E0425Y

THE
EARTH'S HISTORY.

THE

EARTH'S HISTORY;

OR,

FIRST LESSONS

IN

GEOLOGY.

BY

D. T. ANSTED, M.A., F.R.S.,

ETC.

FOR THE USE OF SCHOOLS AND STUDENTS.

LONDON:

Wm. H. ALLEN & CO., 13, WATERLOO PLACE, S.W.

1869.

LONDON:
PRINTED BY WOODFALL AND KINDER,
MILFORD LANE, STRAND, W.C.

INTRODUCTORY NOTICE.

THE following pages have been written with a view to communicate a simple, clear, concise, and, as far as the limits would admit, sufficient account of Descriptive Geology as known at the present time. Technical expressions have been avoided as much as possible, and have been explained generally where it has been necessary to use them. The work is meant principally for the use of students, and may, it is hoped, find a place as a useful text-book, and a companion to "The World we Live in," the Author's treatise of the same nature on Physical Geography. The two works together comprise the "Descriptive Geology" of the earlier authors, and it must not be expected in the present volume that any account will be given of the existing processes of nature, the study of which should precede every attempt to learn Geology.

Although intended as an elementary treatise, and with no pretence to be a complete account of the subject, the Author has endeavoured to write a readable book and present a continuous history. He has also thought it well to append to the notice of each important group of rocks a list of the characteristic British fossils, better adapted, perhaps, to the use of the advanced student than the first beginner. The constant demand for lists of this kind, and the assistance they give in the interesting search for fossils, which often forms the charm and attraction of Field Geology, are a sufficient excuse for their introduction. They may be neglected by the student in first reading the book. The Author cannot omit a word of acknowledgment to his friend Mr. Etheridge, Palæontologist to the Geological Survey, who has kindly assisted him in the revision of these lists.

33, Brunswick Square, London,
May, 1869.

LIST OF ILLUSTRATIONS.

CONTENTS.

CHAPTER I.

Introduction.

CHAPTER II.

Rocks.

CHAPTER III.

Fossils.

CHAPTER IV.

Disturbance and Arrangement of Rocks.

CHAPTER V.

Older Palæozoic Rocks and Fossils.

CHAPTER VI.

Newer Palæozoic Rocks and Fossils.

CHAPTER VII.

Older Secondary Rocks and Fossils.

CHAPTER VIII.

Newer Secondary Rocks and Fossils.

CHAPTER IX.

Tertiary or Cænozoic Rocks and Fossils.

OLDER TERTIARY SERIES.

CHAPTER X.

NEWER TERTIARY AND QUATERNARY ROCKS AND FOSSILS.

CHAPTER XI.

Igneous and Metamorphic Rocks.

THE EARTH'S HISTORY;

OR,

FIRST LESSONS IN GEOLOGY.

CHAPTER I.

INTRODUCTION.

WHETHER our earth was always made up of land, partly covered with water and altogether surrounded by air, there are no means of knowing with certainty; but, at any rate, careful observation has proved that the position of the land, the proportion of land and water, and the climate experienced in the lands that formerly existed, were all very different in ancient times. The sea appears always to have worn away the land, as it does now; the rain has long continued to wash down mud and stones from the mountains and hills, and carried them into the plains, leaving behind, on the low ground and near the sea, most of the remains of the country over which it has passed, while the rest passes, with the water, into the vast ocean. The volcano and earthquake now, as formerly, supply the means of breaking up the surface, and throwing out large of melted rock and other matters from the interior; and they also lift up large tracts of land, when the force is insufficient to rend asunder the surface. The coral animal also builds walls, consisting of its own stony skeleton, as it has always done. Man, newly introduced on the earth, helps in various ways to bring about great changes; but he adds only his proportion to the work; and the result of all these causes incessantly operating is now, as it has always been, to open the way to still further changes; slow, and hardly perceptible, when watched from day to day, or year to year, but visible enough when we are able to examine what has been done in the course of centuries, or thousands of years. There are many historical documents in existence proving that, within the range of human experience, there have been serious modifications of parts of the surface inhabited by man. There is ample evidence to prove that the same work commenced and was carried on long before man was introduced on the earth.

FIG. 1.

General Ideal Section, illustrating Conformable Stratification.

If we examine with a little care a quarry, a railway cutting, or a sea cliff, it will be easy to see that beneath the vegetable soil, and in what is called the "rock," there is generally an appearance of order and arrangement which seems to have required a long time to produce, assuming the continued action of causes similar to those which are now produced daily and hourly in many parts of the earth. One kind of stone or earth is heaped over another, not in confusion, but so that there is a succession of regular beds, some thick and some thin; but each bed is of the same general kind. Sometimes these beds slope, and are even highly inclined (*see* fig. 1). Sometimes they are level with the ground. In the great majority of cases they possess a true mechanical arrangement—that is, they seem to have been thrown down either in the way that a deposit settles at the bottom of muddy water when kept quite still, or in the way of stones and rubbish carried down by floods, or sometimes like the heaps formed near the entrance of a mine or quarry, or those artificially conveyed to form an embankment. It is, however, almost always by deposit from water that most of the beds seem to have been formed; and if so they must have been originally formed at a lower level than the existing land on the spot, and in a large majority of cases below the level of the sea.

The first thing that strikes one on looking at a cliff or quarry is generally the appearance of lines in it, marking a succession of beds—one deposited after another, the last being, of course, the uppermost. In a mountain country, or in a lofty cliff, we may sometimes see examples of great thickness of deposits, and, if made in water, they must evidently have taken a long time. But if deposited under water, and now seen in a cliff above water, they must have been lifted up, or the sea level must have sunk a great deal. Thus we see that there have been great changes in the earth.

To account for these changes we must have a history; and the history of the formation of the earth is, to a certain extent, taught by the study of cliffs, cuttings and exposed faces of rock. The history of the earth differs from a mere account of the earth's surface as we find it, just as the history of a country or a person is different from a statement of the condition of the country or the person at any time. The earth's history is called GEOLOGY, and is a different thing from a description of the surface, which is called Geography. The derivation of the two words is nearly the same, and the difference of meaning altogether arbitrary. *Geology* is derived from two Greek words—*ge*, meaning "the earth," and *logos*, "a discourse," and *Geography* also from two Greek words—*ge*, "the earth," *grapho*, "to write." We are concerned in this book only with geology, by which we mean the history of the earth from the beginning, so far as the history can be learnt by the study of the earth itself.

