* (*Parkinsonia*) *Parkinsoni.* Inferior Oolite (about ⅓). (Z.)

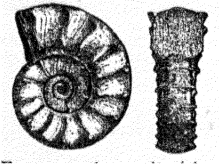

FIG. 231.—*Ammonites* (*Aspidoceras*) *perarmatus.* Oxford Clay, ⅙. (Z.)

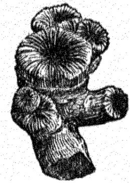

FIG. 232. — *Thecosmilia.* Trias to Tertiary, ½. (Z.)

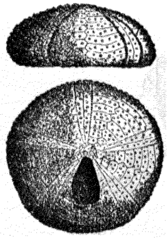

FIG. 233.—*Pygaster,* Jurassic and Cretaceous, ½. (Z.. after Cotteau.)

were being formed. Their shore-beds occur near Oxford, and the land gradually rose higher, driving the sea back so far that in Purbeck times all Britain was land except what is now the south coast, which was occupied by an estuary or a lake, into which a large river emptied itself. Few fossils are found in these highest rocks, the chief being land-plants in old soils, and pond-snails (*Paludina*), which sometimes build up the masses of limestone called Purbeck marble, used as an ornamental stone for architectural purposes.

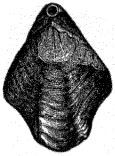

FIG. 234.—*Terebratula*. Palæozoic to present day, ½. (Z.)

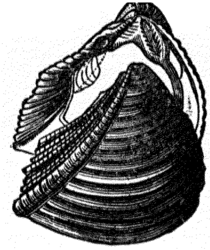

FIG. 235.—*Trigonia*. Jurassic to present day, ½. (Z.)

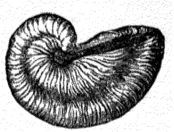

FIG. 236. — ***Gryphæa arcuata***. Lias, ¼. (Z).

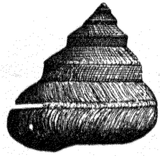

FIG. 237 —*Pleurotomaria*. Cambrian to present day, ⅙. (Z.)

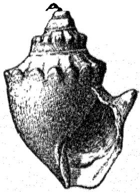

FIG. 238.—*Purpuroidea*. Jurassic and Cretaceous, ½. (Z.)

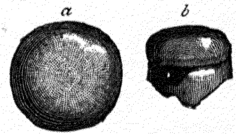

FIG. 239, *a*, *b*.—*Lepidotus*, teeth of. Jurassic to Eocene, 1/1. (Z.)

Fossils.—The fossils of this Period demand careful study. First and foremost we have the cephalopoda, no longer represented solely by types related to *Nautilus*, but by abundance of *Ammonites*[1] and *Belemnites*[2] (Fig. 228). The shell-chambers of the Ammonites were much more complicated than

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[1] Named from resemblance to horns on statue of Jupiter Ammon.

[2] Gr. *belemnon* = a dart.

in *Nautilus* or *Ceratites*, and the edges of the septa were crenated into an extremely complex pattern (see Figs. 150 and 250). *A. communis* (Fig. 229) occurs in the Lias, *A. Parkinsoni* (Fig. 230) in the Lower Oolites, *A. perarmatus* (Fig. 231) in the Middle, and *A. biplex* in the Upper. Foraminifera are tolerably abundant; corals are no longer rugose, but more nearly related to our modern madrepores, like *Thecosmilia*[1] (Fig. 232); abundant echinoderms, like *Cidaris*[2] (see Fig. 142) and *Pygaster*[3] (Fig. 233), and the crinoids *Apiocrinus*[4] and *Extracrinus*; crustacea, polyzoa, and brachiopods, chiefly *Rhyncho-*

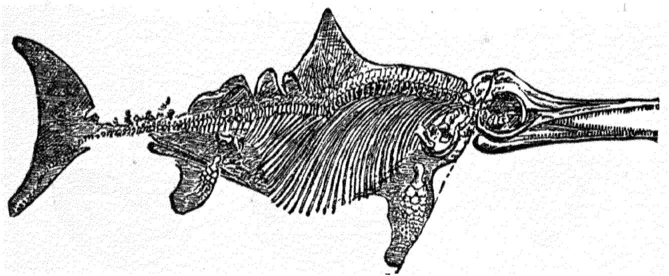

FIG. 240.—*Ichthyosaurus*. Jurassic and Cretaceous, $\frac{1}{30}$. (Z. after Eb. Fraas.)

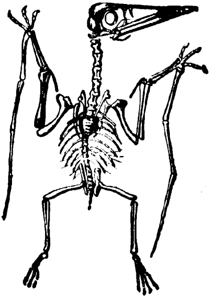

FIG. 241.—*Pterodactylus*. Jurassic and Cretaceous (about $\frac{1}{3}$). (Z. after H. v. Meyer.)

FIG. 242.—Jaw and teeth of *Plagiaulax*. B, slightly enlarged; A, one tooth. (Z. after Falconer.)

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[1] Gr. *theke* = a case, *smileuo* = to carve finely.
[2] Gr. *cidaris* = a turban.
[3] Gr. *pygos* = thick, *aster* = star.
[4] Gr. *apion* = a pear, *krinon* = a lily.

nella[1] and *Terebratula* (Fig. 234), the latter showing *T. punctata* in the Lias, *T. obovata* in the Lower, *T. oxoniensis* in the Middle, and *T. subsella* in the Upper Oolites. The lamellibranchs show great numbers of *Trigonia*[2] (Fig. 235), *Lima*,[3] *Pholadomya*,[4] *Gryphæa*[5] (Fig. 236), and *Ostrea* (oyster), and the gastropods innumerable genera, including *Pleurotomaria* (Fig. 237), *Chemnitzia*,[6] and *Purpuroidea* (Fig. 238). Fishes with a bony skeleton do not appear till Cretaceous time, *Lepidotus* (Fig. 239, *a*, *b*) being protected by armour of bony scales. But one of the characteristic features is the abundance of reptile life: Ichthyosaurs[7] (Fig. 240), Plesiosaurs,[8] and Teleosaurs[9] in the water; Pterodactyles[10] (Fig. 241) or winged reptiles in the air; and Dinosaurs[11] on the land. Remains of the earliest known birds (*Archæopteryx*[12]) have been found in the equivalent of the Upper Oolites in Bavaria. Bones of mammals (*Plagiaulax*,[13] Fig. 242) have been found in the lower part of the Great Oolite, and in the Purbeck Beds. They all belong to small animals probably of marsupial affinities related to the kangaroo-rats of Australia. Indeed, the fauna of Jurassic times has many affinities with that of Australia. It is noteworthy that *Trigonia* also occurs in the seas of Australia at the present day. The vegetation consisted mainly of ferns and horsetails, with cycads and conifers, the last being the highest flowering plants existing at this time.

Physical Geography.—The physical conditions of the Period appear to have been a warm, shallow inland sea, of Mediterranean or Red Sea type, over a great part of Eastern England, and with arms extending far into the west. In this sea grew coral-reefs, while at other parts thick deposits of clay or sand were brought down by rivers. After many oscillations, including a profound and wide-spread depression in Oxfordian times, came a steadfast uprise, and the drying of much of the area.

The movement at the end of Jurassic times did little more

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[1] Gr. *rhynchos* = a [little] beak.
[2] Gr. *treis* = three, *gonia* = a corner.
[3] Lat. *lima* = a file.
[4] Gr. *pholas* = lurking in a hole, *myax* = a mussel.
[5] Gr. *gryps* = a griffin.
[6] After Chemnitz in Hungary.
[7] Gr. *ichthys* = a fish.
[8] Gr. *plesios* = near to, *sauros* = reptile.
[9] Gr. *teleos* = complete.
[10] Gr. *pteron* = wing, *dactylos* = finger.
[11] Gr. *deinos* = terrible.
[12] Gr. *arche* = a beginning, *pteryx* = a wing.
[13] Gr. *plagios* = oblique, *aulax* = a groove (in the tooth).

than lift the land above the sea, without effecting any folding or faulting of the rocks. Some of the rocks were denuded, and the Cretaceous strata consequently rest unconformably on the Jurassic in the north of England. In Southern England the Wealden Beds are conformable to the Jurassic, but the Lower Greensand oversteps on to Kimmeridge Clay, while the Upper Cretaceous overlaps the Lower Greensand and oversteps the Jurassic rocks.

The Cretaceous System

Name, Subdivision, and Conditions of Deposit.—This System is so called because one of the most important members of it is the Chalk, for which the Latin name is *creta.* It tells the history of the slow submergence of the lake or estuary in which the Purbeck rocks were formed beneath the sea, and the gradual encroachment of that sea over the greater part of Britain. The rocks of the System are conveniently divided into two main groups :—

	SERIES	ROCKS
Upper Cretaceous	6. The Chalk	Soft Limestone.
	5. The Upper Greensand	Green sandy beds.
	4. The Gault	Clay.
Lower Cretaceous	3. The Lower Greensand	Green and iron-stained and white glass-sands.
	2. The Weald Clay	Thick Clay.
	1. The Hastings or Wealden Sands	Various sands and clays.

The lowest of the Lower Cretaceous Rocks are of particular interest, as they carry on the history of the Purbeck delta. The fresh-water limestones and clays of the Purbeck Series give place to the formation of masses of sand, passing into clays with which they were interbedded during temporary and local depressions of the delta surface. After the lower beds, which are mainly sandy, had been formed, a more prolonged depression followed, lasting long enough for the deposition of a great thickness of clay known as the *Weald Clay* (see Fig. 298). This deposit is one of the characteristic features of that tract in the south-east of England known as the Weald of Kent, Surrey, and Sussex, and its outcrop forms a continuous line of valleys and depressions situated at the foot of the Lower Greensand hills of Leith Hill, Hindhead, Haslemere, etc. (Fig. 243). Seams of sea shells occur in what have been considered to be the highest part of the Wealden Rocks, but by others have been placed in the Lower Greensand, in the west of the area. It is therefore probable that the sediments formed in a land-locked estuary or a lake, to which the sea only gained access at the very end of the Epoch, establishing itself as soon as the first portion of the succeeding deposit, the *Lower Greensand*, began to accumulate, for in that the shells are all marine. While the Wealden lake or estuary existed in South England marine clays were being formed in Yorkshire and marine sands in Lincolnshire, so that the northern sea must have reoccupied

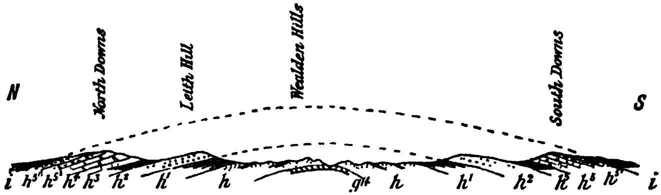

FIG. 243.—Section across the Weald of Kent, Surrey, and Sussex. g^{14} = Purbeck Rocks; h = Hastings Sands; h' = Weald Clay; h^2 = Lower Greensand; h^3 = Gault; h^4 = Upper Greensand; h^5 = Lower Chalk without flints; $h^{5'}$ = Upper Chalk with flints; t = Tertiary Rocks, resting on an eroded surface.

East Yorkshire, with its western shore-line extending into Lincolnshire. This sea must have been separated by a barrier across Central England from the Wealden Lake, and the Lower Greensand rocks tell the story of the slow submergence of the barrier and the gradual growth of the northern and southern seas until they met near Oxford. The Lower Greensand is a shallow-water, marine sandstone, iron-stained and yellow or brown in colour, but frequently containing green grains of glauconite. It is thick in Lincolnshire and the Weald, but oversteps an old land-surface toward the north from the latter, and towards the south from the former place, so that only the highest beds cap the ridge at Oxford. Indeed a portion of the old ridge under London has been proved by borings not to have been submerged until the Gault was being formed, as that is the earliest deposit which covers the whole of the old land-area. It will have been recognised that this old land partly consists of the mountain-chain running from the Ardennes to the Mendips and Devonshire, which was elevated in post-Carboniferous times, and had been undergoing slow denudation and subsidence during the whole of Mesozoic time until the Epoch of the Gault, when it was finally wiped out as a feature of British geography (see p. 261).

The *Gault* is a blue clay full of marine fossils, and often containing layers of nodules rich in phosphate of lime. The *Upper Greensand* follows; it is not unlike the Lower Greensand, but thinner. It does not appear to have been deposited from about Cambridge to Norfolk, for in this region some physical change had occurred, and the Upper Gault was being denuded during the Epoch. The result of this denudation is to be seen in the drifting away of the clay, leaving behind worn nodules of phosphate of lime and fossils derived from the Gault; this bed is known as the "Cambridge Greensand," and occurs at the base of the Chalk in that county.

The Chalk is a pure, white, earthy limestone, largely made up of finely-divided carbonate of lime mingled with the remains of foraminifera (see Fig. 136), very much like those living in the seas of the present day. This deposit is very thick, and spreads all over Eastern England, while it probably at one time occurred far to the west of its present limits, submerging and burying up parts of the Pennine Chain and the Welsh mountains. It was evidently deposited in much deeper water than any other Cretaceous rocks. It sometimes contains seams or nodules of that form of pure silica called flint (see Fig. 18); these contain the spicules of sponges, and indeed they are largely due to the agency of these animals (see p. 91).

Landscape.—The Chalk forms the hill ranges known as the North and South Downs (see Figs. 298, 299), the Chilterns, and the Wolds of Lincolnshire and Yorkshire. Where the Lower Greensand is developed there is a second range parallel to this, called in Kent and Surrey the Ragstone Range; it forms an imperfect ring inside that of the North and South Downs, and is separated from it by a depression caused by the outcrop of the Gault (Fig. 298).

Economics.—Iron-ore is found in the Wealden Rocks of South-east England, and it was much worked until wood for fuel became scarce, in consequence of the destruction of the Wealden forests. Firestone for hearths is quarried in the Upper Greensand; fuller's earth, for taking the grease out of cloth, in the Lower Greensand; so-called coprolites[1] or nodules of phosphate of lime from the Lower Greensand, the Gault, and the Cambridge Greensand; cement and whiting from the Chalk. The Chalk and both the Upper and Lower Greensands furnish excellent supplies of drinking-water, which are reached by means of artesian wells (see p. 327). It was the boring of such wells in the hope of reaching Lower Greensand water under London which revealed the absence of that Series at this spot, and showed that the Gault rested directly on the submerged summit of a range of ancient rocks. The disappointment which ensued on this discovery is to some extent compensated by the scientific interest of the results obtained from the borings, which gave a clue to the possible existence of profitable Coal-measures amongst the ancient rocks beneath Dover and elsewhere (the Kent Coalfield).

FIG. 244.—Foraminifera from the Chalk (about $\frac{100}{1}$). (Z.)

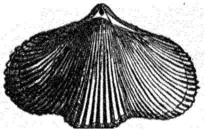

FIG. 245.—*Rhynchonella.* Silurian to present day, $\frac{1}{1}$. (Z.)

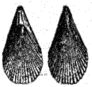

FIG. 246.—*Lyra*, ½. (Z.)

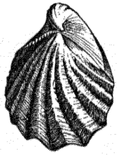

FIG. 247.—*Inoceramus* (*Actinoceramus*) *sulcatus.* Trias to Cretaceous, ½. (Z.)

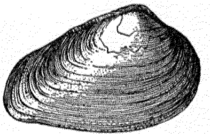

FIG. 248.—*Unio valdensis.* A fresh-water bivalve from the Wealden strata, ½.

Fossils.—The fossils are related to those of the Jurassic Period. Foraminifera occur commonly in the Chalk, many of

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[1] Gr. *copros* = dung.

the genera, like *Globigerina* (Fig. 244) and *Textularia*, existing still. The glauconitic grains in the Greensands are often the internal casts of foraminifera. Sponge spicules occur in the cherts of the Greensands and in the flints of the Chalk. Corals are not common, and polyzoa rare; but brachiopods such as *Terebratula* (Fig. 146) *sella*, *T. biplicata*, *Lyra* (Fig. 246), many species of *Rhynchonella*, and lamellibranchs, including *Inoceramus* (Fig. 247), are abundant.

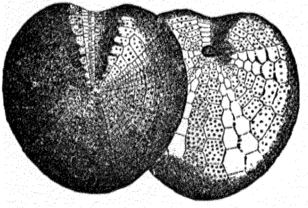

FIG. 249.—*Holaster*. Cretaceous and Tertiary, ½. (Z.)

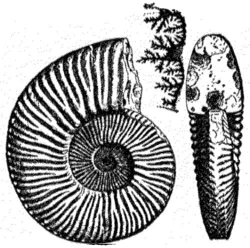

FIG. 250.—*Ammonites* (*Hoplites*) *regalis*. Lower Cretaceous, ½. (Z.)

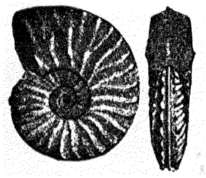

FIG. 251.—*Ammonites* (*Schlœnbachia*) *varians*. Upper Cretaceous, ½. (Z.)

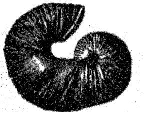

FIG. 252.—*Scaphites*. Upper Cretaceous, ½. (Z.)

FIG. 253.—*Hamites*. Cretaceous (about ⅓). (Z.)

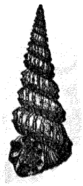

FIG. 254.—*Turrilites*. Upper Cretaceous (about ⅓). (Z. after d'Orbigny)

The fresh-water *Unio*[1] *valdensis* (Fig. 248), and pond-snails, occur in the Wealden Rocks; urchins like *Holaster*[2] (Fig. 249) and *Micraster*[3] are used for zoning the Chalk. The cephalopods yield many *Ammonites*, such as *A. regalis* (Fig. 250), from the Lower, and *A. varians* (Fig. 251) from

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[1] Lat. *unio* = a pearl.