This can be learnt properly only when the student has some previous knowledge of the earth as it is, and thus the study of geology follows what is called "Physical Geography." The reader, therefore, is referred to treatises on physical geography for many facts necessary to a complete understanding of geology, which are sometimes given in geological treatises. Physical geography is that branch of geography which treats of the natural conditions and phenomena of the earth and its inhabitants as they now exist.*

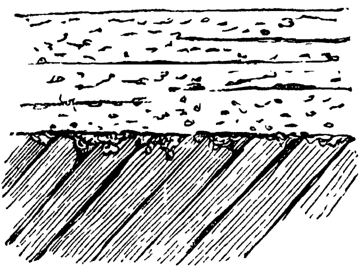
There are many records within the earth communicating more or less of its history. All rocks are such records; they show us, often very clearly, the circumstances under which each was formed, and within the same district they teach us the order of events. This they do by what is called their *superposition*, or the way in which they succeed one

* *See* "The World we Live in," or "First Lessons in Physical Geography." By Professor Ansted.

another. When we see a bed of limestone resting on a mass of sandstone, and covered by another considerable bed of limestone or clay, we see a certain order of succession, demanding time to accumulate. We may perhaps find the same kind of rock, extending for a long distance on the surface, with little difference. Thus chalk is the same rock whether seen on Salisbury Plain or at Dover Cliff, and we may almost walk on this same kind of rock from the coast of Dorset to that of Norfolk. Under the chalk, there is almost everywhere the same peculiar kind of clay, and under that again peculiar sands. This order of superposition is invariable. This extension of the same rock for hundreds of miles proves the action of the same causes, for a long distance, as well as for a long time. It proves the extent of the record, and illustrates its value.

Another record is obtained from the fact, that some lower rocks are tilted, perhaps at a high angle, while others rest on them quite horizontally (*see* fig. 2). It is clear that the movement of the tilted beds must have taken place before the horizontal beds were deposited upon them. If both have been deposited in the usual way, there must have been an interval of time between the end of the first deposit and the beginning of the next. During this time, there

FIG. 2.



Unconformable Stratification.

must have been disturbance, elevation or subsidence, and the removal of part of the lower beds.

Rocks often contain remains of plants or animals, which help to show us, in some degree, the conditions of life at the time when the rocks were deposited. These are records of another kind, but not less valuable. Time is needed that the animals or plants should live, die, and be buried. Time is needed that they should be preserved in such a way as to remain unchanged for an indefinite period. According to the nature of the remains, this time may have been long or comparatively short, but when we find the leaves and fruits of trees, and even, sometimes, the flowers, retained in rocks, the most delicate and fragile shells uninjured in beds of clay, and the smallest bones of fishes converted into stone—it is clear that the time needed to complete a very thin bed must have been something more than days or months, and that for thick beds, and a succession of beds, years must have passed into centuries. It is only when the student of geology passes from the study of books to the study of nature in the field, that he learns to appreciate the weight of evidence in favour of the conclusion that geology involves questions of time, to an extent of which people who have not studied it can have little idea.

There is another kind of record also very important. It is found in the change that has taken place in the material accumulated. Mud has had time to become fine clay or even to be converted into slate. That which was once mere powder mixed with water is now limestone, hard, and even brittle, and almost free from water. Even fine sands are cemented together into sandstones. Such alterations cannot, so far as we know, be brought about without either great heat, sufficient to destroy the texture and all appearance of the remains of life within the material, or of moderate heat and considerable pressure, acting for a very long while. The great thickness of such beds, and the fact that they are covered up, or have been covered up, by other beds, also of great thickness, are facts sufficient to render probable the latter conditions. The state of most beds, and the absence of any marks of great heat, render the former highly improbable if not impossible.

To make out and understand the value of such records as these, requires careful and long continued observation in a district or country favourable for work of the kind. There are some countries where the facilities for such observation are very small. There are few hills perhaps, and no sea-cliffs at hand, or the beds, when reached, are too nearly horizontal to show more than one. Other countries, and of these England is perhaps the most remarkable, are singularly well placed by nature for geological work. Every one in England may learn some geology in his own neighbourhood by his own observations. In one district there is a cliff, in another a quarry, in a third a mine. Everywhere there are roads and rivers, and almost everywhere railroads, and their cuttings and tunnels. Thus, geology has always been essentially an English branch of science.

Geology, the general result of the study of all these records, may therefore be described as the knowledge obtained by a careful examination of so much of the earth as we can reach for the purposes of observation. It involves inquiries in islands and continents, along sea coasts and inland cliffs, up the sides of mountains, in narrow glens, valleys and river courses, in quarries and artificial cuttings for roads and railways, and, lastly, in the deep recesses of the earth, where mining is carried on for coal and metals, or where sinkings and borings are made for water. Thus the geologist must be a traveller, or must at least know what travellers have observed. He must be a miner, or at least must learn much from miners, and quarrymen, and well-sinkers. He must also be a naturalist, familiar with the structure, the habits, and the peculiarities of plants and animals of all kinds, that he may measure the value and interest of the observations made concerning fragments of plants and animals found in rocks.

And when all the discoveries are made, and the facts known, there is still much to be done to apply them, and connect the various chapters that have been collected together into a history. For at the best this geological record is very imperfect. We know here a little and there a little, and between and among these fragments of knowledge there lies much that we may learn hereafter, but much, also, that we can never hope to discover. It is like what the History of England would be if all records for scores of years in some of the centuries were missing, or if two or three successive reigns of kings were lost. As it is, human history is imperfect enough in details, but we have the general outline complete. It is not so in geology. All those parts of the earth covered with the sea, amounting to three-fourths of the whole, are total blanks, in which no geological inquiry is available—even of the remaining fourth part there are large tracts—almost the whole of the interior of Africa, much of South America, and much even of Asia and Australia, which have not yet been examined, or which, if visited, cannot be said to be known geologically. Here we may expect future discovery. All our conclusions at present are based on results of the examination of less than an eighth of the surface of the globe, and though the observations may be good and sound, and the inferences true as far as they extend, it is clear that we cannot pretend to know the truth in any other than a partial form.

Geology having to deal with many things that are not generally familiar, and in that department which relates to natural history having to refer to plants and animals that often have no living representatives, it has been found necessary to introduce many new words, and employ others not in common use, so that the science has become one rather unpleasantly crowded with hard words. These having been formed chiefly by making use of the Latin and Greek languages, instead of our own, are, unfortunately, difficult to understand and remember. Many of them are, however, indispensable, and, therefore, the student should learn at once to understand their exact meaning, and then use them habitually. In the following pages every new and unfamiliar word shall be explained as it is used.