[2] Gr. *holos* = entire, *aster* = a star.

[3] Gr. *micros* = small.

the Upper Cretaceous; while the *Belemnites* are sufficiently abundant to serve for the zoning of the Lower Cretaceous. Before the Belemnites and Ammonites become extinct the latter give rise to a number of curious forms in the Cretaceous Rocks: *Crioceras*,[1] loosely coiled; *Ancyloceras*,[2] loosely coiled and hooked; *Scaphites*[3] (Fig. 252), close coiled and hooked; *Hamites*[4] (Fig. 253), hooked; *Turrilites*[5] (Fig. 254), coiled in a spire; and *Baculites*,[6] straight. The earliest fishes with complete internal bony skeletons occur in Cretaceous Rocks, and reptiles are very abundant. *Iguanodon*[7] (Fig. 255) *Megalosaurus*[8] and a large related group of dinosaurian reptiles, some

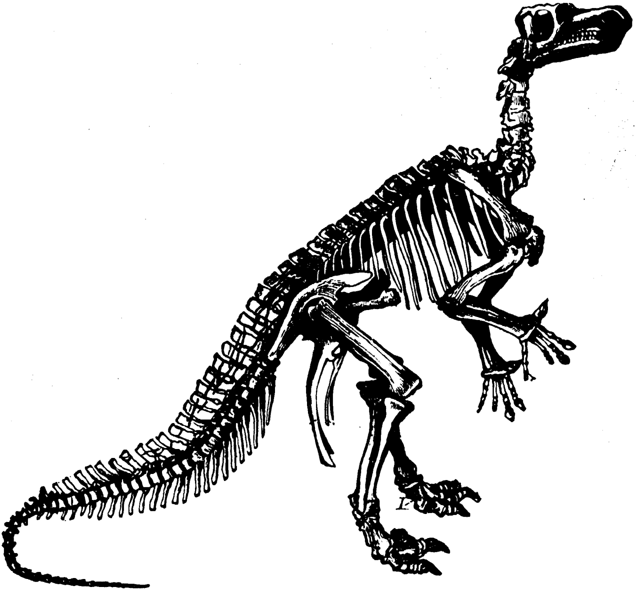

FIG. 255.—*Iguanodon*. A herbivorous dinosaur, $\frac{1}{80}$. (Z. after Dollo.)

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[1] Gr. *crios* = a ram, *ceras* = a horn.

[2] Gr. *ancylos* = incurved.

[3] Gr. *skaphis* = a skiff.

[4] Lat. *hamus* = a hook.

[5] Lat. *turris* = a tower.

[6] Lat. *baculum* = a stick.

[7] With teeth like the iguanas.

[8] Gr. *megalo-* = large, *sauros* = a reptile.

of them herbivorous, frequented the shores of the Wealden Lake, walking on their hind legs like great kangaroos. Ichthyosaurs, plesiosaurs, pterodactyles, and the sea-serpent-like *Mosasaurus* abound. The Lower Cretaceous flora contained abundant cycads and conifers, but none of the higher flowering plants, which, however, begin to occur in American Upper Cretaceous Rocks, the willow, walnut, aralia, and fig being amongst the genera which have lived on to the present day.

Earth-Movement.—At the end of the Period the Chalk was lifted above the ocean, forming a broad land-area in North Britain, and causing the denudation of much of the Cretaceous sediment which went to build up the Tertiary strata. There is no evidence in Britain of the gradual shallowing of the Chalk sea, and the deposits which rest on the Chalk are the deltaic Eocene sediments which close the *third marine phase.* The amount of visible unconformity is not great, as little tilting of the strata took place ; but folds and faults occur in the Chalk which are not continued into the overlying beds. The chief proof of unconformity, however, is that Tertiary Rocks are found resting now on one zone of the Chalk and now on another ; the upper ones must have been removed before the lower ones were exposed for the Tertiary Rocks to rest on them (see Fig. 243).

RECAPITULATION

A newer and more advanced fauna and flora was establishing itself during Neozoic time, and the earliest types of these life-forms to appear characterise the *Mesozoic* or middle-life *Era.* Great abundance of *reptiles*, advanced cephalopoda, rudimentary *mammals*, and the *earliest known birds*, associated with a preponderance of lowly plants, form some of the marked characteristics of the life of the time.

The *Triassic* Rocks carry on the history of the *inland salt lake*, continental, and *desert* conditions begun in the Permian Period. The earliest known *mammals* have been found in the rocks of this Period.

A *mediterranean sea* overspread England in the *Jurassic* time, and in it were deposited alternating strata of clay and limestone. Fossils are abundant, and many of the limestones are *oolitic* and furnish a fine building stone. Valuable iron-ores also occur at several horizons in the System. *Marine* and *flying reptiles* were very common during the Period, and the earliest known *bird* has been found in Jurassic Rocks. The sea shallowed during the later part of the Period, and a *delta*, probably formed in a lake, overspread the southern part of England.

The *Cretaceous* Period tells the history of the *gradual submergence* of this delta beneath the sea, which took place very slowly, and not quite continuously. The Wealden delta was inhabited by a set of remarkable reptiles, many of them herbivorous, now extinct and known as *Dinosaurs.* On the whole the sea deepened and widened until, when the Chalk was forming, it probably spread over the major part of Great Britain.

QUESTIONS ON CHAPTER XX

1. Give a brief description of the Triassic rocks of England. (1888.)

2. In what strata do the earliest known Mammal, Bird, Fish, and Reptile occur? (1893.)

3. What are the general characters of the Oolite series in England without reference to fossils? (1880.)

4 Mention the chief economic products of the Lias. (1890.)

5. In what parts of England are strata of Mesozoic or Secondary age to be seen? Give a table of these strata, noting the general character of the rocks, and also remarking those which contain (*a*) abundant marine fossils; (*b*) fresh-water fossils; (*c*) few or no fossils. (O and C.)

6. Write down the names of any six genera of common occurrence in the Lias, stating whether each genus ranges above or below the Lias. (1878.)

7. Name in order the formations between the Permian and the Eocene; describe one of them as fully as you can, and point out where, in England, it can be conveniently studied. (O and C.)

8. Describe briefly the succession of deposits in the Jurassic System of the West of England. Are any peculiarities in the character of these beds exhibited in Yorkshire? (O and C.)

9. Name in chronological order, placing the youngest at the top and the oldest at the bottom—

(*a*) The geological systems forming the older Palæozoic [Group].
(*b*) The geological systems forming the Mesozoic [Group].

State what great groups of animals occur only—

(*c*) In the older Palæozoic.
(*d*) In the Mesozoic. (1897.)

10. What formations in the Mesozoic Period are considered to be of estuarine or fresh-water origin? Give reasons for so assigning them. (1881.)

11. Concerning a piece of chalk, state what you know on the following points—

(*a*) Its chemical composition.
(*b*) The characters exhibited by it under the microscope.
(*c*) Its mode of occurrence and geological age.
(*d*) Its mode of formation. (1895.)

12. Write the names of three genera of fossils that are of common occurrence in the Cretaceous [rocks], stating the natural history division to which each genus belongs. (1882.)

13. In what British formations do remains of Reptiles most frequently occur? (1877.)

14. Describe briefly the Chalk rocks of England, their geographical position, their physical characters, and the nature of their fossil remains. What light is thrown on the origin of chalk by processes going on at present? (O and C.)

15. How does an Ammonite differ from a Nautilus and a Goniatite? (1881.)

16. Describe an Ammonite. In what rocks do Ammonites occur? (1886.)

17. Give the names of two genera of Cephalopoda, and two of Brachiopoda of common occurrence in the Oolites; and two others of each common in the Cretaceous rocks. (1877.)

18. Mention two living genera of animals found in Palæozoic strata, and four found in Mesozoic strata. (1889.)

19. Name two genera of fossils confined to, or specially characteristic of Secondary rocks. (XII.)

20. Briefly describe four genera of Mollusca which are confined to Secondary rocks. Note their geological horizon or range. (1892.)

21. To what formations do the following fossils belong, namely, *Gryphæa*, Belemnite, Calamite, *Micraster*? (O and C.)

22. Give a short account of the general aspect of an ordinary Silurian fauna, and contrast it with that of one of Cretaceous age. (O and C.)

CHAPTER XXI

THE NEOZOIC GROUP—CAINOZOIC DIVISION
THE ERA OF MAMMALS

The Cainozoic or Tertiary Division

THE second great set of Systems in the Neozoic Group is called the Tertiary or Cainozoic Sub-group, the latter term being used to imply that the life-forms now begin to approach very closely those in existence at the present day. In time the Tertiary Era comprises the period from the end of the deposition of the Chalk till the present. The life-record shows most remarkable advances. Instead of the abundant reptiles of Mesozoic times mammals appear in great numbers, at first in marsupial forms related to those found in the Jurassic strata, but afterwards taking on the characters of the placental mammals — the group to which the living lions, horses, cattle, mice, deer, and elephants belong. As time passed these forms became more and more nearly linked to still existing genera, until at last they are undistinguishable from them. The climate was at first temperate; then it became very hot, and the vegetation was sub-tropical, being accompanied by shells like those of the Indian Ocean; but by degrees the climate got cooler, and at last intensely cold and arctic in character. The abundantly preserved and fully represented suites of organisms render it possible and most convenient to divide the Sub-group into Systems by means of the steadfast development of life exhibited by them. The words employed are all derived from the Greek word *kainos* (*cene*), which means recent, with the prefixes *pleion* = majority, *meion* = minority, *oligos* = few, *eōs* = dawn, so that the words express the proportion in the deposits of such species of mollusca as are still living.

The following classification is that now generally adopted:—

SYSTEMS.	MOLLUSCA.	MAMMALS.
5. Post-Pliocene	Few or no extinct species	Existing *species* abundant
4. Pliocene .	A major proportion of recent species	Existing *species* appear
3. Miocene .	A minor proportion of recent species	Existing *genera* appear
2. Oligocene .	Few recent species	Existing *families* appear
1. Eocene .	Dawn of recent species	Existing *orders* appear

The Eocene System

Subdivision.—The rocks of this System are met with in two great basins, once connected, but now separated by an anticline of Chalk running from Andover towards Horsham, bringing up older rocks to the east of Alton and Petersfield. The northern, called the London Basin, occupies a triangle with its corners near Hungerford, Yarmouth, and Thanet, London being about the centre of it. The southern, called the Hampshire Basin, covers the greater part of Hampshire and parts of the Isle of Wight, Dorset, and Sussex.

The rocks of the System are mainly marine and estuarine deposits, and they are classified as follows :—

SERIES	HAMPSHIRE	LONDON
Upper Eocene	6. Barton Stage	
	5. Bracklesham Stage . .	M. and U. Bagshot Sands.
	4 Lower Bagshot Sands . .	Lower Bagshot Sands.
Lower Eocene	3. London Clay (Bognor Beds)	London Clay.
	2. Reading Beds	Woolwich and Reading Beds.
	1. Absent	Thanet Sand.

The *Thanet Sands* are yellow or green, based upon a conglomerate of unworn and green-coated flints. The fossils are mostly marine shells, but the deposit becomes more estuarine in character when traced westwards. The clays, loams, and pebble-beds of the *Reading Series* are of freshwater character near the town of that name, but become estuarine near Woolwich. The *London Clay*, which is a thick mass of dark brown or grey clay containing abundant fossils and occasional nodules of impure limestone, is marine throughout its whole extent from Reading to Thanet and Ipswich, and from Dorchester, by Alum Bay, to Worthing.

The *Upper Eocene* of the London basin is represented by sands with occasional beds of clay in which fossils are rare. In the Isle of Wight and the neighbouring mainland of Hampshire there are on this horizon the beds of pipe-clay in which many plant-remains have been found, and the richly-fossiliferous sands and clays of *Bracklesham* and *Barton*.

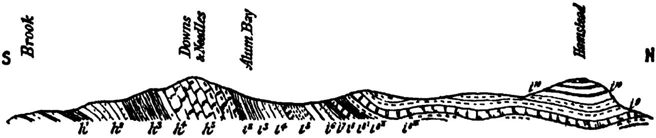

FIG. 256.—Section across the Isle of Wight, h^1 = Wealden strata; h^2 = Lower Greensand; h^3 = Gault; h^4 = Upper Greensand; h^5 = Chalk, i^2 = Woolwich and Reading Beds; i^3 = London Clay; i^4 = Bagshot Beds, i^5 = Bracklesham Beds; i^6 = Barton Clay; i^7 = Upper Bagshot Beds; i^8 = Lower Headon Beds; $i^{8'}$ = Middle Headon Beds; $i^{8''}$ = Upper Headon Beds; $i^{8'''}$ = Osborne Beds; i^9 = Bembridge Beds; i^{10} = Hamstead Beds.

Economics and Landscape.—The nodules of argillaceous limestone in the London Clay have been much used for cement, the Bagshot Sands for glass-making, and the beds of lignite for fuel, although they are of little value for this purpose; amber, the gum of fossil pines, is sometimes found in connexion with Tertiary lignites. The sand-beds give rise to great heaths like those of Hampstead, Aldershot, and Bagshot, and the sand-layers yield a supply of water of varying quality.

Fossils.—The fossils found in the Eocene rocks of Europe include a large number of plants. Dicotyledons, the highest division of angiosperms, which first appear in the Cretaceous Rocks, are now abundant and of sub-tropical character (Fig. 257). Cinnamon, fig, palms, *Nipadites* (Fig. 258), *Pandanus* and *Sabal* (Fig. 259), magnolia, and *Sequoia*, all indicate that a warm climate prevailed during the Period. The fauna tells the same story, for the mollusca are related to those now living in the Indian Ocean. Of the foraminifera the genus *Nummulites*[1] (Fig. 260) makes up thick limestones in the Alps. Brachiopods begin to be less abundant, and their place is taken by vast numbers of lamellibranchiata and gastropoda, amongst which genera like *Voluta*[2] (Fig. 261), *Conus*[3] (Fig. 262), *Cypræa*[4] (Fig. 263), *Murex*[5] (Fig. 264), and *Rimella*

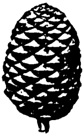

FIG. 257. *Petrophiloides*, ½.

FIG. 258.—*Nipadites*, ⅜.

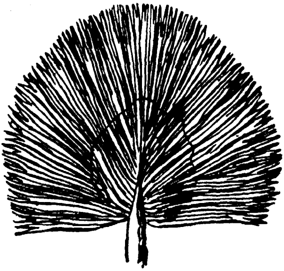

FIG 259.—*Sabal* (fan-palm), $\frac{1}{24}$

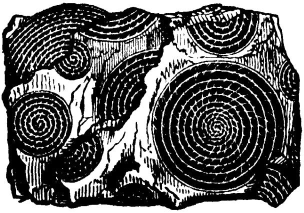

FIG. 260.—A piece of nummulitic limestone. Carboniferous to present day, $\frac{1}{1}$. (Z.)

FIG. 261.—*Voluta*. Cretaceous to present day (about $\frac{1}{1}$). (Z.)

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[1] Lat. *nummus* = a coin.

[2] Lat. *volvo* = to turn about.

[3] Gr. *conos* = a cone.

[4] From *Cypris*, a name of Venus.

[5] Lat. *murex* = a shell-fish from which dye was obtained.

(Fig. 265) are very common. Ammonites and Belemnites have disappeared, but *Nautilus* survives, and genera related to the cuttle-fish become more common than before. Fish with a complete bony internal skeleton preponderate over other types, and in place of the ichthyosaurs and mososaurs of the Mesozoic rocks we now have turtles, sea-snakes, and crocodiles. The few fossil birds found have lost their peculiar reptilian characters, and are more like existing forms. Mammals now begin to take their place as the most important life-forms, but they are at first almost as unlike the types living now as are those of Mesozoic times (*Anoplotherium*,[1] Fig. 266, and *Uintatherium*, Fig. 267). Opossums represent the true marsupials, but other forms are intermediate in their organisation between true marsupials and carnivores; other mammals come between the hogs and carnivores, and others again

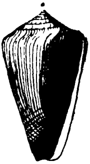

FIG. 262.—*Conus*. Cretaceous to present day, ½. (Z.)

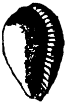

FIG. 263.—*Cypræa* (cowrie). Cretaceous to present day, ½. (Z.)

FIG. 264.—*Murex*. Cretaceous to present day, ½. (Z.)

FIG. 265.—*Rimella*. Cretaceous to present day, ½. (Z.)

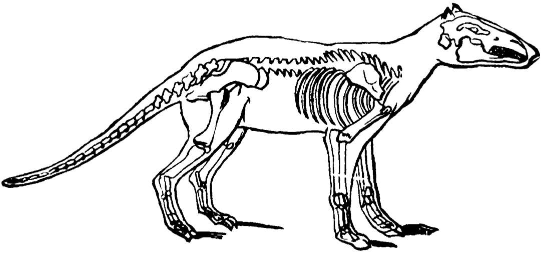

FIG. 266.—*Anoplotherium*, $\frac{1}{24}$. (Z. after Cuvier.)

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[1] Gr. *a* = without, *hople* = hoof.

between the tapirs and horses. Indeed, while a few genera can be classed in Orders which still exist, the majority of types present characters which link them to two or three Orders, and they seem to represent the original stocks from which two or more Orders may have descended, each along its own lines. The deer of the Period had no antlers.

Condition of Deposit.—The physical conditions under which the rocks were formed have to some extent been indicated in describing the rocks. There appears to have been a great river flowing from the west and reaching the sea in an estuary, the waters of which gradually extended farther westwards while the lower Eocene rocks were forming, and then much more slowly retreated while the upper beds were being laid down. The rocks were deposited in a vast delta, to which the bodies of the mammals of the period and the plants growing on the banks were borne by the water.