Geology may be taught either by pointing out to the student, as far as may be, the earth's history from the beginning, or by working back from the present through all the successive stages to the oldest formed rocks, and the earliest state of our globe. Each method has its advantages and its disadvantages. For the purpose of actual discovery it is not only safest, but almost necessary, to begin with what we know, and work backwards; but for teaching it has generally been found more convenient to proceed from the other end.

In a History of England it would seem strange to begin with an account of the reign of Queen Victoria, instead of the Saxon kings; although no one could have worked out the obscure points of ancient history without a familiar knowledge of the later and intermediate events. So, in geology, we must begin with the dark ages.

But, first of all, there are certain things to be taught which are quite necessary to an understanding of the history. The earth's external coating—the earth's crust, it is often called—contains the foundation of all geological knowledge. To understand geology we must know what this crust is composed of—what it contains, and how it has been made to show the history we desire to learn from it. In other words, we must learn something about rocks, about the remains of plants and animals mixed up with, and buried in, them; about the changes that have taken place in their composition, and the movements by which they have been brought under the sphere of observation. These four subjects must precede our account of the arrangement of rocks, and the actual history of the earth.

CHAPTER II.

ROCKS.

It may seem, perhaps, unnecessary to the student to devote an entire chapter to the consideration of rocks. Most people fancy that they know, at least, what the word "rock" means; and have no idea that its use may be so far technical as to need explanation. But geology is the study of rocks, and there are many varieties of composition and other interesting facts connected with them that must be learnt.

In the first place, in geology all natural groups of mineral matter that make up the earth's external crust are called by this name. Thus sand, even when quite loose, and clay, even if quite soft, are called rocks as much as sandstones and slates. Each of the mineral masses found in a sinking or a cutting, or forming one of a group of beds that make up a cliff, is a rock in this new sense.

Then rocks are of different kinds, according to the way in which they have been accumulated. Thus all sands and clays, and most limestones, that have once consisted of material moved by water, and left behind when the water has departed, are called *aqueous*, or formed by water (Latin: *aqua*, water). Such rocks as are formed by melting, as the lava or melted stone poured out by volcanoes, are called *igneous*, or formed by fire (Latin: *ignis*, fire). Certain rocks, such as the fine ashes thrown out from volcanoes, and forming large heaps, such as buried the town of Pompeii near Vesuvius; or sea and desert sands, pushed or blown along by the wind, might, in the same sense, be called *aërial* (Greek: *aer*, the air).

But scarcely any rocks, forming large masses, exist now in the exact state in which they were formed. Sands and mud of different kinds, once thrown down from water, have been changed into sandstones, limestones, and clays. Even lavas do not remain long unchanged. Rocks become hardened by getting rid of the water they were formed with; they lose, underground, some of their original ingredients, and obtain others; they are squeezed by others being heaped over them, and are made more compact; and in a thousand ways they take new forms. Out of sands come not only loose sandstones, but hard gritstones, and the clear, white, intensely hard rock called quartzite.* Out of mud, made up of the powder of chalk cliffs, or beds of limestone, come limestones that are hard, and can be used for building purposes. Out of clayey muds, come hard slaty rocks. In these cases, the original appearance and character have been changed or *metamorphosed*, a word derived from two Greek words (*meta*, change; *morphe*, shape), signifying a change of form—a kind of harlequinade. Many rocks are of the class called *metamorphic*. They belonged originally to the

* *Quartz* is the name given by miners in Germany to the transparent or white silica found in mineral veins, and generally crystalline. It is sometimes called crystal, and is used instead of glass for spectacles. It is a form of crystallized silica, silica being a mineral substance, common and very important. Quartzite is a stone having the general conditions and properties of quartz, but not transparent or crystalline.

aqueous or igneous group, but are so changed that their former state is obscured and lost sight of.

Rocks are, then, of three kinds (neglecting those formed under the action of the atmosphere only), named according to the mode in which they have been accumulated ; and this is one way, and not an inconvenient way, of thinking of them. But they must also be considered in reference to their material origin. Some are entirely composed of the mineral called "carbonate of lime." All the varieties of limestone and marble, including chalk, are of this kind. They have been formed in water generally ; and a great part, perhaps the greater part, of all limestones has been separated by animals from water. Coral is a structure of this kind ; it is a kind of skeleton, and is built up in large quantities, and very quickly. The shells that are so common by the seaside are chiefly carbonate of lime. Many limestones are altogether made up of fragments of shell, some broken up into fine powder, others in fragments, and a few entire. Lime is a substance used by all animals that are not quite pulpy to make frameworks of some kind, on which their muscles are fastened. Our own bones are made up of salts of lime, to which they owe their hardness. Many of the limestones retain in their structure and appearance clear marks of their history. One may see the fragments of shell and coral sticking out from the broken stone in some parts of a limestone or chalk quarry. Elsewhere, the rock is made up of the fine mud of broken shells that has been carried some distance in water, and there is then either no appearance of shells, or only a few fragments here and there. In some cases the rock still consists of limestone mud mixed up with clayey mud or fine sand. There are thus limestones more or less pure, and more or less provided with the true limestone character. These are mixed rocks, and we may speak of them presently.

Other deposits evidently thrown down from water are of the nature of clay. Clay is a mineral altogether different from carbonate of lime, or limestone. The two are indeed constantly mixed in nature, but they can be separated. Technically, clay is made up of silica and alumina. Flint is a variety of silica, having many of its peculiarities. Pure alumina is never seen in nature, except in very small crystals, almost as hard as the diamond, highly valued as gems under the names "ruby" and "sapphire," and small fragments of stone, almost equally hard, called "corundum," used in the arts for polishing The combination, however, called by chemists "silicate of alumina," and by ordinary people "clay," is infinitely common everywhere, and is constantly mixed with other substances. We need not describe clay, but we must remind the student that, as a rock, it is almost always impure, and often greatly altered. It is the basis of many rocks of igneous origin.

Besides limestone and clay, there is another substance that helps to make up the great mass of rocks. It is sand, or, rather, silica sand, for sand may be made up of grains of limestone, and silica we have already seen to be a name for flint. Most of the sea sand, all the sands called silver sands, and sharp sand, are of this kind, and every one knows how abundant sand is. Sands cemented naturally in any way become sandstones. They generally keep the appearance of distinct beds, or strata, one variety alternating with others, slightly different perhaps in colour and texture.