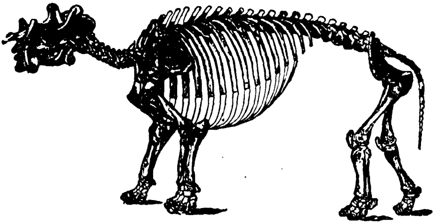

FIG. 267.—*Uintatherium*, $\frac{1}{60}$. (Z. after Marsh.)

The Oligocene System

Subdivision.—These rocks consist of an estuarine series found in England only in the Hampshire basin. They follow the Eocene Rocks in regular succession, and may be best studied on the northern coast of the Isle of Wight. They are subdivided as follows:—

4. Hamstead Beds	Marls and clays.
3. Bembridge Beds	Marls and limestone
2. Osborne Beds	Variegated marls.
1. Headon Beds	Marls, sands, and limestone.

Marine beds are interstratified with the lowest and highest division, but the rest of the strata are typically of fresh-water or estuarine origin. The limestones are tufaceous and contain fresh-water and land shells.

Fossils.—The fossil plants are chiefly evergreens of subtropical character, such as fan-palms, feather-palms, conifers, spindle-trees, oaks, laurels, and vines. The fossil shells comprise many gastropods, such as land- and pond-snails, *Helix*[1] (Fig. 268), *Bulimus*,[2] *Planorbis*,[3] *Paludina*[4] (Fig. 269), and *Limnæa*[5] (Fig. 270), and the brackish forms like *Melania*[6]

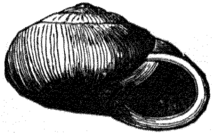

FIG. 268*a*.—*Helix* (*Campylæa*) (snail), a land-shell. Eocene to present day, $\frac{1}{1}$. (Z.)

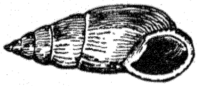

FIG. 268*b*.—*Bulimus*, a land-shell. Oligocene to present day, about ½.

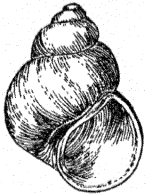

FIG 269.—*Paludina* (pond-snail), a fresh-water shell. Jurassic to present day, $\frac{1}{1}$

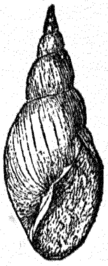

FIG. 270.—*Limnæa*, a fresh-water shell. Jurassic to present day, $\frac{1}{1}$.

FIG. 271.—*Melania*, a brackish water shell. Cretaceous to present day, ½. (Z.)

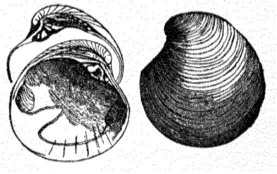

FIG. 272.—*Cytheræa incrassata*, Middle Headon beds, ½. (Z.)

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[1] Lat. *helix* = a coil.
[2] Gr. *boulimia* = ravenous hunger.
[3] Lat. *planus* = flat, *orbis* = a circle.
[4] Lat. *palus* = a marsh.
[5] Gr. *limnaios* = marshy.
[6] Gr. *melas* = black.

(Fig. 271), *Cerithium*,[1] and *Neritina*[2]; lamellibranchs such as oysters, *Cyrena*,[3] and *Cytherea*[4] (Fig. 272). Among the mammals are many pachyderms such as tapir, *Hyopotamus*,[5] *Palæotherium*,[6] and *Anthracotherium*.[7]

The Oligocene Rocks are not more than 620 feet thick in England, the Upper Oligocene being absent, and they represent the filling up of the delta and its invasion by fresh water. In the Paris Basin they are of much more importance, and in Switzerland there are still thicker masses of marine and lacustrine deposits locally called Molasse, which build some of the border ranges of the Alps such as the Rigi.

Older Tertiary Rocks of Scotland and Ireland

Volcanic Rocks.—The Eocene and Oligocene Rocks attain a vast development in the Inner Hebrides of Scotland and the north-east corner of Ireland, where great volcanoes were in full activity. The earlier eruptions were of basic lava, and formed far-reaching sheets of basalt (the "Plateau Basalts") that built up a plateau of which parts of Antrim and Argyll, the islands of Mull, Skye, Eigg, and St. Kilda (and probably part of Iceland, the only point where the volcanoes are still active), are all that are left. Eruptions of rhyolite succeeded, in Ireland at any rate, and then renewed eruptions of basalt, on almost as large a scale as at first, took place. Beds of old soil and clays occur between the basalt sheets, associated with tuffs and ashes, and plant-remains found in them enable us to institute a comparison with the Eocene beds of Southern England. This comparison shows that the fossils belong to the Lower Tertiary Rocks, so that the major eruptions date to the older part of the Eocene Period. They do not appear to have begun before this Period, because the sheets rest on and the dykes penetrate Carboniferous (see Fig. 126), Triassic (see Fig. 112), and Cretaceous Rocks, including the upper part of the Chalk (see Fig. 18). The

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[1] Gr. *keras* = horn.

[2] From Nereus, a sea-god.

[3] From Cyrene, a daughter of the river Peneus.

[4] *Cythereis* or Venus.

[5] Gr. *hus* = a hog, *potamos* = a river.

[6] Gr. *palaios* = ancient, *therion* = animal.

[7] Gr. *anthrax* = coal or lignite.

basalts of Ireland rest on an eroded surface of Chalk. Probably the activity lasted till Oligocene times, for considerable denudation hollowed valleys in the lavas and ashes before the final phase of volcanic action. This consisted of the formation of small cones like the "Puys" of Auvergne in Central France (see Fig. 107, p. 155), from which were poured out pitchstone and basalt lavas. The Sgurr of Eigg, now forming the highest ridge on the island of the name, is made of one of the pitchstone lavas which rests on an old river-gravel, showing that at the time of its eruption it flowed in a valley

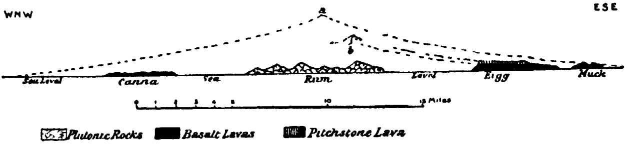

FIG. 273.—Section across the Islands of Muck, Eigg, Rum, and Canna, to show their rocks and the connexion of them with the denuded Tertiary volcano of Rum, the outlines of which are restored in dotted lines. The heights of the islands are slightly exaggerated, but the outline of the volcano is probably about true scale: a=crater of the volcano; b=parasitic cone, from which probably the pitchstone lava flowed.

hollowed in the basalts. Denudation has now removed the sides, head, and foot of this old valley, and so much of the surrounding rock, that the lava which flowed into the lowest depression it could find is now the highest point in an island separated by several miles of sea from its nearest neighbour. The diagram (Fig. 273) gives some idea of the present and the ancient (Oligocene) outline of the land at this spot.

The Miocene System

The lacustrine clays of Bovey Tracy belong to this Period. England appears to have been lifted and its rocks folded by the movement which initiated the *fourth continental phase*, that which gave to the Alpine Range the greater part of its elevation. There the Miocene strata rest unconformably on the denuded edges of the Eocene and Oligocene Rocks which were involved in the great Alpine overfolds. The Miocene Rocks are, however, also folded to some extent, proving that the movement continued during and after this Period.

Fossils.—The Miocene flora was a sub-tropical one in the earlier part of the period, but that of the later part is of a more temperate type. The shells are similar to those of the Oligocene Period, but of course belong to different species. Amongst the mammals one of the most remarkable is the *Deinotherium*,[1] a huge elephant-like creature with recurved tusks in the lower jaw. Living genera of mammals include otters, antelopes, beavers, and cats. Forms allied to the anthropoid apes also occur.

The Pliocene System

Subdivision.—The rocks of this System are best seen on the eastern side of England, in the counties of Norfolk, Suffolk, and Essex, where they take the form of a series of shelly deposits locally called "crag"; these crags if indurated would be shelly limestones. The succession is as follows:—

SERIES

6. "Forest-bed" Series of Cromer.
5. Weybourn Crag.
4. Chillesford Clay and Sand.
3. Norwich Crag.
2. Red Crag.
1. Coralline Crag.

The *Coralline Crag* is chiefly made up of the remains of polyzoa, formerly called corallines (hence the name of the deposit), and of shells. The *Red Crag* consists of sand with the remains of a vast number of shells, such as *Astarte*,[2] *Tellina*,[3] and *Pectunculus*,[4] sometimes whole, but generally broken; the deposits are false-bedded, as if they had been piled up on a foreshore or sandbank. The *Norwich Crag* is a shelly sand and gravel, the *Chillesford Beds* are not very fossiliferous, and the *Weybourn Crag* is a sand with shell patches. The "*Forest-bed*" *Series* consists of estuarine and fresh-water lignite and clay in which have been found abundant driftwood and the remains of a large number of mammals, many of which

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[1] Gr. *deinos* = terrible.

[2] *Astarte* = a Syrian divinity.

[3] Lat. *tellus* = the earth.

[4] Lat. *pecten* = a [little] scallop.

are now extinct. The sands of Lenham in Kent and St. Erth in Cornwall, and the "Boxstones" of Suffolk, are Pliocene in age but older than the Coralline Crag.

Landscape and Fossils.—Barren heaths occur in the crag areas, and the chief economic value of the deposits is for marling the fields; but phosphatic nodules were formerly worked in the Red Crag. The fossils indicate a gradual refrigeration in the climate; that of the Coralline Crag was warmer than at present, of the Red Crag much the same as the present; and then it became distinctly colder. In the Coralline Crag a considerable proportion of the shells are of Mediterranean species; in the Red Crag, Mediterranean and

FIG. 274.—*Voluta*[1] *Lamberti.* Red Crag, ½.

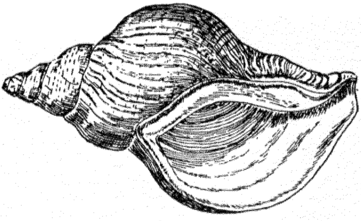

FIG. 275.—*Trophon*[2] *antiquum* (*Neptunea contraria*). Red Crag, ½.

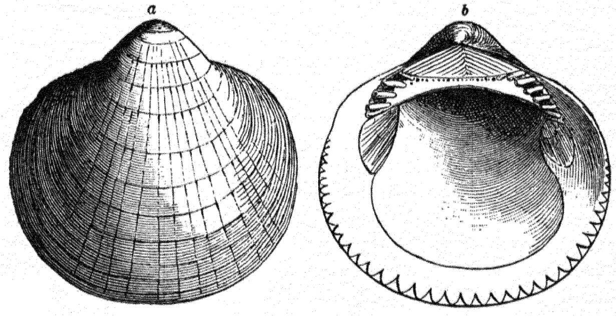

FIG. 276.—*Pectunculus.* Cretaceous to present day, 1/1. (Z.)

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[1] Lat. *volvo* = to turn about.

[2] Gr. *trophis* = big.

Arctic forms are mingled with those now found in British seas; but the Mediterranean species die out in the Norwich Crag, and are completely replaced by British mingled with Arctic forms.

The shells of the period are only slightly different from those of the present day, 84 per cent of the Coralline Crag and 92 per cent of the Red Crag shells being of still living forms. *Voluta* (Fig. 274) and *Trophon* (Fig. 275) amongst the gastropods; *Pectunculus* (Figs. 276 and 147) and *Astarte* (Fig. 277) among the Lamellibranchs are deserving of notice. Amongst Arctic forms may be noted *Astarte borealis* and *Scalaria*[1] *grœnlandica* (Fig. 278). There existed in Britain large numbers of pachyderms like the elephant and *Mastodon*,[2] ruminants like deer and antelopes, and the wonderful carnivore, *Machærodus*,[3] the sabre-toothed tiger. The horse-like *Hipparion*[4] still survived, but was soon replaced by the modern genus *Equus*, and in South America gigantic extinct sloths and armadillos have been found. Camels, llamas, and numerous apes, many of them of anthropoid forms, also occur in foreign deposits of this age.

FIG. 277.—*Astarte*. Silurian (?) to present day, ½.

FIG. 278.—*Scalaria grœnlandica*, 1/1.

One of the most instructive examples of evolution is that of the horse, which was traced out in certain fossils from the Tertiary Rocks by Huxley. The anatomy of the horse shows that it is highly adapted for speed. It has only one toe on each foot, terminated by a hoof, but the probability that it has

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[1] Lat. *scala* = a ladder.

[2] Gr. *mastos* = nipple, *odous* = tooth.

[3] Gr. *machaira* = a sabre.

[4] Gr. *hipparion* = a little horse.

descended from a three-toed ancestor is indicated by two

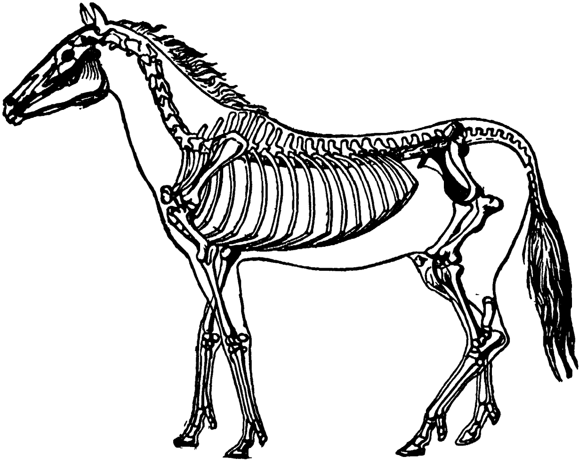

FIG. 279.—*Hipparion.* Miocene and Pliocene. One of the ancestors of the horse; it has three hoofs on each foot, but two of them do not touch the ground, $\frac{1}{23}$. (Z.)

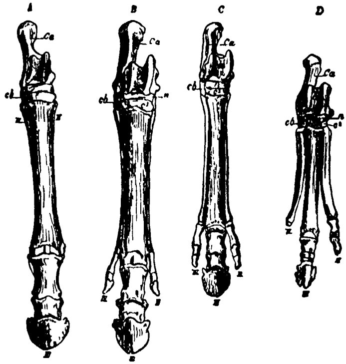

FIG. 280.—Bones of hind-leg in the various ancestors of the horse. (Z.):—A. *Horse*—one hoof and two splint bones; B. *Hipparion*—one large hoof and two very small ones; C. *Anchitherium*—one large and two small hoofs; D. *Paloplotherium*—three hoofs.

small bones, the splint-bones, under the skin (ii. iv. Fig.

280, A). In *Hipparion* (Pliocene and Miocene) these bones are larger, three-jointed, and terminated by small hoofs which could not have touched the ground (Fig. 280, B). In *Anchitherium*[1] (Middle Miocene) and *Paloplotherium*[2] (Upper Eocene) the secondary hoofs are still larger (C, D); in *Hyracotherium*[3] (Lower Eocene) there are four hoofs. Earlier less horse-like, five-toed ancestors probably existed, but have not yet been identified. Gradual evolution is also seen in the increase in size, and in the adaptation of the teeth to grazing.

The Post-Pliocene System

Subdivision.—We shall group under this title all the deposits formed between the date of the Cromer Forest-bed Series and the present day. It is not an easy matter to classify them satisfactorily, but the following grouping gives the divisions usually adopted:—

2. Recent Deposits.
1. Palæolithic and Glacial Deposits.

The first sign of a very cold climate is found in the Arctic plant-bed which follows the Forest-bed Series, and comes below the oldest glacial tills and boulder-clays.

Rocks and Conditions of Deposit.—The older part of the Post-Pliocene Period is known also as the *Glacial Epoch*, or the *Great Ice Age*, as its climate was so intensely cold that glaciers and ice-sheets spread over the greater part of Britain. The most characteristic deposits are tills and boulder-clays, which are tough clays usually unstratified and unfossiliferous, but stuffed full of blocks of stone (Fig. 281) that are angular, and often polished and scratched (see Fig. 34). The absence of sorting, stratification, and fossils seems to show that these deposits have not been made by water-action; while the polishing and striation of the contained fragments, the derivation of the blocks from sources often many miles, even hun-

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[1] Gr. *anchi* = near.

[2] Gr. *palaios* = ancient, *hople* = hoof, *therion* = animal.

[3] Gr. *hyrax* = a coney.

dreds of miles, away, the striated surfaces on which the deposits often rest, their general resemblance to the deposits now forming as moraines from glaciers and ice-sheets, and the occasional presence of seams or pockets of sand and clay with Arctic shells like those of Bridlington in Yorkshire, all point to the agency of ice in some form. But the exact form

FIG. 281.—Boulder-clay in railway-cutting south of Harlech (about 15 feet high).

has been a matter of dispute. By some observers they were attributed to the action of floating icebergs, the ice-foot, and so forth; by others they are supposed to be the material carried in, on, and under moving masses of land-ice. In addition to the bearing of some of the facts already noted there are several others which go to support the latter supposition; the transport of boulders uphill and over watersheds, the kneading and contortion of the clays, the continuity and regularity of the rock-striation (see Fig. 37), and the relation of the composition of the tills to the rocks over which the striation indicates that the ice must have moved, seem only to be explicable on the hypothesis of transport by moving sheets of land-ice and direct deposit from them. The study of the Greenland ice-sheet by Chamberlin shows that it contains vast quantities of drift in its lower part; that this is contorted, torn, and sheared by the motion of the ice; and that it is deposited in the moraines, where the ice melts, in such a fashion as to retain some of the structures impressed on it while still embedded in the moving ice. In short, transport by ice differs more in speed than in character from that in water; as the ice increases in velocity from point to point its erosive power increases, as it slackens deposit must take place; the material is carried in "suspension" in ice, and it will be dropped, with the structures acquired during its motion, when the ice melts.

The direction of the striation of rocks shows that, while the mountain regions and higher grounds were occupied by their own ice, this was thrust aside when it reached the lowlands, as in Yorkshire, Caithness, the Orkneys, and parts of Ireland, by some moving body which came from the north-east. This could hardly be anything but ice moving from Scandinavia, which must have crossed the site of the North Sea before it could reach our shores. In the eastern counties this body of ice appears to have encroached upon Norfolk, and the boulders found there are largely of Scandinavian origin. The boulder-clay here is often highly contorted, thrust, and sheared, and it contains large masses of Chalk sometimes hundreds of feet in length. In many parts of western and midland England ice from Scotland and Lakeland, which was occupying the site of the Irish Sea, also encroached upon the land.

Boulders which have been carried great distances by the ice often occur in these deposits; and similar boulders, not actually embedded in them, but scattered over the surface of the ground, are common features of many parts of England. Thus granite blocks from Shap Fell in Westmoreland have been carried through the gap in the Pennine Range west of Barnard Castle, and thence they have spread over Yorkshire as far as the coast, and into Lincolnshire. Granite boulders from Eskdale and Skiddaw in the Lake Country, and from Criffel in South Scotland, are found as far south as Wolverhampton; and on the Welsh borders are blocks brought from the Arans and Arenigs and other parts of the Welsh mountains.

Later *Boulder-clays* rest on the older ones, the chief being the Great Chalky Boulder-clay of Eastern England, characterised by containing an immense quantity of comminuted chalk. Terminal moraines and glacial mounds in the valleys of the mountain districts of North Wales, Lakeland, Scotland (see Fig. 36), and Ireland, bear witness to the gradual dying away of the ice. In several cases glacial deposits have altered the drainage of the valleys by acting as dams, and many of the lakes of Wales and Lakeland are held back in this way. In Ireland much of the Central Plain is covered with long mounds which are built of deposits of gravel and sand. These do not conform to the existing geography, contain no fossils, and are stratified parallel to the outlines of the mounds. They are called eskers, and are probably the material deposited by rivers which flowed on, in, or under the ice-sheet.

Associated with the boulder-clays there are sometimes patches or irregular beds of sand and gravel containing boulders and marine shells. These deposits reach high elevations about Macclesfield, near Oswestry, and at Moel Tryfaen in North Wales. While some observers have considered them as evidence of a great inter-glacial submergence, the broken state of the shells, their occasional striation, and the method of occurrence of the sand-patches in boulder-clay, seem to indicate that they were scraped from sea-beds by moving ice, and deposited in frozen lumps as if they were boulders, being sometimes rearranged by glacial rivers or lakes on deposit. There are, however, other sands and gravels, either interbedded with boulder-clays or occurring as river-terraces in non-glaciated areas, which, by their fossils, both plant and animal, indicate inter-glacial phases when the climate ameliorated.

Deposits bearing Human Relics.—It is the deposits last mentioned which yield the first indisputable fossil relics of human handiwork, and in all probability they will eventually be classified primarily by the advance in human culture that they exhibit. They may be provisionally classified as follows :—

3. Bronze Age.	
2. Neolithic Age .	Alluvium, gravels, submerged forests, raised beaches, and peat-bogs.
1. Palæolithic Age .	Cave Man. River-drift Man.

The relics of the *Palæolithic Age* consist of rudely-chipped flint weapons, probably used as knives, scrapers, and daggers, and possibly as spear-heads. Man was contemporaneous with several extinct animals, *Elephas primigenius* (Fig. 282, the mammoth), *Rhinoceros tichorhinus* (the woolly rhinoceros), *Megaceros*[1] *hibernicus* (Fig. 283, the Irish elk), *Bos primigenius* (the long-faced ox), *Hyæna*, and *Hippopotamus*.

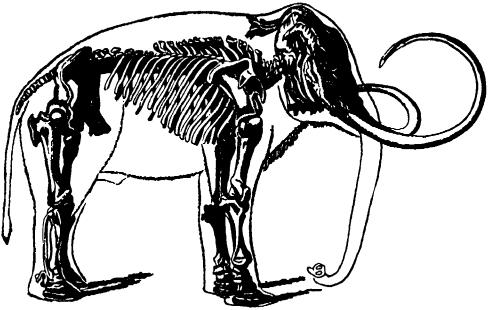

FIG. 282.—*Elephas primigenius* (mammoth), $\frac{1}{85}$. (Z.)

These remains are found in old river-gravels and alluvia which are now as much as 80 or 100 feet above the rivers, but at the time of their formation the river valleys cannot have been so deeply excavated (see Fig. 56). The rivers must

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[1] Gr. *megas* = big, *keras* = a horn.

have excavated their channels to this extent since the gravels were deposited. On the floors of many caves there also occur deposits in which human remains have been found in considerable abundance, often sealed up under layers of stalagmite which must have taken centuries to form, as they have been deposited from the calcareous water penetrating into the caves. In the lowest layers flints like those found in the river-drifts (Fig. 284) occur, but in the higher layers there is evidence of considerable advance in the skill with which the flint is worked. Long flakes, arrow-heads, and spear-heads, elaborate and well-shaped knives and scrapers, are accompanied by harpoons and spear-heads of bone. In one of the English caves a rude incised drawing of a horse's head in bone has been found, and in the caves of the Dordogne in France and elsewhere a

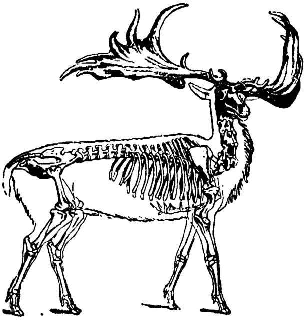
FIG. 283.—*Cervus* (*Magaceros*) (the Irish Elk). (Z. after Owen.)


FIG. 284.—Palæolithic flint implement, ⅛.

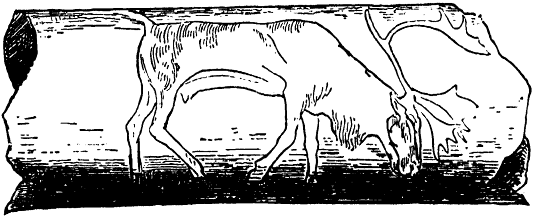
FIG. 285.—Piece of bone carved with a representation of the reindeer. From the Kesserloch Cave, Switzerland. (Z.)

series of elaborate drawings and pieces of carving have been discovered; many of these represent extinct animals like the mammoth, or animals now living in more northern latitudes, like the reindeer (Fig. 285 from the Kesserloch Cave, Switzerland). Remains of half a dozen extinct mammals are found together with those of the reindeer, lemming, marmot, and musk-sheep. It is evident that the climate in which these early men lived was only a little warmer than that of the extremes of the Glacial Epoch. Raised beaches occurring under Boulder-clay in Yorkshire and elsewhere indicate that the land was lower than at present just before the Glacial Epoch; and others, probably of later but uncertain date, in Scotland, North England, Devonshire, &c., give evidence of even greater depressions. On the other hand the existence of old valleys, below present sea level and filled with boulder-clay, testify to some hundreds of feet of elevation at intervals during this time.

As the rivers cut down lower they formed gravels successively at lower and lower levels until they reached their present positions. It is in the alluvia, not more than ten feet above the present levels of streams, that the remains of *Neolithic Man* are to be found. These consist of weapons of polished stone indicating a distinct advance in the art of working that material. The only extinct mammal associated with these remains in the Irish elk. That the last movement in Britain has been downward is proved by the existence of relics of forests buried in peat, blown sand, or other deposits, and now submerged under the sea, along the coasts of Cheshire (see Fig. 63), Lancashire, and Devonshire. It is due to this last submergence that the English rivers end in estuaries (drowned valleys) instead of deltas.

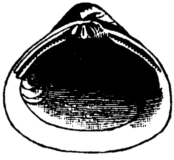

FIG. 286.—*Cyrena* (*Corbicula*) *fluminalis*, a shell found in river gravels; it is extinct in Britain, but exists still in the Nile, ½. (Z.)

In certain lakes or swamps in Suffolk, Somerset, and Yorkshire the relics of old dwellings built on piles over the water have been discovered, and in the Swiss lakes these villages are found to belong to several ages, beginning with the Neolithic and covering the time of the introduction of bronze, and until it was at last replaced by the use of iron.

Peat-bogs (see Fig. 97), *Blown sand* (see Fig. 22) near the coast, gravels and alluvia, *Soils*, *Cave* *deposits*, *Tufas* from springs, *Lake deposits*, the infilling of swallow-holes, and a number of other deposits, contain the records of the later part of Post-Pliocene time, but it is very difficult to arrange these deposits in any satisfactory order. The period when bronze was in use appears to overlap that of the most ancient known history, such as that of Egypt and Babylon, and rude iron weapons soon came into use, so that at this point geology leaves its task to be carried on by written history.

RECAPITULATION

In the second or Cainozoic division of the Neozoic Era the plants and animals found fossil begin to resemble closely those now existing. The mammals are *no longer exclusively marsupial*, although most of the earlier ones have affinities with the opossums and kangaroos. The steadfast *evolution* of these mammalia may be watched during Cainozoic time, first through extinct forms which link together two or more living Orders, then two or more Families, next two or more Genera, and, in the later part of the Era, two or more living Species.

The *Eocene* Rocks are the deposits of the *delta* of a great river on which the *sea* gradually encroached ; then the water slowly deepened. *Volcanic activity* was rife in North Britain and Ireland. The return of shallow-water conditions is marked by the *Oligocene* Rocks, and the upward movement culminated in *Miocene* times, with the formation of a continental area in Britain at a time when the Alps were being lifted.

The sea again encroached on the British coasts while the *Pliocene* Crags were being deposited, and the climate slowly became colder, until most of Great Britain, and the North and Irish Seas, were covered in an *ice-sheet* like that of Greenland at the present day.

During warmer intervals of climate *man* made his appearance in the country, his earliest relics being rude implements and weapons made of *chipped flint*. His gradual evolution in the matter of culture can be traced ; the use of *polished stone*, which succeeds, being in time replaced by that of *bronze* and lastly of *iron*.

QUESTIONS ON CHAPTER XXI

1. Explain the meaning of the term Tertiary as used in geology. (1886.)

2. Write in a columnar form, with the oldest at the top, the main divisions of the Cainozoic and Mesozoic groups of rocks. (1879.)

3. Briefly describe the main divisions of the Eocene series. In what part of England do such strata occur? (1894.)

4. Arrange the following formations in descending order, placing the newest at the top, and state to which of the great geological systems each belongs—London Clay, Bagshot Sand, Red Crag, Plateau Basalts of Antrim, Headon Beds. (1885.)

5. Explain the meaning of the geological terms Eocene, Miocene, Pliocene. By what formations are they represented in the British Islands? (1880.)

6. Write the names of the following geological formations in correct order—Headon Beds, Crag, Bagshot Beds, Chalk, Gault, Upper Greensand, Great Oolite, Lias, Permian, New Red, Old Red, Carboniferous, Silurian. (1882.)

7. Explain the terms—outcrop, synclinal, oolitic, porphyritic, Tertiary, drift, breccia, Permian, dyke, Boulder-clay, schistose, talus. (XII.)

8. Describe the Pliocene rocks of England. (1890.)

9. State the nature of the evidence from which the former existence of glaciers in certain districts may be inferred. (1883.)

10. What is the general character of Boulder-clay? Give one explanation of its origin. (1889.)

11. What is the nature of the evidence from which we arrive at the conclusion that an Arctic climate formerly prevailed in the British Isles? (1887.)

12. Explain the meaning of the word "drift" as used in geology. (1887.)

13. What evidence have we in past geological periods in Britain (1) of a warmer climate, and (2) of a colder climate, than at present? (1891.)

14. What do you understand by "the Glacial Drift"? (1877.)

15. Refer the following formations to their geological age, and note briefly their distribution in this country—Gault, London Clay, Magnesian Limestone, Millstone Grit, and Wenlock Limestone. (O and C.)

16. From what indications would you infer the former presence of glaciers in a country? Where are such indications seen in the British Isles? (O and C.)

17. In what systems of rocks are the following genera found—*Nummulites*, *Mastodon*, *Cervus*, *Voluta*, *Pandanus*, *Rhinoceros?* To what zoological classes do these genera respectively belong? and mention if any of them are still living. (XII.)

18. What is amber? Where does it occur, and what fossils does it often contain? (1893.)

19. What is gravel? Mention some important deposit of this material, stating its composition and mode of occurrence. (1889.)

20. What is meant in geology by a "basin"? Give a diagram of a well-known example. (1881.)

CHAPTER XXII

THE ORIGIN OF LANDSCAPE

History of Landscape.—Now that we are familiar with the general course of events expressed by geological history, we are in a position to appreciate the idea that some parts of the earth's surface have been above sea-level for a long time, while others have been submerged and elevated more than once. So it will be readily granted that the scenery of different parts is of different ages, some dating back to remote periods, some due to more recent action. It is also clear that this scenery is due partly to the character and structures of rocks deposited at each place, and partly to the particular kind of denudation that has taken place there. Some features are due to simple marine denudation, others to stream action, others to moving ice, others again to frost, but most of them to several of these agencies acting one after the other. Sharp cliffs and peaks at once tell of the work of frost, but when most of the peaks in a given district reach approximately to one level, this is an important additional fact which needs explanation. Again, we can recognise that ice may have smoothed the rocks in a valley and given to it its present outline and character, but the valley may have been cut out first by a river, and a river may now be again occupying it after the disappearance of the ice. Land once denuded to a flat plain of marine denudation by the sea may have been elevated to form land again, and it may now give birth to rivers which are cutting valleys through it and gradually destroying all signs of marine action.

Plains are either the result of simple deposit on a flat sea-floor or in the lowest part of a river valley, and the subsequent elevation of the sediments, like the plain round the Wash and the flats in the east of Lincolnshire; or they are the result of denudation beneath the sea, followed by re-elevation. A plain formed in either way, when elevated above sea-level will soon have water flowing over it, for it is never absolutely horizontal, and rain-water will take advantage of every slope, and will begin to run down it.

Valleys.—As the water gathers into streams and rivers it will at once begin to roll along material and carve its bed deeper, producing a valley, the special character of river denudation being to concentrate erosion upon particular paths and thus produce differences of level and unevenness of surface. At first traces of the plain upon which the rivers began to work will be easily recognised in the flat areas between adjacent streams; in this stage the landscape is called a *plateau*. As the valleys get deeper and wider on account of the action of gravitation, rain, frost, wind, streamlets, and organisms, these flat areas will become narrower, and at last no trace of them

FIG. 287.—Hardraw Scar, near Hawes, Yorkshire. The sill of the fall is limestone with shaly beds below it. (From a photograph by Mr. G. Bingley: copyright)

will be left except that the summits of the hills between the valleys will approximate to one level. When a river is young and has not occupied its valley very long, it erodes it rapidly, as slopes are steep and vary much from point to point. Particularly where beds of hard rock crop out is this the case; the slopes are steepest there, and a rapid is formed where the river works at great speed. When the hard rock dips in the opposite direction to the slope of the valley, the soft rock below may be eaten back so fast that the hard rock overhangs and forms a cornice, over which the water leaps and makes a waterfall, like that shown in Fig. 287 and in section in Fig. 288. The water breaks into spray which splashes up and denudes the soft shale *s* underlying the limestone *l*, until the latter can no longer support itself and breaks away in lumps; then the process begins over again, and the site of the waterfall slowly retreats up the valley. Probably the air currents originated by the rushing water also aid in the process. By slow degrees, however, the river smooths out all irregularities, denuding away the harder parts and depositing gravel over the softer parts, until the whole has a gentle and graded slope from source to sea. Then its work is done, its valley is completed, and no change except widening and wandering of the stream takes place until an alteration in level or some other physical change occurs to alter the relationship of river and valley.

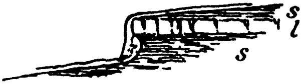

FIG. 288.—Diagrammatic section of a waterfall. *s*=soft shales; *l*=limestone, which forms the sill of the fall.

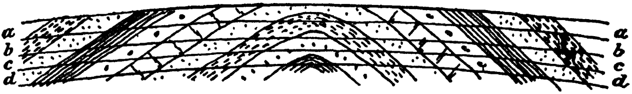

FIG. 289.—An anticline slowly rising and denuded by the sea as it rises, producing in succession the surfaces *a a*, *b b*, *c c*, *d d*.

Formation of Escarpments.—Now consider the case of a very simple form of such an elevated plain consisting of a number of alternating beds of rock, some of which will be harder and some softer than others. Let it be elevated in the simplest way by the formation of an anticline, but let the sea endeavour to plane it down as it rises; sheet after sheet (*a*, *b*, *c*, *d*, Fig. 289) would be taken off, and if denudation was rapid enough it would never get above sea-level. If, however, it was not fast enough to do this, the part rising most rapidly, the crest of the arch, would first come out of the water, and rising first beyond the reach of the sea, it would be the highest part of the plain formed, as the flanks, rising more slowly, would be longer exposed to marine action. The successive stages and resulting form are shown in section in Fig. 289, and in plan and section in Figs. 290. Now rain-water falling on this surface would flow outwards from *a* to *b* and *a* to *c*, and this would make streams running in the same direction as the rocks are dipping, that is across the *strike;* this is clear in a map of the rising area (Fig. 290 *a* and *b*). These *transverse streams* will run outwards across hard and soft rocks alike, and, when they have begun to cut down their valleys, will find it difficult to escape from them; so valleys will be formed which will pass indifferently through hard and soft rocks. But in softer rocks the sides of the stream will crumble away more and more, and the valley will become wider in the soft rocks, and remain narrow, steep-sided, and gorge-like when traversing hard rocks; such a stage is indicated in Figs. 291. At this stage the water falling on the soft rocks of the valley sides instead of obeying the original outward slope of the plain, will begin to

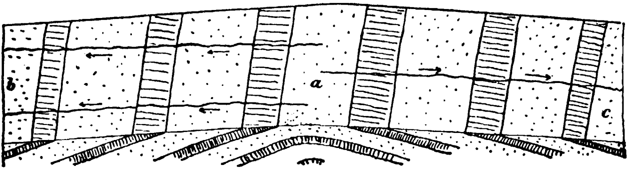

FIG. 290 *a*.—Section and plan of planed anticline with transverse streams, *a b*, *a c*, flowing down the steepest slope, across the strike.