Sands are very often mixed with clay, and then form what is called "loam." Sands are sometimes mixed with limestone, and alter its character a good deal. Clays are often mixed with limestone, forming "marl," and sands, clays, and limestones, are frequently all to be found in the same aqueous rock. But some one of the number is almost always predominant, and the rock must be named from that.

Besides sandstones, limestones, and clays, deposited by water, there are also the melted rocks of which *lava* is the name given to those thrown up from volcanoes. *Basalt* is the geological name of lava poured out of old volcanoes and bedded among rocks. Basalt and lava are not so simple in composition as those we have been talking about, nor do they resemble any of them. We need not here trouble ourselves about their composition, beyond the fact that their actual ingredients are not really different from those which make up the limestones, sandstones, and clays. But they represent these rocks after they have been molten in the interior of the earth under the great pressure of the thick mass of rocks lying over them. As is the case with many things fused together at the surface, the resulting mass is very different from any one of the separate parts, or from any mere mixture of the parts.

Another class of rocks, made up of certain proportions of the same minerals as those most common at the surface, and that belong also to the igneous type, as having passed through the action of fire, is that of which granite and various porphyries are examples. Of these the component parts have been intensely heated and softened, if they have not been molten, and in this state they have entered into fresh combinations. They have become crystalline, and consist now of crystals embedded in a kind of paste, which is itself crystalline. Let the student examine carefully a slab or fragment of granite, and he will learn to distinguish this character. The varieties of colour, appearance, texture, grain, etc., are almost infinite. The actual variety of crystals embedded is exceedingly great. The most common condition, perhaps, is that of flat spangles of mica, and flesh-coloured prisms of felspar, imbedded in half-transparent quartz. These form granite. But no two slabs of granite are exactly alike, and nothing is more common than to find granite losing all its peculiar characters, and passing into some other compound.

Slates, and the rocks called "schist" (from a Greek word, meaning a division or splitting), are very different from igneous rocks, as we have just described them, and also from aqueous or water-formed deposits. They belong to the last of the groups we have to consider, and are called *metamorphic*, or changed. They have certainly in many cases (probably in all) been changed from the ordinary condition of clays, limestones, and sandstones, partly by mechanical means, or ordinary force of squeezing, producing slate, and partly by chemical agency and forces of other kinds, affecting the ultimate particles of the bodies, and forming the rocks called schist and gneiss, passing into porphyry. Thus clay, which is an aqueous rock, becomes slate by pressure; limestone becomes marble by metamorphic action; and sand, quartzite in the same way. In an important sense, indeed, all rocks that are not precisely as they were when deposited are metamorphosed; but, besides this wide use of the term, we find some so completely metamorphosed as to have parted with their ordinary character. Such rocks are truly metamorphic.

Let us now look back a little, and collect together into a short table the various divisions of rocks. We have seen them to be as follows:—

First. AQUEOUS, or IGNEOUS, according as they were formed under water, or by intense heat within (often far within) the earth, and METAMORPHIC if altered, but not melted, by heat or chemical action.

Secondly. LIMESTONES, SANDSTONES, or CLAYS, if of aqueous origin; LAVA, BASALT, and GRANITE, or PORPHYRY, if of igneous origin; and SCHIST, QUARTZITE, and MARBLE, if metamorphic.

According to the arrangement of their material these rocks are either *stratified*, or *unstratified*. This means that they are, or are not, arranged in regular layers or *strata*. The Latin word *stratum*, in geology, is used very generally to mean a bed, or layer, and its plural, *strata*, is equally commonly used in speaking of groups, or series, of many beds, or layers, of the same material. Thus we speak of a stratum, or strata, of limestone. Each bed, or stratum, may be a few inches, or only a few tenths of an inch thick, or it may be many yards. The whole group of strata may be scores or hundreds of feet in thickness.

Aqueous rocks are generally arranged in parallel layers, or, in other words, are stratified (*see* fig. 1, p. 2). Igneous rocks are very often not so arranged, and are therefore called *unstratified*. Metamorphic rocks are often arranged in layers, but these are not generally the original layers, or beds, in which the material was deposited, but have been produced since by various causes, chiefly pressure. Another word is used, therefore, in speaking of their mechanical condition, and they are called *laminated*, or arranged in thin plates (Latin: *lamina*). The word "stratified" may also be applicable to them when the original strata-marks are seen. Slates are clays exceedingly compact, and caused to split readily owing to their having suffered enormous pressure. Particles of clay, or of other substances, that can be worked into a paste with water, may, in this way, be forced into such an arrangement that they split very easily in a direction parallel to that of the squeezing force. The original strata-marks, if they remain at all, are often obscured, while the lamination marks, being very distinct, are indications of structure. In this confusion of true and apparent stratification the term "metamorphic" is a convenient substitute for either. Igneous rocks are not unfrequently called *crystalline*, to distinguish them from stratified and metamorphic varieties. There are many other varieties of structure and composition of rocks that must be learnt by the student, if he would follow the progress of geology; but we must not in this short outline attempt to give other than large and general ideas, to avoid confusion.

Almost all visible rocks have undergone change in consequence of the force that has uplifted them from their original position below the bed of the sea, to their present place at the earth's surface; and one important change has been the cracking and splitting of the mass in various directions. The cracks formed in this way have often been since filled up by minerals crystallized on the wall. It is in these cracks that many of the minerals are found that yield metals. Most of the ores of copper, and even metallic copper, in large quantities, occur in this way. The ores of tin, lead, and zinc, are also deposited in such fissures. Some of the ores of iron are found in this way, but the largest quantities and those most used in England form parts of regular beds.

Not only is iron ore obtained in the way of beds, or strata, forming part of the regular crust of the earth, but the same is the case with coal always, and salt sometimes. Coal is all that now remains of ancient vegetation buried deep in the earth, under water, and there changed into the black, brittle, dirty mineral so valuable to man. Salt in the solid state, or rock salt, is generally the result of the evaporation of salt lakes, covered afterwards with sand and mud.