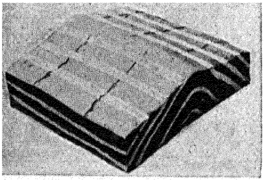

FIG. 290 *b*.—Model illustrating the same stage as Fig. 290 *a*.

be tributary to the transverse valleys, and this will still further erode the soft rock, and bring in more and more of the rain, until distinct little tributary valleys will originate along the strike of the soft rocks, all carrying their waters into the main transverse valley (see Fig. 292 *b*, *de*).

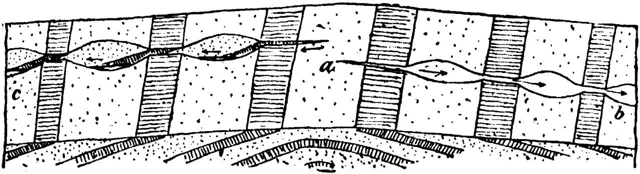

FIG. 291 *a*.

Further denudation will increase the width and length of these lateral or strike valleys, and both their water and their denuded material will be brought into the transverse stream to be carried away. The hard beds of rock will be left almost untouched, their summits remaining on a level with the original plain of marine denudation, so that by degrees they will come

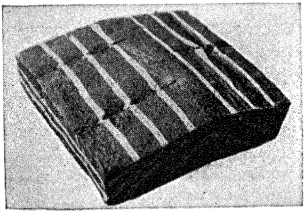

FIG. 291 *b*.—Model showing on left side two transverse streams in early and later steps of development by widening in the soft bands.

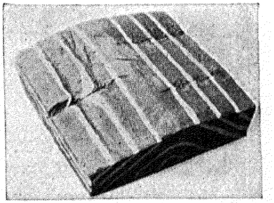

FIG. 292 *a*.—Model showing on left side a transverse stream with well developed lateral streams.

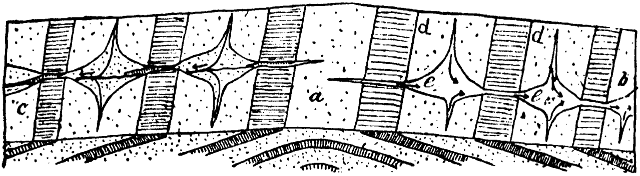

FIG. 292 *b*.

to stand at a considerable height above the lateral valleys, and will look like hills through which the transverse valleys have forced their way. The section shown on the side of a transverse valley, cutting across the ends of the lateral valleys, will make this clearer (Fig. 293); AB is the original slope of the ground, CDE hard beds, and FG sections across lateral valleys, flowing towards you as you look at the figure. The successive V-shaped lines one below another will show the gradual deepening of the lateral valleys by their streams. As long as the valley is in contact with soft rocks on both flanks, it will open out on both sides equally, but at last the valley F will come down upon the hard rock D on one side, and will no longer find it so easy to cut *directly* down into it; so it will work in future more easily on the soft rock of the other bank and thus cut sideways and downward, that is, into its *right* bank (left to any one looking at the figure). Thus it

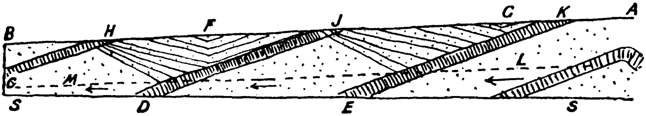

FIG. 293.—View of the side of (or section along) the transverse stream, *a c* of Fig. 292, showing the path (sole) of the stream LM, and the gradual enlargement of the two lateral streams F and G, which are tributary to it. Both streams tend to shift towards the left, down the dip of the beds. S S = sea-level.

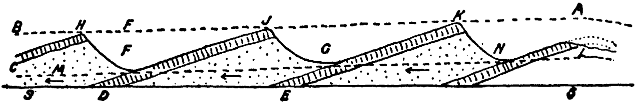

FIG. 294 *a*.—Section of the outline produced by joint action of transverse stream L M, and lateral streams F G N. A B = the original plain of marine denudation on which both classes of streams began to work. The *escarpments* K N, J G, H F, facing the path of the transverse stream, and the *dip-slopes* C H, F J, G K breached by it, are the result.

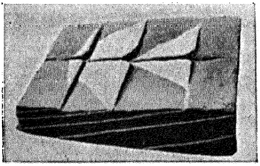

FIG. 294 *b*.—Model showing transverse stream and six lateral tributaries which are cutting valleys along the outcrop of the softer rocks, and leaving three lines of escarpment.

will shift towards H, and the valley G will shift towards J, until one has cut directly up to the hard rock C, and the other up to the hard band D. Now it has hard rock on *both* sides, but the stream F is *on* the bed D, and *under* the bed C at H, and a hard rock can be more easily broken up by cutting away the soft rock under it than by digging down into it from above. Thus the stream will still continue to shift towards H, but more slowly, the soft rock being cut away till its slope is steep enough to render the position of the hard rock C unstable, and that will break away in blocks down the slope. The lateral valley will now be bounded on one side by the *dip-surface* of the hard rock D, from which the soft rock has been peeled by the stream, and by a steep slope, crowned by the hard rock C, on the other side. The same thing will have happened in the valley G, and indeed along all the contacts of hard and soft rock, so that the general outline produced will be like that represented in Fig. 294, in which there are a series of ridges opposing the direction in which the transverse rivers are flowing. These rivers will appear to have plunged at the hard rocks on their steepest faces, and to have cut channels through them. What has really happened is, that the soft rock alone has been eaten away by the lateral streams at the same time as the transverse river was breaching the hard rock; the hard rock has merely been left standing at about the height at which it was left originally by the sea. The general outline of the country is shown by the diagrammatic picture, Fig. 295. The type of hills thus produced by the outstanding hard rock is known as a wold (or cuesta) having a gentle *dip-slope* in one direction, and a steep *scarp* looking *up* the transverse river. As lateral streams effect so much de-

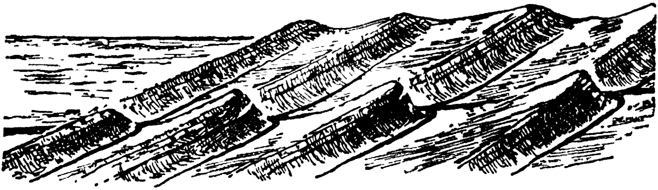

FIG. 295.—View of country made up of escarpments and dip-slopes, with their transverse valley and eight tributary, lateral streamlets.

nudation, and have the advantage of working in soft rock, they gather more water and attain greater size and strength, so that at last they may be mistaken for the main courses of the rivers; but their real history is revealed by the fact that they will in the end turn abruptly and cut through the escarpments which bound them, and so escape into the old transverse valleys. It will be easily seen that the rate of cutting downward by lateral streams will be regulated by the rate of work of the transverse streams, as, unless the latter have a sufficient flow to carry off the material brought down by the lateral streams, and to keep their own beds deepened, the strike valleys will become choked up and do no more work until the transverse rivers have further deepened the cut through the hard rock. Thus the depth of the breach through the hard rock-bands regulates the depth to which the lateral streams carve down their valleys, and in reality the breaching of the high land (or escarpment) precedes the apparent elevation of it to form a hill.

FIG. 296.—Escarpment of the Millstone Grit at the Roaches near Leek, Staffs. (From a photograph by Mr. A. A. Armstrong: copyright.)

Examples.—Looking back at the numerous sections given in this book, the predominance of escarpments will be recognised (see Figs. 166, 168, 177, 180, 197, 216, 243). The Chalk Downs, the Ragstone Range, the Cotteswolds, some of the Millstone Grit ridges (see Fig. 296), the "Edges" of Silurian Rocks (see Fig. 297), and even the greater mountain-masses of Scawfell, Snowdon, and Cader Idris, are all essentially escarpments limited by bands of hard rock, which owe their elevation not to any special uplift, but to the fact that all the rocks of the region were elevated as an anticline and then carved out by streams which did most of their work on the softer strata, leaving the harder beds standing at nearly their original height. In many cases the country was planed by the sea before streams began to work, giving an explanation of the remarkable fact that so many of the summits, like Snowdon and its spurs, the Glyders, Tryfaen, the Carnedds, all approach so nearly to the same altitude.

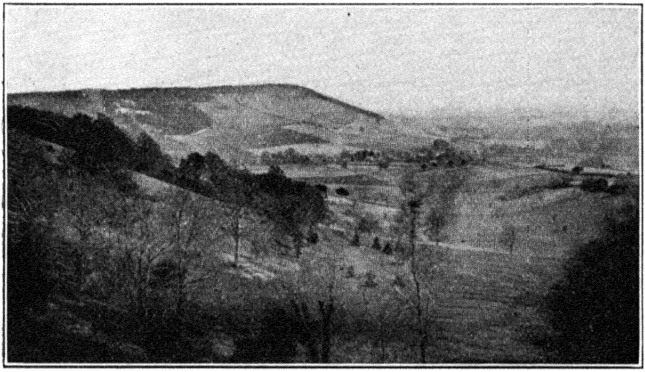

FIG. 297.—Escarpment of the Chalk at Box Hill, near Dorking.

The Weald.—A study of geological and geographical maps of the Weald of Kent and Surrey and Sussex (Fig. 298) shows that the rocks there were folded into a dome instead of a simple anticline (see Fig. 243). The transverse valleys start near the centre and, radiating out like the spokes of a wheel, they cut through the two rings of escarpment, one made by the Lower Greensand and one by the Chalk, forming the gorges by which the railways cross the country. The gorge of the Ouse at Lewes, the Adur at Shoreham

Gap, the Arun at Arundel, the Wey at Guildford, and the Mole at Box Hill, are all typical *transverse valleys*. The *tributaries* of these rivers generally run in *strike valleys*, like that part of the Mole in a clay bed at the foot of Box Hill (Fig. 299), the Medway and the Beult in the Weald Clay, and the Ouse in one of the clays of the Hastings Sands series. The section across the Weald (see Fig. 243) shows the way in which these lateral streams have eaten out the softer rock forming the wold-like ridges, which run like oval, concentric, rings round the Weald, with their steep, scarped faces looking towards the interior, and their gentle dip-slopes towards the outside. Fig. 299 is from a photograph looking along the Chalk escarpment, which is seen to the left with the River Mole flowing parallel to it, for a time, a lateral stream.

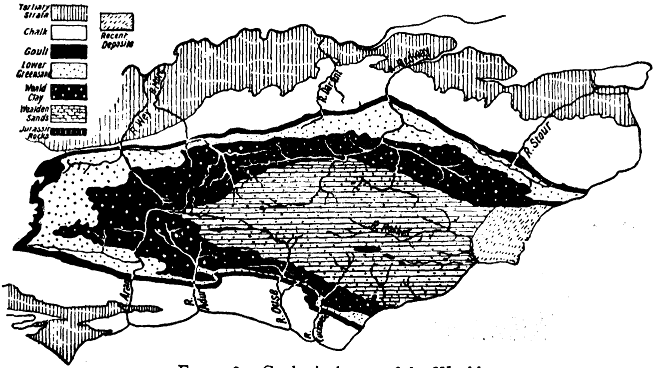

FIG. 298.—Geological map of the Weald.

Base Levels.—It is not absolutely necessary that the sea should have begun this work. A similar result would be obtained if an anticline had been directly exposed to stream action, and if the stream had started work on the dome of chalk which originally covered the whole Weald. Indeed the final action of streams, as already shown, is to reduce a country to a series of slopes so gentle as to be almost a plain. It must be remembered that in order to effect denudation a river must have sufficient velocity, and this depends on slope.

Now as it digs down its valley its velocity will slacken. It can do no work at the flat sea-level except carry down the transported materials which it already has obtained; denudation will soon lower the level so far that the velocity is no longer sufficient to do any erosive work; the work will then be concentrated higher up, and that part gradually reduced to such a slope that no more denudation will be done; and so, right up to its head, the valley will be reduced to such an average slope that no work is being done. Some obstinate bits may remain for a while, but velocity will still be greatest there until these too are cut down, and then the slopes throughout will be very gradual, and the river will be practically *dead.* Its tributaries down to the smallest will go through the same stages and the whole river will cease to erode, but will become a mere transporting agent; at last even this action will stop unless either an increased supply of water or an elevation of the land makes its slopes steeper and sets it to work again. In this way a country may be reduced to a series of gentle slopes, almost a plain, until the activity of its rivers recommences with

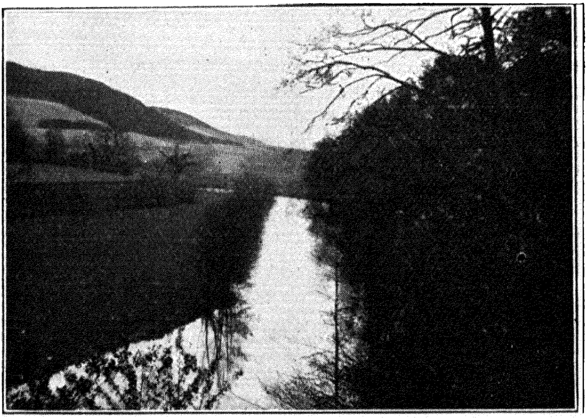

FIG. 299.—The Mole as a lateral stream in a strike valley at the foot of Box Hill, Surrey. The Chalk escarpment rises to the left. (From a photograph by Mr. G. T. Atchison: copyright.)

a renewed elevation of the land. This accounts in part for the traces of old valleys and slopes with new ones cut down in the midst of them. It is quite possible that some supposed plains of marine denudation are really "*base levels*" produced by completed river erosion, and when a new uplift takes place they are ready for new streams to go to work and produce a new series of escarpments and valleys.

Later Drainage.—When hills and valleys are sketched out by drainage systems like that just described, frost, rain, glaciers, and streams will act upon the escarpments and dip-slopes thus produced, and give them their own peculiar characters. The escarpments may even be cut to pieces by the secondary denudation of streams which take their rise in them and cut their way back into them. The beautiful hollows called Cwms on Snowdon (Fig. 300 and Frontispiece) are the result of this action, and they have so far cut into the escarpment that it is difficult to recognise its outlines.

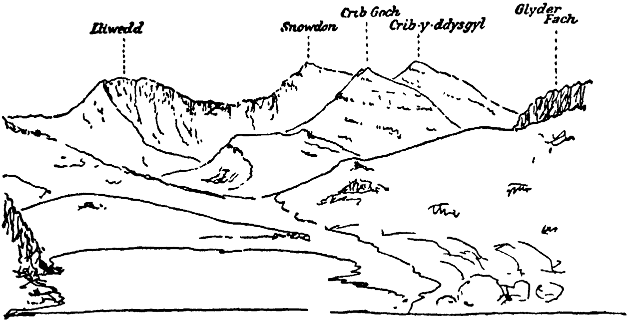

FIG. 300.—View of the Cwms of Snowdon from Capel Curig. Cwm-Dyli lies between the Lliwedd and Crib Goch, Cwm-Glas between Crib Goch and Crib-y-Ddysgyl.

Lakes.—But earth-movement may not only increase a river's activity, it may slacken it generally or locally. When the former is the case its valley becomes choked with débris; when the latter, a lake will be formed. Suppose a valley sloping gently downwards, an irregular rise of the land, greater at one point than another, will dam up the stream where the uprise is greatest, unless the river is powerful enough to cut through the rock as fast as it is uplifted. Local subsidence will effect the same result. A lake formed thus would be gradually filled with the débris of the river, and form an alluvial flat through which the river would flow and continue the work of cutting down the barrier, until it was able again to clear out the alluvium which fills the old lake-basin. If, however, the uplift has been enough to cause the water of the lake to attain so high a level that it has found a new outlet, this outlet will be cut down in its turn instead of the old one. A lake-hollow or rock-basin cannot be excavated by a river, because the chief work of the stiller water thus produced is to receive deposit and fill up hollows. The frequent occurrence of lakes in rock-basins in association with past or present glaciation suggests that they may have been excavated by glaciers. Dams formed by moraines and boulder-clay may give rise to hollows which will be lakes when rivers reoccupy the valleys. The water will work upon the moraine first, if that happens to be the lowest point, and will gradually cut it away. If not, it may escape over the rock at the sides, as seems to be the case with lakes like Windermere and Thirlmere.

Destruction of Valleys.— Marine denudation carves land away almost wholly irrespective of its surface configuration. It is true that hard beds tend to form headlands and soft ones bays, but eventually all are swept back, so that on a sea-coast the sea may cut away the head of a valley from which a stream may be flowing, and indeed it may even completely destroy one side of a valley, as it has done in the case of that of the river which once flowed through the Solent. Here submergence appears also to have taken place, but the Isle of Wight is the only relic left of the south side of a river once as large and important as the Thames.

Mountains.— Elevation is accentuated in mountain-chains where the rocks are intensely contorted, faulted, cleaved, and intruded upon. Water soon flows down from these elevated tracts, producing transverse and lateral valleys, which dissect the rocks into chain after chain of escarpments, breached by the swiftly-flowing transverse rivers. The Rhone occupies a lateral valley from its source to Martigny, but from thence to the Lake of Geneva it turns sharply and flows in a transverse gorge, cutting through the western end of the Oberland Mountains. It sometimes happens that mountain-chains have been elevated across the path of great rivers, but the elevation has been so slow and the river so powerful that it has cut down its valley as fast as the rocks rose; thus the chains themselves are trenched by deep valleys originating beyond the chain. This is the case with the Indus and Brahmapootra, which rise north of the Himalayas and cut a way through them. The broad valleys are sketched out by stream action, and then frost, glaciers, wind, and rain execute the final modelling, each agent acting in its own way and producing its own characteristic result. Hills are often found along synclinal folds, and valleys along anticlines, because synclines are in a position of stable equilibrium, having escarpments on either side.

Effect of Joints and Faults.—In mountain districts, and indeed elsewhere, denudation is guided by the results of movement; the direction of rivers and caves in Derbyshire is largely influenced by the planes of jointing (see Fig. 25), and valleys often run in lines of fault because of the soft, broken rock found there. But strike faulting and folding, running parallel to the lateral valleys, often accentuate their relief and that of the escarpments bordering them. The repetition of a hard bed by a fault will also often cause the repetition of an escarpment, by giving denudation two hard beds at the surface to work on instead of one (see Fig. 216).

Dry Valleys.—It has been shown above that rivers once in a valley tend to remain there, but there are marked exceptions to this law. When valleys have been cut through soluble rocks like limestone, a certain proportion of the water makes its way underground through the joints of the rock, and then it enlarges these, making caves sometimes large enough to take the whole of the drainage of the valley in average seasons; the original valleys may thus be left dry except in wet years. An example from Yorkshire is given in Fig. 301.

Superposed Drainage.—If a denuded country with its systems of hills and valleys is submerged beneath the sea or covered by glaciers or ice-sheets, the valleys may be filled with débris or sediment. After re-elevation a new system of streams will be formed which will have a tendency to scour out the old valleys simply because the softest material occurs there. In doing this, however, the streams may often *lose* *their way* and cut across old buried ridges. Having started valleys in these new directions the rivers must maintain them for reasons already given, and thus a new drainage system

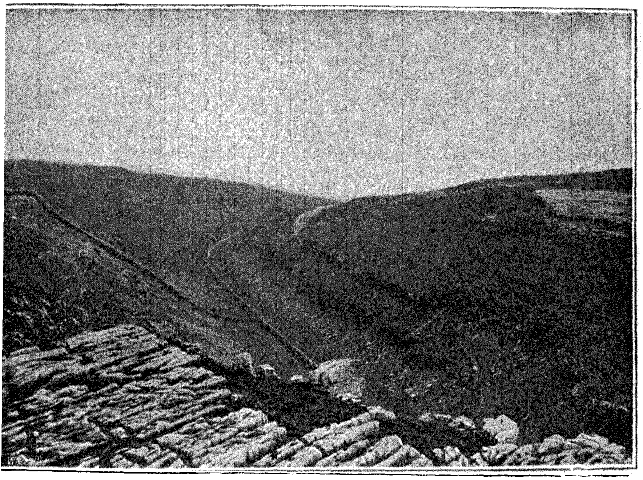

FIG. 301.—The dry valley near Malham, Yorkshire, from above, looking down the valley. (From a photograph by Mr. Godfrey Bingley : copyright.)

will be *superposed* on an older one which will to some extent be redeveloped by weathering action. Superposed drainage may be recognised in England where new systems originated

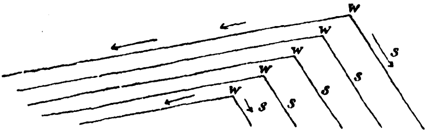

FIG. 302.—To show the more rapid cutting by the streams of the steep side (S) of the col or watershed (W).

after the Trias had buried up the old Midland ridge, and also where new valleys have been excavated after the Glacial Epoch.

Shifting of Watersheds.—When two rivers are cutting their valleys *back* on opposite sides of a watershed as illustrated in Fig. 302, their rate of excavation may not be equal. The larger stream and that running down the steepest slope will work back quicker than the other, and may, as it were, cut the ground away beneath its feet. In such a case the quickly-working stream will absorb the tributaries of the other, one by one, and rapidly increase its own power by doing so. This is of common occurrence in the Alps, where the southern slopes are always much steeper than the northern ones. Again, a lateral stream belonging to one system may cut back the escarpment from which a transverse stream is flowing to another drainage system, and deprive the latter of its tributaries and of the ground it drains. In this way the Severn is enlarging and widening itself at the expense of the headwaters of the Thames in the Cotteswold Hills (Fig. 303).

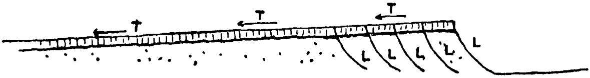

FIG. 303.—Section to show the recession of an escarpment by the cutting and widening of lateral streams (L) at the expense of the drainage ground of the transverse streams (T).

RECAPITULATION

The fact that rocks are gradually and successively formed proves that their appearance at the earth's surface and the features or *landscape* which they present must have also been gradually formed. Landscape depends on two broad factors: first, the nature of the *rocks* and their structure; and, secondly, the class of *denudation* they have undergone. Each denuding agent produces characteristic features of its own: a river, a valley which is opened out until it becomes a base level; glaciers, a smooth and polished surface; frost, a rough, edged outline; wind and rain, smoothed surfaces, with jutting irregularities where durable rocks crop out; and the sea, a level plain.

On following out the gradual denudation of a plain of sedimentary rock upheaved above the sea, it is seen that there is evolved a set of slopes in which the *harder rocks* tend to stand out as *hills*, while the softer and *less durable* are worn into hollows and *valleys*. Here and there, however, the harder rock will be cut through by *transverse valleys*, while the hills will reach an almost uniform height, that of the original plane of marine denudation or *base-level*. The hills produced will tend to have one side steep, the *scarp* face, but the other will slope more gently, the *dip-slope*. *Earth-movement* taking place while denudation is proceeding will sometimes have the effect of producing *lakes* or *alluvial flats*.

QUESTIONS ON CHAPTER XXII

1. Explain how valleys are formed. (1882.)

2. In what respects does marine differ from subaërial denudation? To which agency are inland escarpments due? on what reasoning does your answer depend? (O and C.)

3. Describe and illustrate by drawings the following:—
   (*a*) Dip-slope.
   (*b*) Hade.
   (*c*) Overfolding.
   (*a*) Thrust-plane. (1897.)

4. One bank or valley-slope of a winding river is usually steeper than the other. Draw a diagram illustrating this point, and explain how the difference in the slope is caused. What arrangement of strata is necessary for the production of a waterfall in a river's course? (O and C.)

5. Give diagrams with descriptions of the following:—
   (*a*) Overfolded strata.
   (*b*) Unconformity.
   (*c*) An escarpment.
   (*d*) A reversed fault. (1896.)

6. Give the meaning of the following terms—base-level, plain of marine denudation, superposed drainage.

7. Trace the steps in the denudation of a rising anticline.

8. What would be the effect of an uplift of the ground after the formation of a base level?

9. What is the origin of lakes?

10. Hills frequently coincide with synclinals, and valleys with anticlinals. Why is this? Draw a section to illustrate your answer. (1892.)

11. What are the characteristic features of the land when formed—(*a*) of a thick mass of limestone; (*b*) of clay; (*c*) of sand? (1892.)

CHAPTER XXIII

ECONOMIC GEOLOGY

THE more important substances of economic value derived from the rocks are the following: Water for drinking, manufacturing, and medicinal purposes; Fuels like coal and oil; Building stone and Roofing slate, Lime and Cements, Clays for brick-making and pottery, Fire-resisting clays, Road metal and Flagstones, Ornamental Stones and Marbles; Whetstones and Grindstones, Sand for glass-making, Fuller's Earth, Salt; Soils and Manures; and last but not least the precious and useful Metals.

Water

Springs.—Water is obtained from natural springs or wells, rivers, and natural or artificial lakes. In many places rain-water which has percolated underground through the rocks comes to the surface as springs; wells are merely artificial springs made by boring into rocks saturated with water. When the rain-water falls upon a porous rock like sandstone or a

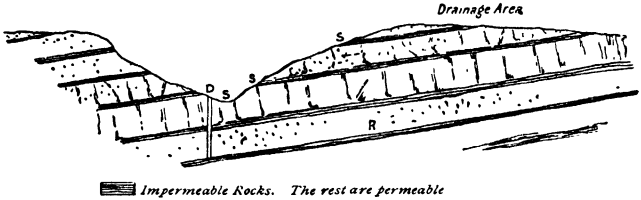

FIG. 304.—Diagram of surface springs (S) and deep-seated springs (D).

pervious one like limestone penetrated by joints or fissures, it continues to travel downward till it is stopped by some impermeable rock like clay. It is then compelled to pass along the junction plane of the two rocks, and if it comes to the surface again by travelling steadily down-hill it issues as a *surface spring*. This is illustrated in the diagram (Fig. 304) by the springs at S. Patches of porous gravel if underlain by clay give supplies of impure water to surface springs. The water in the seam marked R has no such surface outlet, and it will continue to accumulate and saturate the stratum till it is full of water. If a natural crack reaches this stratum at D, or a well be sunk there, the water will be driven up to the surface by hydraulic pressure within R, and a *deep-seated spring* will occur there. A similar deep-seated spring occurs at F in Fig. 305, the end of the porous stratum here abutting against impervious rock in consequence of the fault.

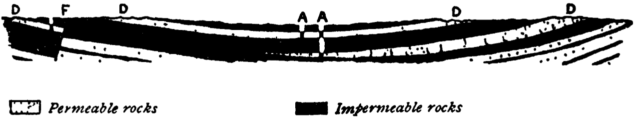

FIG. 305.—Diagram to show the conditions for the formation of an artesian well (A) and a fault spring (F).

Artesian Wells.—One kind of artificial deep-seated spring, called an *artesian well*, is also shown in Fig. 305. The beds are here bent into a basin with no escape for the water in the porous strata, until wells are bored at A and A to reach the higher or lower permeable bed. Hydraulic pressure of water in the permeable rocks forces the water up to the surface and even above it. The Chalk basin under London, having one clay seam above and another below it, yields a large supply of water to artesian wells.

Mineral and Hot Springs.—Well and spring waters are *hard* if the water dissolves carbonate or sulphate of lime, or salts of iron or magnesia, in passing through a permeable stratum, but *soft* if they do not dissolve such matter. If the water contains much dissolved matter it is called a mineral spring, and it is named according to its constituents; chalybeate, if salts of iron are present (Harrogate); calcareous, if lime; magnesian, if magnesia (Epsom); saline, if salt (Droitwich), and so on. Many of these springs are of medicinal value. If the water penetrates to great depths it frequently comes up hot, as at Bath and Buxton, and then it is called a thermal spring. These springs are common in volcanic districts, and there they are sometimes boiling hot, and even give off steam like the geysers.

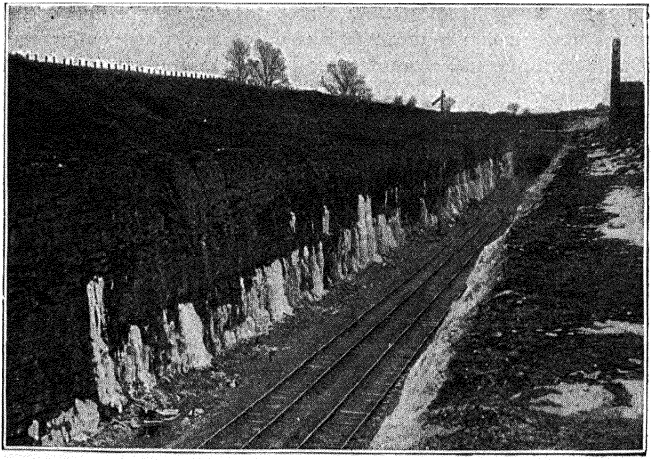

FIG. 306.—The cutting of the Severn Tunnel, in winter, showing by the line of the top of the icicles the position of the junction between a porous bed above and an impervious bed below. The springs issue along this line. (From a photograph by Mr. H. L. P. Lowe: copyright.)

There are many important permeable, either porous or pervious, water-bearing strata in England, and there may be especially mentioned the Millstone Grit, Coal-measure sandstones, Triassic sandstones, the Greensands, and the Chalk. The water from the Trias, which generally contains much sulphate of lime in solution, is especially good for brewing.

The remarkable picture (Fig. 306) shows a line of frozen springs which mark the junction of a porous and an impervious rock.

Fuels

Coal.—Although a little lignite occurs in Tertiary and Jurassic Rocks, our principal supply of fuel comes from the Coal-measures, and a little from the coals in the Millstone Grit and Lower Carboniferous. An account of the character and method of occurrence of coal has already been given, and it only remains to say that the seams are generally very regular over large areas; that they are as a rule folded into basins which may be broken and bent by minor folds and faults, and partially concealed by Permian, Triassic, or newer rocks; and that they are worked from shafts by driving galleries along the seams. Coals thinner than two feet cannot as a rule be profitably worked, but very thick seams, like the Ten-yard Seam of the South Staffordshire coalfield, are usually worked out seven or eight feet at a time. *Peat* is cut and burnt in the mountain districts of Great Britain and Ireland.

Oil.—Mineral oils only occur in small quantities in England, but they furnish freely running wells on the Caspian, in America, etc. A certain amount of oil has been obtained by distilling bituminous shales in Scotland.

Building Material

Building Stones.—Limestones and sandstones are most commonly employed for this purpose, particularly the oolitic limestones and free-cutting sandstones, both of which are known as *freestones.* But granites, basalts, grits, and a host of other rocks are used for rough work, and especially for building walls with or without mortar. The Jurassic Rocks and the Magnesian Limestone furnish our best limestones, and the Carboniferous, Permian, and Triassic Rocks the best sandstones for building.

Roofing-slates proper are obtained from Pre-Cambrian, Cambrian, Ordovician, Silurian, and sometimes Devonian Rocks, where fine-grained sediments have been affected by cleavage. In the Eastern and South Midland Counties, *fissile* limestones which split readily along the bedding into thin plates and are locally called "slate," are found at the base of the Great and Inferior Oolites, and they are much used for roofing.

Lime and Cements.—All limestones when burnt can be used for mortar, but the Wenlock, Carboniferous, Liassic and Jurassic Limestones, and the Chalk, are especially good. Impure argillaceous limestones like that obtained from the Lias furnish a mortar which has the property of setting under water, and similar hydraulic cements are obtained from the calcareous nodules (septaria) in the London Clay, and from chalk mixed with the mud of rivers, like the Medway.

Clays.—Where there is no building-stone, the clays are much used for brick- and tile-making. The clays of the Trias, the Oxford and Kimmeridge Clays, the Gault and the London Clay, and even the Boulder-clays, brick-earths, and alluvia of rivers are much used for this purpose. The non-alkaline clays of the Coal-measures resist intense heat, and are hence called fire-clays; bricks made from them are useful for furnace linings, but, where their composition would be harmful to the molten metal, bricks of siliceous gannister are used instead. Kaolin for making the better classes of china and porcelain is generally derived directly from disintegrated granite in Devon and Cornwall, where there has been no glaciation to sweep away the result of long ages of weathering and decomposition.

Road Metals and Flagstones.—As a rule it is now found economical to use the hardest and toughest materials for mending roads and for paving setts, and diorites, dolerites, granites, and kindred stones are in much demand. The intrusive and interbedded igneous rocks in the Carboniferous, Ordovician, and older rocks in Wales and the Midlands, and the granites of North and West England are chiefly used for the purpose. The Old Red Sandstone of Scotland and the Carboniferous Rocks of Yorkshire yield the chief flagstones, the properties of which are that the rock must split into fairly thick slabs, and yet resist the disintegrating action of frost and rain. Many local stones, such as magnesian limestone, oolites, and even granite, are sometimes used, and artificial slabs are now frequently employed.

Ornamental Stones.—Britain possesses few of these. Some of the igneous rocks, like the granites of Shap and Aberdeen, some of the felsites (porphyries), and the serpentine of Cornwall, are favourable examples. The Carboniferous and Devonian

Limestones yield ornamental "marbles," black or marked by crinoids, corals, shells, or mineral veins, and the Purbeck, Sussex, or Petworth (Wealden) and Cotham ("Landscape") marbles have been used for church work.

Other Useful Materials

Grindstones, Millstones, and Whetstones.—Rough grits and siliceous sandstones like the Millstone Grits have been used for grindstones and millstones, and the Greensand of Blackdown, fine-grained lavas, ashes, and metamorphic rocks for whetstones.

Sand for Glass-making has been obtained from the Lower Greensand and from the Bagshot sands; **Fuller's Earth**, for taking the grease out of cloth and for filtering oil, from the Jurassic Rocks and from beds in the Lower Greensand in Surrey and Bedfordshire. **Salt** occurs in masses in the Permian and Keuper Marls of Worcestershire, Cheshire, Yorkshire, Durham, and the Isle of Man. It is obtained by mining or by pumping natural or artificial springs from the deposit, and concentrating the brine by evaporation. **Phosphate of Lime** has been obtained from the Upper and Lower Greensands, the Gault, and the Red Crag, all in the Eastern Counties; it furnishes a valuable manure.

Soils

These are the *sedentary* residues left by the disintegration of rock on the spot, mingled with animal or vegetable refuse (Fig. 28), or they result from the *transport* of material by rivers or glaciers. The last generally furnish the more valuable soils, as they contain a mixture of materials brought together from widely-separated localities. The nature of the soil will depend upon the agencies of transport, upon the nature of rock disintegrated, and the character of disintegration which it has undergone, whether by rain, dry air, or frost. Limestones yield a thin rich soil good for pasture, clays form heavy lands suitable for wheat, marls and mixed soils are useful for general agriculture.