The fissures, or cracks, that contain ores of metals are called *mineral veins;* but, besides them, there are others whose number and variety of appearance it would be impossible to describe, which contain various minerals, among which crystals of quartz, and crystals of carbonate of lime (or limestone), are very common. They are not, however, alone. In these same crevices, or veins, are concealed a large proportion of the valuable and useful crystalline minerals, besides many more neither valuable nor useful, whose names would be of little value or interest to the student, and which are described in works on mineralogy. Comparatively few crystalline minerals (or minerals in a state of purity that have assumed the form that naturally belongs to them), are found in beds, or strata. Some are bedded in a kind of paste in the igneous rocks, but the great majority are found in fissures in the rocks, whether aqueous or igneous, that form large masses. A knowledge of these minerals, and of the way in which they are found in veins, is extremely valuable to miners and practical geologists. It belongs, however, to a part of the science of geology which cannot be regarded as elementary.

When the geologist calls in the aid of the chemist, and is able to find the ultimate composition of rocks, it becomes evident that a few elements are present everywhere in extraordinary abundance, a few others are also very widely spread, but in comparatively small quantity, whose influence is great and strongly marked, while, of the rest, it can only be said that they are exceptional, and not necessary, so far as we can judge, to the general working of the system. Of the whole number of elementary substances oxygen is most abundant and is almost universal. The constituent parts of combinations that make up, with oxygen, the common rocks, are, chiefly, silica, lime, and alumina. These with carbon and sulphur, soda, potash, and magnesia, iron and manganese, chlorine and nitrogen, make up the list of elements and first combinations that we most frequently meet with. Hydrogen is everywhere present, combined with oxygen, as water. It is inferred, by experiments on the surface, that in the interior of the earth, in Nature's vast laboratory, under the pressure there uniformly exerted, a great interchange of elements takes place, assisted, no doubt, by the high and uniform temperature we have every reason to believe is present. In this way, the mud and sand become converted into limestone and sandstone, and in time into marble and quartzite. In this way also the coal and the ironstone have been separated from the mud with which they were deposited, and many others of the less common minerals have been found. Water has generally, if not always, been present in these transformations, and many results, once thought mysterious and inexplicable, are now clearly referred to known causes.

In the above brief notice of the formation of rocks mention has been made only of those few which serve as types or models of groups, many of them broken up into many varieties. It is often useful to the student to be able to refer to some account of this kind in case of difficulty; but for such a purpose the list needs to be greatly extended. A list is given below of the rocks most commonly alluded to in descriptive geology, with some explanation of each.

Actinolite-schist. A porphyry, consisting of crystals of actinolite embedded in felspar. The crystals of actinolite are glassy and fibrous varietiēs of hornblende. (Derivation: Greek: *aktin*, a ray; *lithos*, a stone.)

Alabaster. The name given to the fine varieties of gypsum, or sulphate of lime. Its name is derived from that of a village in Egypt, whence it was obtained by the Greeks.

Amygdaloid. (Greek: *amygdalon*, an almond.) The name of certain porphyries where crystalline minerals occupy almond-shaped cavities.

Basalt. (Latin.) A close-grained hard rock of igneous origin, consisting of ancient lava.

Boulder and Boulder-clay. Boulder is an old English name for rounded or angular blocks of stone distributed over the surface. Geologically, boulders are only such blocks as have been removed from a distance by the action of ice or water. Boulder-clay is a deposit of mixed sand, gravel, and boulders in stiff clay, left behind by icebergs.

Breccia. (An Italian word signifying fragments.) A rock composed of angular fragments cemented into a compact mass.

Calc spar, Calcite. (Latin: *calx*, lime.) The name given to crystallized carbonate of lime, sometimes found in very large quantities. When the crystals are clear and transparent they are called *Iceland spar;* when white and opaque, *calcite.*

Chlorite, Chlorite-schist. (Greek: *chloros*, green.) Chlorite is a soft friable mineral of greenish colour, very widely dispersed among metamorphic rocks. It resembles mica and talc, and often replaces it in granite. It contains much magnesia. Chlorite slate contains 40 per cent. of magnesia. Chlorite-schist consists of quartz and foliated chlorite.

Claystone. A yellowish or brownish rock, composed chiefly of felspar, and resembling burnt clay. It sometimes contains felspar crystals, and then passes into *claystone porphyry.*

Clinkstone. (Named from its giving a clear sound or clink when struck.) It is also, and for the same reason, called *Phonolite.* (Greek: *phone*, sound; *lithos*, a stone.) A felspathic rock splitting into slabs, and consisting of felspar.

Conglomerate. (Latin: *con*, with, and *glomerare*, to collect into heaps) A rock consisting of a mass of pebbles or rounded and angular stones cemented together, and forming a compact stone. *Pudding stone* is another name for the same structure. When the stones are chiefly angular the name *breccia* is given.

Diorite. (Greek: *diorizo*, to separate.) A variety of greenstone; dark coloured, and composed of plates of hornblende in felspar. The hornblende is readily distinguished from the felspar.

Dolerite. (Greek: *doleros*, deceptive.) A variety of greenstone, composed of augite crystals in felspar. The augite and felspar are distinguished with difficulty.

Dolomite. (From Dolomieu, a distinguished mineralogist.) A half-crystalline or crystalline magnesian limestone, abundant in certain districts. Ordinary magnesian limestone is not crystalline.

Eurite. A variety of granite of white colour, in which felspar is largely distributed.

Felspar. (German: *feld spath*, rock spar.) A very important and abundant constituent of the class of rocks of which granite is the familiar example, and of most porphyries. There are many varieties, but it consists essentially of the same elements as ordinary clay, silica, alumina, and either potash, soda, and lime, or mixtures of these. Iron is also present.

Flagstone. A rock that splits into plates or slabs of moderate thickness, capable of being used as flags or paving-stones.

Gneiss. (German.) A name given to certain rocks made up of the same minerals as granite, but having them arranged in layers or strata. It is sometimes called stratified granite.

Granite. (Latin: *granum*, a grain.) A very familiar and widely-spread rock, consisting of crystals of felspar, quartz, and mica irregularly intermixed. There are many varieties, chiefly owing to the absence of one component part, or the replacement of one by some other mineral. It will be found on reference to the chemical analysis of most granites that they differ but little from common clays. The crystalline character is therefore the distinctive mark. Besides granite there are rocks called *granitoid* or *granitiform*, from their resemblance to granite. See *Syenite*, *Protogine*, *Pegmatite*, *Eurite*.

Grauwacke or Greywacke. (German.) Certain hard gritty strata, partly clayey, and imperfectly stratified, common in the rocks of the older period, and especially seen in many parts of Germany. They are metamorphic, and were originally (but incorrectly) supposed to mark the passage from fossiliferous to unfossiliferous rocks.