Metals.

Lodes and Veins.—Many of the metals are derived from crystallised minerals, which are usually found filling fissures in the rocks. As a general rule these veins occupy faults, but occasionally joints. These cracks afford a passage for springs, and the water laden with mineral matter in solution frequently deposits crystalline minerals as it comes up to the surface. Quartz and calcite are two very common minerals formed in this way, the former usually in siliceous, the latter in calcareous rocks. Mixed, however, with these *spars*, as they are called by miners, there often occur *ores* of lead, zinc, copper, tin, and other rarer metals. Occasionally uncombined, or native, metals are found under these circumstances, such as gold and copper. More usually they are combined with other groups of elements, and form sulphides, oxides, carbonates, or even silicates.

The crystals are usually deposited on the rock face of the crack, and point inwards from its walls (Fig. 307), and it often happens that a crack has been filled in two or three stages, so that successive double rows of crystals may be found one within another (Fig. 307). The broken-up rock which fills the crack is sometimes cemented into a solid mass of fault-rock by

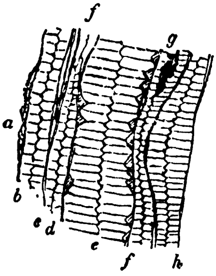

FIG. 307.—A "comby" lode with paired bands of crystals pointing inwards along the cracks: a = blende, ff = copper pyrites and zinc blende; the rest of the letters indicate quartz crystals. (B.)

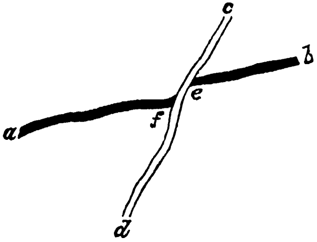

FIG. 308.—Faulting of lode ab by lode cd (B.)

spar or ore minerals deposited amongst the fragments. As the fault cracks are often irregular, the thickness of a lode may vary from point to point, not only in depth, but in the *course* of the fault across the country, and as a fault may die out, so too a lode may die out. A vein is therefore by no means so easy a thing as a bed of rock to follow, particularly as it may be faulted and broken like a bed. In Fig. 308 the newer vein *c d* faults and shifts the older one *a b* from *f* to *e*. Sometimes

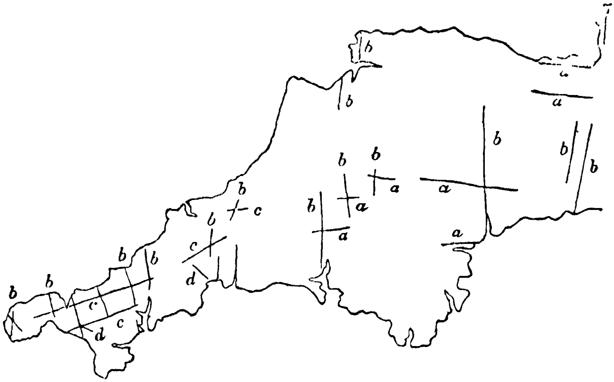

FIG. 309.—Map of Cornwall to show the dominant direction of the lodes. There are three main sets, *a*, *b*, *c* (B.)

veins occur which appear to be simple fissures, wider at the top than at the bottom. These are called gash-veins. More usually the fault has some displacement, and the richness of the lode often depends on the particular kinds of rocks brought into contact with one another by means of the fault. This is well seen in the mines in the Dale district of Yorkshire, where the "country rock" consists of beds of grit, shale, and limestone; the richest ores occur where a vein has limestone on one side and shale on the other; the thinnest where shale abuts on shale; and the poorest where shale or limestone abuts on grit. This connexion is partly physical, due to the compressibility of the rocks causing the practical closure of the fissure, and to the permeable character of some of the rocks in allowing water to trickle away through them without depositing the ores it has in solution. It also suggests that the mineral ingredients may have been in part derived from the country rock in which minute quantities of such metals as occur in lodes have been found. But the majority appear to have been derived from the liquids and gases associated with intrusive masses of plutonic rock. Indeed, many ore-bodies are actually segregations of minerals in the igneous magma. That the general course of lodes across the country is like that of faults will be seen from the map (Fig. 309). The N. and S. lodes in Cornwall (*b*) bear lead, and the E. and W. lodes (*a*) carry tin and copper (Fig. 309).

Other Mineral Deposits.—In addition to veins, metalliferous minerals occur as (1) *impregnations*, (2) *irregular masses*, (3) *stockworks*, The first consists of beds cemented or saturated with sufficient of a valuable mineral to be worth working; the second represents the filling of irregular cavities, occurring in limestone, etc., by metalliferous deposit, like the hæmatite deposits of Cumberland in the cavities of the Carboniferous Limestone; the third the branching out of innumerable veins amongst the fractured rocks which form the cheeks of an ill-defined fissure.

Beds.—Some valuable minerals occur in beds. The iron ores are the chief of these. They occur as seams interbedded with sandstone, coal, and clay in the Coal-measures. Other beds have been formed by the cementing of sandstone by oxide of iron to a large extent, or by the alteration of limestones into masses of carbonate of iron, the method by which the Liassic ore of Cleveland has originated. Sometimes metallic ores or native metals are washed out of these veins and deposited by streams in alluvial flats or gravels. These deposits are called *placers;* alluvial tin and gold occur in this fashion. They are found in lumps, nuggets, or dust which have been washed out of veins in the rocks and accumulated, in some cases enlarged, by the action of water.

Metalliferous Minerals.—Amongst the chief metalliferous minerals the following are the more important:—

Lead occurs chiefly in cubic crystals of sulphide of lead or *Galena.* It has a silvery lustre, and is soft, dense, and opaque.

Zinc also occurs as sulphide, and is known as *Blende* or black-jack. It is dark brown in colour, slightly transparent, with a faint metallic lustre, and crystallises in the cubic system.

Iron occurs as a sulphide, *Pyrites*, in brassy-looking cubic crystals. It also occurs as the red oxide known as *Hæmatite*, in kidney-like masses, crystallising in the hexagonal system; the streak is bright red. *Magnetite* is a black oxide which crystallises in octohedra, belonging to the cubic system. The carbonate known as spathose iron ore or clay ironstone is usually impure and massive.

Copper is occasionally found native, but more usually as a sulphide combined with sulphide of iron, as *Copper Pyrites*, crystallising in the tetragonal system and with a brown streak. The green carbonate called malachite is used as an ornamental stone.

Tin occurs as the oxide known as tinstone or *Cassiterite*. It often replaces the form of felspar crystals, but itself crystallises in the tetragonal system.

Silver is generally found as an impurity in *Galena*.

Gold when native occurs in cubic crystals, but it is frequently found combined with tellurium as a telluride.

RECAPITULATION

Water is obtained mostly from *springs* or *wells*. The position and nature of these depend upon the character and arrangement of the *permeable* and *impermeable* rocks in the earth's crust. Fuels comprise *coal* and *oil*, which seem to be chiefly derived from the organic remains in the rocks. *Building stones* should be *durable*, *strong*, free-cutting, and beautiful. These qualities are best exhibited in Britain by the Carboniferous, Permian, Triassic, and Jurassic Rocks, both sandstones and limestones. Slates are mostly found amongst the older rocks, brick-clays amongst the newer, but ornamental stones are rare in this country.

Soils are either the result of the disintegration of rock in place (*sedentary*), or of the *transport* of loose debris to one spot.

Our chief supply of *metals* comes either from *beds*, as in the case of iron, or from the crystalline substances which fill the cracks and hollows of fractured rocks known as *lodes*. These valuable deposits result from the concentration into certain spots of some of the substances which are to be found all over the world disseminated through all kinds of rocks and even in the sea, but in such minute quantities that it is difficult to recognise them and impossible to recover them.

QUESTIONS ON CHAPTER XXIII

1. What do you understand by the terms "permeable" and "impermeable" as applied to strata? Give examples of each from the Cretaceous and Oolitic Systems of rocks. (1883.)

2. Explain the theory of artesian wells, and illustrate your answer by means of a diagram. (1888.)

3. How are supplies of drinking-water to be obtained otherwise than at the surface of the ground? Draw a section showing favourable conditions for obtaining a supply. (1889.)

4. (*a*) How are springs formed?
 (*b*) What are mineral springs?
 (*c*) What are hot springs, and where are they usually found?
 (*d*) What are geysers? (1895.)

5. What are chalybeate springs? How may they originate? (1890.)

6. What are thermal springs? Name an English example. (1894.)

7. Shallow wells sunk in gravel often yield large supplies of water. How is this? (1882.)

8. What is meant by the term "hardness" applied to water? How is this hardness produced? (1893.)

9. Explain what is meant by a "mineral spring." Give two well-known examples of such springs. (1878.)

10. Explain the action of an ordinary spring and of an artesian well? (O and C.)

11. What do you understand by a permeable formation? Give instances in this country. (O and C.)

12. Explain the origin of springs. What evidence is there of the relation of thermal springs to volcanic action? (O and C.)

13. In what British formations, other than the true Coal-measures, do seams of coal or lignite occur? (1883.)

14. What kinds of sedimentary rocks afford good building stones? Name three examples, with their positions in the geological scale. (1877.)

15. What do you mean by hydraulic limestone? Give the names of one or two varieties, and mention their places in the geological scale. (1883.)

16. From what rocks do we derive supplies of common salt, and in what ways is it obtained? (1889.)

17. How does a bed differ from a vein? Name some minerals of economic importance which occur in one or other of them. (1883.)

18. Define the terms—fissile, hade, joint, lode. (1892.)

19. What is hæmatite? Where do important deposits of this occur in Britain? (1892.)

20. Name the British strata from which iron-ores are obtained. (1890.)

21. Under what conditions and in what state is gold usually found? (1889.)

22. Describe the chief ore of tin. Where, and under what circumstances, does it occur? (1891.)

GENERAL QUESTIONS

1. What are moraines? How do they differ from river-terraces? (1892.)

2. Explain fully the terms—strata, stratification, conformability, cross-bedding. What do they teach as regards the history of any rock in which they occur? (O and C.)

3. Describe how a soft calcareous deposit may be converted into crystalline limestone. (1893.)

4. What are the following, and how do they originate—barrier-reefs, deltas, earth-pillars, land-slips, and medial moraines? (O and C.)

5. State the broad distinction between flagstones, slates, and shales. (1887.)

6. What is a trap-dyke [ancient igneous rock]? How does it differ from a fault or from a mineral vein? (1887.)

7. What are the following rocks, and how have they been formed—amygdaloidal andesite, oolite, gabbro, trachyte, and serpentine? (O and C.)

8. Describe and indicate the botanical affinities and the range in time of—

   (*a*) *Lepidodendron.*
   (*b*) *Nipadites.*
   (*c*) *Calamites.*
   (*d*) *Stigmaria.* (1897.)

9. Describe clearly the nature and mode of production of an unconformity. Mention the geographical and geological position of some important unconformities in England. (O and C.)

10. Name and state the formations in which they are found—

    (*a*) Three fresh-water fossils.
    (*b*) Three marine fossils.
    (*c*) Three brackish-water fossils.
    (*d*) Three terrestrial fossils. (1897.)

11. Mention three British formations in which Fishes frequently occur. (1891.)

12. In what British formations do fossil footprints occur? (1891.)

13. What is chalk, and how has it been formed? What beds lie above it (*a*) in England, and (*b*) in Ireland? (1883.)

14. Mention the characteristic fossils of the following formations—Silurian, Devonian, Cretaceous. (O and C.)

15. Draw a section through any part of the British Islands, stating the age of the rocks shown. (1890.)

16. (*a*) To which of the great geological eras do the Jurassic, Triassic, and Cretaceous systems belong? Place them in their proper sequence.
  (*b*) Give the name of a Jurassic echinoderm, a Triassic echinoderm, and a Cretaceous echinoderm.
  (*c*) Give the name of a Jurassic cephalopod, a Triassic cephalopod, and a Cretaceous cephalopod.
  (*d*) Give the name of a Jurassic vertebrate animal, a Triassic vertebrate animal, and a Cretaceous vertebrate animal. (1886.)

17. What was the condition of England during the Glacial Period, and what indications and relics of that condition are still to be found in this country? (O and C.)

18. Mention some of the chief evidences of ice-action to be seen in Great Britain, giving their localities, and describing the kind of action which has gone on at each place named. (O and C.)

19. Give one Limestone of the British rocks, mainly of chemical origin, and one of organic origin. (1890.)

20. Name four of the important deposits of limestone in the British Isles, and give their geological positions. (1878.)

21. Draw a diagrammatic section through the London Basin, indicating the various sources from which supplies of water are obtained. (1885.)

22. Write a list of the geological formations which occur in the district known as the Wealden area. (1879.)

23. Arrange the following formations in descending order, placing the newest at the top, and state to which of the great geological systems each belongs — Cornbrash, Gault, Kellaways Rock, Chalk, Forest Marble, Kimmeridge Clay, Lower Greensand, Lias, Portland Stone, Keuper, Upper Greensand, Oxford Clay, New Red Marl. (XII.)

24. Give what you know of the systematic position and geological occurrence of each of the following genera—*Aviculopecten*, *Cidaris*, *Favosites*, *Hamites*, *Monograptus*, *Neuropteris*, *Nummulites*, *Plesiosaurus*, *Schizodus*, *Trinucleus*. (O and C.)

25. What are the following genera, and to what geological periods do they belong—*Atrypa*, *Belemnites*, *Calymene*, *Cidaris*, *Inoceramus*, *Lepidodendron*, *Monograptus*, *Nummulites*, *Plesiosaurus*, and *Pterichthys?* (O and C.)

26. In what series of rocks are the following genera found—*Inoceramus*, *Ammonites*, *Plesiosaurus*, *Ventriculites*, *Belemnites*, *Pterodactylus*, *Terebratula*, *Globigerina*, *Megalosaurus*, *Micraster*, *Nautilus*, *Scaphites*, *Ichthyosaurus*, *Ostrea*, *Pleurotomaria*, *Trigonia*, *Rhynchonella?* To what zoological classes do these genera respectively belong? and mention if any of them are still living. (XII.)

27. Describe and give a rough sketch of each of the following fossils: *Ammonites*, *Scaphites*, *Belemnites*, *Nautilus*, *Orthoceras*, a Crinoid, Trilobite, Graptolite, and a Brachiopod, stating to which class each belongs. (XII.)

28. State the group of plants or animals to which the following fossils belong, and the strata in which they are found:—

(*a*) Calamites.
(*b*) Belemnites.
(*c*) Trilobites.
(*d*) Graptolites. (1896.)

29. What are the following, and in what geological ages have they flourished—Ammonites, Graptolites, Trilobites, Lepidodendra, Ganoid Fishes, and Rugose Corals? (O and C.)

30. Name the chief land and fresh-water formations of England, assign them to their proper position among the stratified rocks, and mention some of their characteristic fossils. (O and C.)

31. Write a brief sketch of the order of succession of the strata, their distinctive features, and the nature of their included organisms in one of the following areas: the Isle of Wight, the Mendip Hills, Norfolk, the Yorkshire Coast, the Lake District. (O and C.)

32. In what formations are the following fossils found—Trilobites, Graptolites, *Lingula*, *Ichthyosaurus*, *Belemnites*, *Nummulites*, and *Nautilus*? (O and C.)

33. Where, and in what geological periods, has volcanic action been prevalent within the British area? (O and C.)

34. If you were shown the following fossils—

(*a*) *Gryphæa incurva*,
(*b*) The tooth of an elephant,
(*c*) Calamite-stem,

what would you state as to the group of plants or animals to which they respectively belong, and the beds from which they must have been originally derived?

(*d*) If you were told that all three fossils were found together in the same pit, how would you account for the fact? (1895.)

35. What rocks by their decomposition produce red soils? Explain this. (1892.)

CHAPTER XXIV

GROWTH OF THE GEOGRAPHY OF BRITAIN

The Four Earth-Movements.—The geological history of Britain is responsible for the growth of the geography and landscape of the country. We can trace *four principal earth-movements* since early Archæan times, as well as some other minor movements (see Fig. 310). Each is marked by important changes in the rocks then in existence, and by unconformities dated by their earliest covering rocks (see page 224). The *first* of which we have certain knowledge produced folds and other structures trending N.W. to S.E., and Charnwood Forest and some parts of the north-west Highlands of Scotland and Ireland show land-forms resulting from it. It is known as the *Charnian movement*, and it affects the rocks of that area and all older ones.

The *second* or *Caledonian movement* trends N.E. to S.W. (see Fig. 311) and is responsible for the Highlands and Uplands of Scotland, the mountains of the Lake District, and those of North Wales and the Border Counties. The movement really began between Ordovician and Silurian times, and, after a pause, was taken up again in Devonian time.

The *third* movement trends N. and S. in the *Pennine* Range and E. to W. (*Armorican* direction) in South Wales and Devon, and in the older rocks which lie under the newer sediments of the Weald and the London Basin. Features like the Pennines, the Mendips, Exmoor, and Dartmoor are due to it.