Gravel. The name given to an accumulation of rounded water-worn stones, generally siliceous, but always hard, none of the stones being very large, but the mass mixed with small pebbles and sand. Gravel is a superficial deposit lying on the surface of other rocks.

Greensand. The name of a rock, remarkable for generally containing small crystals of a greenish chloritic silicate of iron, often abundant enough to colour the mass.

Greenstone. A common name for much of the ancient lava, forming large deposits in certain places. Its name is derived from the dark green colour of the rock. Greenstone differs from basalt, by its containing more distinct crystals, and passes into greenstone porphyry.

Gritstone. A variety of sandstone, in which the grains are larger, and more angular, than grains of sand.

Gypsum. A common rock in some districts, especially volcanic, consisting almost entirely of pure sulphate of lime. It is often associated with sandstones and salt.

Hornblende Rock. A rock made up chiefly of the mineral called hornblende, forming part of the series both of granitic, and volcanic, or basaltic rocks.

Lava. The rock poured out in a molten state from volcanoes.

Lignite. (Latin: *lignum*, wood.) The variety of coal, or mineral fuel, that is made up of wood.

Magnesian Limestone. A variety of limestone consisting of carbonate of magnesia mixed with carbonate of lime. (*See* Dolomite.)

Mica Schist. A flaggy, or roughly splitting rock, consisting of mica and quartz. It is strictly a metamorphic rock.

Mudstone. Fine shales, splitting easily, and easily disintegrating into mud.

Obsidian. A variety of lava, much resembling the slag from glass works. It is a kind of felspar.

Oolite. (Greek: *oon*, an egg; *lithos*, a stone.) A calcareous rock, made up of round grains resembling the roe of a fish.

Ophiolite or Ophite. (Greek: *ophis*, a serpent; *lithos*, a stone.) The name given on the continent to the rock called serpentine,

Pegmatite. A variety of granite, composed of felspar crystals imbedded in quartz.

Pisolite. (Latin: *pisum*, a pea.) A variety of oolite, in which the grains are as large as a pea.

Porphyry. An igneous (or metamorphic) rock, consisting of crystals of various kinds embedded in a felspathic base.

Protogine. A variety of granite, in which talc replaces mica.

Pudding Stone. The name given to conglomerates, made up of oval and rounded pebbles, like plums.

Pumice. The light porous scum or froth formed on the surface of certain erupted lavas by the passage of gases.

Quartz. Crystallized silica.

Quartzite. A variety of quartz in a granular state. The rocks thus named are often altered sandstones.

Schist. A rock that splits, but not so regularly as slate. Schists are of much greater hardness, and of a more sandy nature than slate.

Serpentine. A metamorphic or altered rock, in which magnesia is an important constituent. Its colour is varied, generally green, and often like the skin of a serpent. It is soft and soapy to the touch.

Shale. A clay hardened and splitting in the direction of bedding.

Shingle. Loose rounded stones and pebbles.

Sinter. (German: *sintern*, to drop.) Mineral incrusted on the surface of other rocks, in a compact form, by the dropping of water from springs.

Slate. The rock thus called is made up of clay in a peculiar state, owing to enormous squeezing. The finer and more perfectly splitting samples only are used for roofing, etc., but the whole mass is of the same nature.

Syenite. A variety of granite, in which hornblende replaces mica. It is so called from *Syene*, in Upper Egypt, where it was anciently worked.

Talcose Schist. A metamorphic rock, splitting readily, and made up of talc and quartz. It is soapy to the touch.

Toadstone. (German: *todt-stein*, or dead stone.) A basalt found in Derbyshire, so called because no ore is found in it, when it crosses the lead-bearing veins in the gritstone.

Trachyte. (Greek: *trachys*, rough.) The name of an important group of felspathic rocks, chiefly ancient lavas or basalts, which have a coarse cellular paste, and feel rough to the touch. Occasionally quartz forms an important part of the rock, which then becomes *trachytic porphyry.*

Trap. (Swedish: *trappa*, a stair.) Ancient volcanic lava or basalt; so called because it often occurs in terraces, or successive steps. The name is applied indifferently to all the varieties of basalt.

Tufa. (Italian.) A spongy or porous rock. The word was originally used only with reference to cemented volcanic ashes, but is now applied also to spongy deposits from water containing carbonate of lime.

Whinstone. A Scotch name for basalt. It is sometimes used for other hard stones that interfere with quarrying.

Before concluding our account of rocks, some mention must be made of those which are produced directly by the solid matter secreted by animals. Almost all animals separate from their food, or from water, a certain quantity of mineral matter, which they use as a skeleton for the attachment of their muscles. The higher animals secrete phosphate of lime to form bone; the lower animals, either carbonate of lime, forming shells, covering them more or less completely, or covered by them, or else silica generally in crystalline threads. The quantity of matter in a living state among the lower orders of animals being enormously large, and some of them secreting very rapidly, there are thus great accumulations formed of these mineral masses, entirely due to animals now or recently alive. Coral reefs are amongst the most remarkable of these. They are sometimes of enormous magnitude, reaching in length for a thousand miles, and rising out of deep water. Ancient coral reefs form part of the earth's crust. The chalk is also a rock made up almost entirely of the matter secreted by animals.

There are thus many kinds of rocks, of which the earth is built up. Some are mere heaps of loose material; some are made hard and compact by enormous pressure; some are cemented together with minerals once dissolved in water, and left behind when the water evaporated. Some, however, have been molten with the heat of intense fire, in the interior of the earth, and most of them have been changed by contact with each other, by the passage of water through them, by the gases rising out from great depths, and from other causes less familiar. Those remarkable forces, which we hear spoken of under the names "electricity" and "magnetism," act on rocks far below the earth's surface, and help to change them; and however little we may really know about their nature and bearing on each other, we are, at any rate, sure that they have helped to bring about the changes here alluded to. Many, perhaps most, of the changes are, however, due to the simple passage of water derived from rain and circulating everywhere through the earth's interior.

CHAPTER III.

FOSSILS.

Buried with the mud, sand, and pounded shells that make up rocks are innumerable fragments and many perfect remains of the plants and animals that flourished on the earth at the time and in the place of the deposit of the rocks. Those who are accustomed to observe the way in which at present the mud and sand and stones washed and worn away from the earth's surface, in various countries, are re-formed into strata, are aware that remains of life are almost always conveyed along, but only occasionally preserved in anything like a complete state. During volcanic eruptions under water, it often happens that vast numbers of fishes and other water animals are killed, and that many of them are at once buried under heaps of mud. At all times certain shells, such as those of oysters and other animals sticking to rocks, are left to form heaps after the death of the inhabitant. Animals inhabiting shells leave their shells behind them after death, and these are generally drifted by the sea into certain recesses. Coral reefs are in the same way very permanent. So also trees and plants of many kinds are often buried in large quantities at the mouths of great rivers, and much of them is certainly retained in a perfect state. The hard bones of many land animals, drifted along for a time, must often be caught in hollows, and soon become covered up. Thus there are plenty of ways in which the remains of plants and animals (called, for the sake of convenience, *organic remains*) are preserved from decay and handed down to succeeding generations.

But when, in opening or working a quarry, or in a railway cutting, or in a coal mine, the labourer comes upon fragments that speak of life in connection with the history of the rock he is working in, he is generally surprised, if at all an intelligent man, and naturally asks himself what such remains mean. They can indeed only mean one thing, namely, that they are indications of the inhabitants of the world when the rocks were being formed. This, as we shall see in another chapter, means a great deal, and it carries back the history of animals and plants to a much earlier period than most of us are prepared for. Still, as at present we are not talking about these results, but about simple facts, we must collect the facts, leaving the explanation for another time.

It is impossible to carry on any inquiries as to the kind of animals whose remains are found without some knowledge of natural history. There are two main departments of natural history so far as regards life, which are called respectively BOTANY (Greek: grass, herbage), or an account of plants and plant life; and ZOOLOGY (Greek: *zoon*, an animal; *logos*, an account of), or an account of animals and animal life. The laws which govern life are so far understood at present, and the contrivances of nature with reference to what is needed for the proper carrying out of the objects of existence are so carefully described and recognized, that it is possible by a careful study of *biology*, or the natural history of life (Greek: *bios*, life; *logos*), to make out the plant or animal from any of its more important parts or members. Thus, as quadrupeds are chiefly dwellers on land, their bones are large in proportion and closely jointed. Their teeth and extremities correspond with their habits, and every part is so completely dependent on the general result, that the species may be determined in some cases from a single bone. Birds, reptiles, and fishes in the same way and for the same reason are distinguishable. So also are the species of the lower animals, where in many cases the shell is an external skeleton in one piece. In a large number of cases the naturalist can detect a difference of species without seeing the whole plant or animal complete. An important part always, and sometimes a very small fragment, answers the purpose.

Now, the first fact that the naturalist learns when he begins to examine the remains of animals dug out of the ground, (thence called *fossils*, from the Latin, *fossilis*, that which is dug out of the earth,) is, that he cannot refer the fossils to recent species. Instead of this there is often a very marked difference. Let us see what this difference means.

The remains of life found in rocks are not usually those of land plants or animals, and this for a very sufficient reason. The great majority of all rocks must be evidently formed under water, and in most cases they are deposited from salt water of considerable depth. No large proportion of the remains of land plants or animals could be expected under such circumstances. River mud and gravel tend, no doubt, to form and grow with great rapidity, and these may entangle bones of quadrupeds and birds, and all kinds of land produce, but they form a small proportion of the whole deposits of a period, and are not carried far beyond the river mouth. On the other hand, aquatic animals provided with hard parts, of whatever nature these may be, sink to the bottom of the water they have lived in, and are soon buried with mud and retained. It is only of late years, since there have been found means of bringing up mud and its contents from the bottom of the ocean in deep water, that naturalists have found to how very great an extent this mud is due to marine animals, and how varied and numerous are the inhabitants even of the bottom of the sea. Almost all kinds of marine animals are probably able to live in water three, four, or five thousand feet deep; but we are by no means sure, and have no great reason to suppose, that they may not abound in water twice, thrice, or even ten times that depth. There is no limit of depth at which animals are known to be unable to live.

It is almost inevitable, from the nature of the case, that where deposits are formed in deep water they should retain remains of hardly any other than the lower animals—by which is meant, in natural history language, those whose structure is most simple, and in whom the nervous system is not, as in man and all the animals called "higher," concentrated in a single brain. Even fishes rarely leave permanent remains, except when their scales are bony, for the ordinary bones of fishes are not formed of mineral matter. This is well seen in the fact that the substance called isinglass, used to make jelly, is obtained by boiling down the bones of fishes. Ordinary scales of fishes are of too delicate a texture to be recognized very easily. Thus we must be prepared to find in rocks the remains chiefly of shells, crustaceous animals (crabs, lobsters, etc.), and corals, using these terms in their most familiar sense. That we do find others is a proof that they were present when the rocks they are found in were deposited; but when we do not find them there is no proof whatever that such animals were not living, and they may even have been as common as those which have left abundant remains as fossils.

Another point that should here be pointed out is the fact that, in proportion almost to the smallness of their size is the amount of mineral matter separated by many tribes of animals. Large animals live long, and most of them leave only one skeleton, easily broken up and destroyed, as the record of their whole existence. The number of such animals living at any one time is small compared with the space they occupy. On the other hand, many small kinds of animals are exceedingly numerous, multiply with enormous rapidity, and die after a brief existence, having already contrived to construct monuments which can endure unchanged for thousands of years. Thus there are good reasons why in rocks we should find an overwhelming majority of the remains of certain kinds of animals which really would hardly be noticed in comparison with the others, if we were able to see the whole animal life of the time and place. With regard to plants, also, there are some kinds whose fibre is tough and not easily destroyed, and the proportion of such among fossils is naturally greater than of mere perishable species.

The result of the careful examination of fossils by naturalists is, that comparatively few species buried in rocks are exactly identical with those of the plants or animals now living in the neighbourhood. In some cases this is clear at a glance. Thus in some gravels in Europe, and in some floors of caverns covered up with thick coats of carbonate of lime left behind by water, are found bones and teeth of certain animals in great abundance. Occasionally entire skeletons have been found. It is not difficult to make out what these animals were, for the shape, size, &c., are peculiar and characteristic. No one who had once seen it could mistake the complete tooth of an elephant for that of any other animal. Almost all the principal bones are equally decided. The teeth of hyænas, hippopotami, rhinoceroses, and many other familiar animals are equally distinguishable. When, therefore, on the examination of the remains alluded to, found in gravel and caverns in England and Western Europe, we discover little besides bones of such animals as we have named, none of whom now inhabit Europe at all, it is easy to perceive that the former land must have been very differently inhabited from the present, and, judging from the inhabitants, we conclude that the climate also was different.