The *fourth* major movement was of Miocene date and built the great *Alpine* Range, sweeping from the Pyrenees to the Himalayas and beyond. In Britain its folding effects were comparatively feeble, and their directions merely echoed

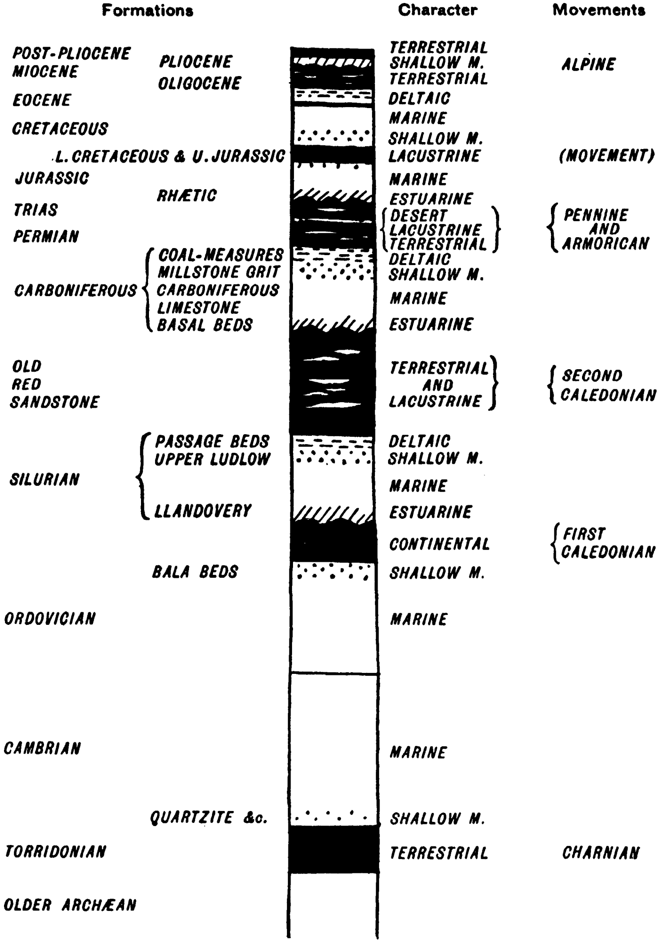

FIG. 310.—Section to show the four main continental phases with their land and lake conditions and deposits; also the three main marine phases with their estuarine, shallow-marine, marine, and deltaic sediments. The diagram is roughly to scale except for the magnitude of the Torridonian* and first Caledonian movements.

those of the older folds on which they rest, trending E. to W. in the Weald and London Basin, northerly and southerly in the folds from which have been carved the escarpments of the Jurassic Rocks of the Cotswolds and Edge Hills, and the Downs and Wolds of the Chalk, from Beachy Head and the Foreland to Flamborough Head.

The Marine Phases.—Between these mountain-forming phases, much, and sometimes all, of Britain sank beneath the sea, often to a considerable depth. Hence there are *three* chief marine phases:—(1) the Cambrian, Ordovician, and Silurian Periods; (2) the Carboniferous Period; and (3) the Jurassic, Cretaceous, and Eocene Periods.

The Cycle of Movement.—The *continental phases* were marked by folding, faulting, and sometimes metamorphism of the rocks, and by volcanic outbursts and intrusive phenomena. Their sediments were laid down on dry land, by rivers, or in lakes or shallow epicontinental seas; and the development of high land is sometimes associated with glaciation.

When sinking began, the land-surfaces developed into strong relief by earth-movement and denudation, gave rise to peninsulas and islands divided by gulfs and estuaries in which characteristic estuarine and marine deposits were laid down in sequence on the terrestrial and lacustrine sediments of the previous continental phase. The seas deepened, generally with checks, pauses, and even reversals, all expressed in the various types of marine sediment, covering ever-widening areas with increasing regularity and uniformity. Eventually sinking ceased or gave place to uplift, and the seas became filled up with flat-lying sediments forming level plains on which were soon formed deltas washed out by rivers from the land.

At last a new continental phase follows, completing the *cycle of movement.* The earth-crust is again uplifted into continental areas, and the estuarine, marine, and deltaic sediments are folded, faulted, and ridged into mountain ranges, with the accompaniment of new terrestrial and lacustrine deposits.

A study of Fig. 310 will enable these principles to be applied to the succession of British rocks given in Chapters XVIII. to XXI.

First Continental Phase.—The Torridon Sandstones bear witness to this phase and are probably terrestrial and lacustrine sediments resting on and among the mountains built from older Archæan Rocks, which may even have been glaciated in Torridonian time.

FIG. 311.—Map of the British Isles to show the trend of the folds and other structures resulting from the four main earth-movements. In the case of the Alpine (Wealden) movement, only the scarps produced by denudation of the folds are shown.

First Marine Phase.—There is a lost interval before the earliest Cambrian Rocks and the estuarine phase is not known, the sediments being definitely marine throughout that and the Ordovician Period. A preface to the *earlier Caledonian Movement* is seen in the blaze of Ordovician volcanoes; and the shallow-water deposits of the Bala Rocks are followed by local uplift and folding. Further subsidence gave the estuarine and marine Silurian sediments which became deltaic as the seas filled (Passage Beds).

Second Continental Phase.—Next rose the mountains of the great North Atlantic continent of Old Red Sandstone date, and sediments were formed on its land or in its lakes, again associated with volcanoes and the intrusion of a vast series of (Caledonian) granites.

Second Marine Phase.—The submergence of the edges of this North Atlantic continent was marked by very variable estuarine deposits in Scotland, North England, and elsewhere, passing laterally and vertically into the Carboniferous Limestone which spread out into gradually broadening areas. But debris from the continent crept out into the seas, overtaking the slow subsidence until the Millstone Grit sediments filled and levelled them up, and the deltas and swamps of the Coal-measures supervened.

Third Continental Phase.—The Pennine and Armorican Ranges were now added to the North Atlantic continent. Denudation provided the screes and gravels on the land which are now breccias and conglomerates, and in the salt lakes the Magnesian Limestone was laid down. Again there was vulcanicity, but no certain evidence of glaciation is known in Britain, though many other regions suffered the most severe glaciation known in geological history. Finally the flatter lands in Britain became overspread with sandy deserts (of the Trias), and here and there were briny lakes in which marls, gypsum, and salt were formed.

Third Marine Phase.—This began with the formation of the brackish and estuarine deposits of the Rhætic, followed by the varied marine sediments of the Jurassic Rocks, the subsidence culminating with the formation of the Oxford Clay. Shallowing followed until in the Purbeck and Wealden strata we have evidence of lacustrine and terrestrial deposits. This uplift was short-lived, and subsidence set in again with the deposit of later Cretaceous sediments succeeded by the formation over a wide European expanse of the Chalk, an organic limestone laid down in clear and moderately deep waters. Again the seas shallowed for the last time ; and the Eocene deltas were followed by the freshwater and brackish strata of the Oligocene as the land rose.

Fourth Continental Phase.—This formed a land area almost without deposits in Britain, but with evidence of uplift to which, by later denudation, we owe the Wealden scarps and the Wolds and Downs. Once again the movement was foreshadowed by vulcanicity, this time centered about west Scotland and north Ireland. The sea encroached for a while on the edges of the land to form the Pliocene marine deposits, but the cold climate which soon came on, coinciding with the formation of high land, brought on the most severe ice-age of which we have evidence in Britain, one from which we have not long recovered.

Thus it would appear that the geological history of our country resolves itself into a succession of pulsing movements during which the face and form of the land have been moulded stage by stage by successive earth-movements, each one bringing into activity the opposing forces of deposition and denudation.

APPENDIX

LIST OF CHARACTERISTIC FOSSILS, FOUNDED ON THAT DRAWN UP BY THE BRITISH ASSOCIATION COMMITTEE, 1924.

INSERTED BY KIND PERMISSION OF THE COUNCIL.

The definition of a Characteristic Fossil adopted by the Committee is as follows :—

> ‘A characteristic fossil is one, either genus or species, that is restricted to a particular horizon, or is abundant at the horizon and comparatively rare elsewhere, so that its presence in a bed would raise a clear presumption of the stratigraphical position or age of the bed.’

A number before a name indicates the biological position (p. 354). One after a name gives the page on which a description or figure of the genus will be found.

CAMBRIAN.

Lower Cambrian.

19 Kutorgina cingulata.
14 Olenellus, p. 233.

Middle Cambrian.

2 Protospongia fenestrata.
14 Agnostus fissus, 234.
14 Paradoxides davidis, 233.
14 Microdiscus punctatus.

Upper Cambrian (*Olenus fauna*).

19 Lingulella davisi, 234.
19 Orthis lenticularis.
14 Olenus, 233.
14 Agnostus pisiformis, 234.
14 Parabolina spinulosa.
13 Hymenocaris vermicauda, 234.

Upper Cambrian (*Tremadocian*).

4 Dictyonema sociale.
14 Angelina sedgwicki.
14 Asaphellus homfrayi.
14 Shumardia pusilla.

ORDOVICIAN.

Arenigian.

4 Didymograptus extensus.
4 Phyllograptus.
4 Tetragraptus.
14 Ogygia selwyni, 238.

Llanvirnian.

4 Didymograptus murchisoni.
4 bifidus, 238.
14 Ampyx nudus.

Llandeilian.

4 Nemagraptus gracilis, 238.
14 Ogygia buchi, 238.
14 Asaphus tyrannus.
14 Trinucleus fimbriatus, 238.

Caradocian.

4 Dicranograptus ramosus.
19 Orthis actoniæ.
19 „ caligramma, 239.
14 Trinucleus concentricus, 238.
14 Calymene senaria, 242.

Ashgillian.

4 Dicellograptus anceps.
22 Tentaculites anglicus.
14 Illænus bowmanni, 238.
14 Staurocephalus.

SILURIAN.

Valentian (Lower) = Llandovery.

19 Pentamerus undatus, 243.
19 Stricklandinia lens.

Valentian (Upper) = Llandovery.

4 Monograptus turriculatus, 203.
4 „ sedgwicki, 243.
4 Rastrites, 245.
19 Pentamerus oblongus, 243.

Salopian (Wenlock Shale).

4 Cyrtograptus murchisoni.
20 Cardiola interrupta.
19 Orthis elegantula, 239.
19 Orthis biloba.
23 Orthoceras annulatum, 244.

Salopian (Wenlock Limestone).

5 Favosites gothlandica.
5 Heliolites megastoma.
5 Halysites catenularia, 243.
5 Omphyma subturbinatum, 243.
19 Atrypa reticularis, 243.
19 Strophonella euglypha, 239.
19 Pentamerus galeatus, 243.
19 Leptæna rhomboidalis.
21 Horiostoma rugosa, 244.
14 Calymene blumenbachi, 242.
14 Phacops caudatus, 242.

Salopian (Lower Ludlow).

4 Monograptus colonus, 203.

Salopian (Aymestry Limestone)

19 Conchidium knighti, 243.
19 Dayia navicula.

Downtonian.

19 Lingula cornea, 234.
19 Chonetes striatella.
19 Camarotechia nucula.
20 Pterinæa danbyi.

DEVONIAN (Marine).

Lower.

19 Spirifer primævus, 253.
14 Homalonotus armatus.

Middle.

5 Calceola sandalina, 248.
5 Pachypora cervicornis.
19 Stringocephalus burtini, 248.
19 Uncites gryphus.

Upper.

5 Acervularia pentagona.
19 Rhynchonella cuboides.
19 Spirifer verneuili, 253.
23 Clymenia sp., 248.

DEVONIAN (Old Red Sandstone).

Lower.

15 Eurypterus anglicus, 249.
15 Pterygotus.
24 Cephalaspis lyelli.
29 Psilophyton.

Middle.

24 Pterichthys, 249.
25 Coccosteus decipiens.
29 Rhynia.

Upper.

20 Archanadon jukesi, 250.
25 Holoptychius nobilissimus.
29 Archæopteris hibernica, 249.

CARBONIFEROUS.

Lower.

5 Lithostrotion basaltiforme.
5 Lonsdalia floriformis.
5 Zaphrentis.
5 Dibunophyllum.
5 Syringopora.
8 Actinocrinus triacontadactylus.
19 Orthis resupinata, 239.
19 Productus giganteus, 253.
19 „ semireticulatus, 253.
19 Spirifer striatus, 253.
19 Syringothyris cuspidatus.
19 Seminula ficoides.
20 Posidonomya becheri.
20 Conocardium.
21 Euomphalus pentangulatus, 253.
14 Phillipsia, 254.
25 Psammodus rugosus.
29 Lepidodendron veltheimianum, 257.

Upper.

20 Carbonicola robusta.
20 Anthrocomya phillipsi.
20 Pterinopecten papyraceus.
23 Gastrioceras listeri, 254.
29 Calamites sp., 257.
29 Lepidodendron aculeatum, 257.
29 Stigmaria ficoides, 256, 257.
29 Neuropteris heterophylla.
29 Alethopteris lonchitica.

PERMIAN.

19 Productus horridus, 262.
18 Fenestella retiformis.
20 Schizodus obscurus, 262.
25 Palæoniscus.
29 Walchia piniformis.

Glossopteris flora.

29 Glossopteris browniana.
29 Gangamopteris.

TRIASSIC.

English Trias (Keuper and Bunter).

13 Estheria minuta.
26 Labyrinthodon, 267.
29 Equisetites arenaceus.

Continental Trias.

8 Encrinus liliiformis, 269.
23 Ceratites nodosus, 269.
23 Arcestes.

Rhætic.

20 Pteria (Avicula) contorta, 270.
20 Protocardium rhæticum, 270.
25 Ceratodus latissimus, 267.

JURASSIC.

Lower Lias.

8 Pentacrinus briareus.
19 Spiriferina walcotti.
20 Hippopodium ponderosum.
20 Plagiostoma gigantea.
20 Gryphæa arcuata, 275.
20 Cardinia listeri.
23 Psiloceras planorbis.
23 Oxynoticeras oxynotum.
27 Plesiosaurus.
27 Ichthyosaurus, 276.

Middle Lias.

19 Terebratula punctata, 275.
19 Rhynchonella tetrahedra, 281.
20 Oxytoma cygnipes.
23 Amaltheus margaritatus.

Upper Lias.

20 Leda ovum.
23 Hildoceras bifrons.
23 Dactylioceras commune, 274.

Bajocian.

6 Clypeus sinuatus.
6 Holectypus hemisphericus.
19 Terebratula fimbria, 207.
19 ,, phillipsi, 275.
20 Trigonia costata, 275.
20 Pholadomya fidicula.
23 Parkinsonia parkinsoni, 274.
23 Ludwigia murchisonæ.
29 Equisetites columnaris.
20 Ginkgo digitata.

Bathonian.

8 Apiocrinus parkinsoni.
6 Acrosalenia wiltoni.
19 Ornithella digona.
19 Terebratula maxillata, 275.
20 Ostrea acuminata.
21 Purpuroidea morrisi, 275.

Cornbrash.

19 Ornithella obovata.
20 Goniomya V-scripta.
23 Macrocephalites macrocephalus.

Oxfordian.

20 Gryphæa dilatata, 275.
23 Belemnites hastatus, 209, 274.

Corallian.

5 Isastræa explanata.
5 Thecosmilia annularis, 274.
6 Cidaris florigemma, 204.
20 Trigonia clavellata, 275.

Kimeridgian.

19 Rhynchonella inconstans, 281.
20 Exogyra virgula.
20 Ostræa deltoidea.
23 Perisphinctes biplex.
23 Aptychus.
27 Pliosaurus.

Portland Beds.

5 Isastræa oblonga.
20 Trigonia gibbosa, 275.
21 Cerithium portlandicum.
23 Olcostephanus giganteus.

Purbeck Beds.

20 Ostrea distorta.
21 Viviparus fluviorum, 293.
16 Archæoniscus brodei.

CRETACEOUS.

Wealden Beds.

20 Unio valdensis, 281.
21 Viviparus fluviorum, 293.
12 Cypris.
25 Lepidotus mantelli, 275.
27 Iguanodon, 283.

Speeton Series.

23 Hoplites regalis, 280.
23 Belemnites lateralis, 209.
23 Belemnites jaculum, 209.

Lower Greensand.

6 Hyposalenia wrighti.
19 Terebratula sella.
20 Exogyra sinuata.
20 Thetironia minor.
23 Parahoplites deshayesi.

Selbornian.

(Gault.)

19 Terebratula biplicata.
20 Inoceramus sulcatus, 281.
20 ,, concentricus.
23 Hoplites lautus.
23 Hoplites splendens.
23 Hamites intermedius, 282.
23 Belemnites minimus, 274.
17 Palæocorystes stokesi.

(Upper Greensand Facies.)

20 Chlamys asper.
20 Exogyra conica.
21 Turritella granulata.
25 Lamna appendiculata.

Cenomanian

6 Discoidea cylindrica.
6 Holaster subglobosus, 282.
3 Scaphites æqualis, 282.
23 Schloenbachia varians, 282
23 Turrilites costatus, 282.
23 Actinocamax plenus.

Turonian.

6 Holaster planus, 282.
19 Rhynchonella cuvieri, 281.
20 Inoceramus.

Senonian.

2 Ventriculites.
8 Marsupites testudinarius.
6 Conulus albogalerus.
6 Echinocorys scutatus.
6 Micraster cor-testudinarium.
6 Micraster cor-anguinum.
20 Spondylus spinosus.
23 Actinocamax quadratus.
23 Belemnitella mucronata, 274.

EOCENE.

Thanet Sands.

20 Cyprina morrisi.

Woolwich and Reading Beds.

20 Ostrea bellovacina.
21 Melania inquinata, 293.

London Clay.

20 Pholadomya margaritacea.
20 Pinna affinis.
20 Teredo sp.
21 Volutilithes nodosa, 290.
23 Nautilus regalis, 208, 253.
17 Xanthopsis leachi.
25 Lamna obliqua.
25 Myliobatis toliapicus.
29 Nipadites, 290.

Bracklesham Beds.

1 Nummulites lævigatus, 290.
5 Litharea websteri.
20 Cardita planicosta.
21 Conus deperditus, 291.
21 Turritella sulcifera.
23 Belosepia sepioidea.

Barton Beds.

1 Nummulites planulatus, 290.
20 Crassatella sulcata.
20 Chama squamosa.
21 Rostellaria ampla.
21 Rimella rimosa, 291.
21 Murex asper, 291.
21 Typhis pungens.
21 Fusus porrectus.
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