The object in view in this chapter is rather to show the reader what has been the result of inquiry than to explain reasons or give details. It is very desirable that every one who studies Geology should know that fossils, or the remains of animals and plants dug up, are indications of a former state of the earth, when some of the strata, now far above the sea level, were being formed under water. It is also necessary that he should know that in most cases the fossil remains belonged to species of animals different from those now living. In using the word "species," we are obliged to suppose that its ordinary meaning is familiar. Animals and plants may resemble each other, and even perform the same part in nature; but unless they breed freely together they are not recognized as of the same species. In rocks we often discover clear proof of the fact that the same work in nature was done at one time by a tribe or species of animals of a certain kind, and is now performed by another species, not much unlike, but not the same. But the same is the case now in different parts of the earth. The elephant of Asia is very like the elephant of Africa, but they are not of the same species. They are closely related, and are spoken of by naturalists as being of the same *genus*. So again the camel of the Old World is represented by the llama of South America; but it is not only by different species but by a different genus, though still of the same *order*. Both perform the same part in nature, but the distinction is wider between animals of the Old and New World than between those living in different countries of the Old World.

Just in the same way there is representation in the remains of animals found in different rocks more or less distant from the surface. Those lying under others were first deposited and are oldest. The representative species, estimated as between the present time and an upper rock, are more nearly allied generally than those between the present time and lower rocks. This law of nature, "the representation of species in time corresponds with the representation in space," is an important guide in geological research.

The species of animals whose remains are found in rocks are of a more ancient date than those living now. Most of them are found nowhere at present, and are therefore called "extinct species." All of them represent the forms of animal and plant life at the earlier periods of the earth's existence, and their number is so great as to create a special department of Zoology and Botany. This department is called *Palæontology* (Greek: *palæos*, old; *onta*, beings; *logos*, an account of), or an account of old beings.

Fossils, therefore, are remains of old species dug up. These species are generally extinct species, and the study of them is called Palæontology. Thus far we have advanced in the way of connecting Geology with the general natural history of the earth and its inhabitants. Let us now speak of those particular groups of animals and plants that are most useful to the geologist in assisting him to arrange rocks; for this is, after all, the geological value of Palæontology, which in other respects belongs to Zoology and Botany.

We have seen that it is chiefly the smaller and less highly organized animals, and certain kinds of plants, whose remains are found in rocks, and that this arises from reasons independent of the absence or rarity of other kinds living at the time It is also made out that in almost all rocks, without exception as to mineral condition, there are indications of the presence of minute aquatic beings of low organization. Many of these belong to the vegetable kingdom, many more to the animal, and some appear to show that there may be life and the separation of inorganic matter (silica or carbonate of lime) without any very clear determination of the form that life may take. These first beginnings of existence are both curious and interesting. The most marvellous beauty of form is developed in the spiculæ, or little shoots of flint, which seem to rush out, as if themselves alive, from the inside of a mass of soft jelly-like matter, enclosing horny fibres, which make up a sponge. Enormous quantities of this gelatinous matter exist at the bottom of the Atlantic, mixed up with a mud formed of minute shells, consisting of hollow globes of carbonate of lime, or tubes and shapes more or less regular, growing one upon another, and adapted in the strangest way to some unknown conditions. Myriads upon myriads of living beings, or heaps of living matter, each assisting in the great work, are at this moment separating from sea water some of its mineral constituents, and arranging them at the bottom of the ocean. It is of little use to speak of the shape in which these wonderful combinations of atoms of silica or carbonate of lime are presented. They are governed by laws, but not such as we can recognize. The form exhibited on one day, or in one place, is capable of great change, and the name "species" can only be applied to them in a very limited sense. A few of the forms of sponge spicules are represented in fig. 3, and some of the shells in fig. 40 (*see* p. 146), but these can give only a very imperfect idea of the variety and beauty of the objects represented.

The simplest and most elementary form of plant life is of the kind called *Diatom* (from two Greek words: *dia*, through; *temno*, to cut), owing to the singular way in which the solid parts, in many cases, seem like stems nearly cut through. Diatoms are incredibly abundant in fresh water, especially when it has been exposed to the air for some time without disturbance. They increase with a rapidity almost inconceivable.

Foraminifera are shells of simple animals, which consist of little more than masses of jelly-like matter, surrounding strange balls and other shapes of carbonate of lime. The name by which the shells are known to the geologist is derived from a little aperture (Latin: *foramen*, an opening) connecting the different chambers of which the whole shell is generally made up. These lowest forms of animal life are called by naturalists *Rhizopoda* (Greek: *rhiza*, a root; *pous*, gen. *poda*, a foot) from the singular projections, like roots, thrown out from the jelly-like mass of the body, by which the animal attaches itself. Each jelly-like mass consists of a multitude of separate little cells or chambers, every one of which has its stony case. The greater part of the mud at the bottom of those parts of the Atlantic that have been dredged, has been found to consist of such stony cases or shells. A large part of the chalk, and of some other limestones, has been formed in a similar manner. The flints of the chalk are perhaps derived from forms of submarine life, which separate silica just as the foraminiferous Rhizopods separate carbonate of lime from the water.

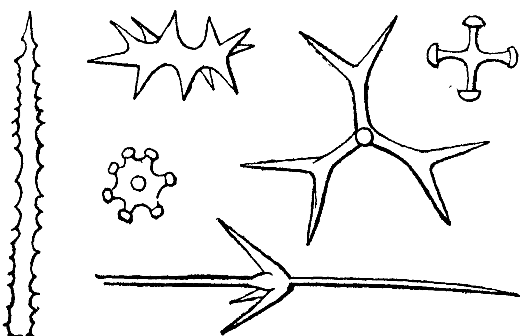


FIG. 3.—Group of siliceous spicules of sponges.

Sponges belong to a very simple form of animal life, called by naturalists *Amorphozoa* (Greek: *a*, without; *morphe*, form; *zoon*, an animal), because they are without any permanent and distinct shape. Their solid parts consist of spicules, or little needle-shaped spikes of silica or flint, often taking the strangest shapes, especially in the way of complicated hooks (*see* fig. 3). These are excessively numerous, and are formed with the most extraordinary rapidity. They are easily retained, and frequently found in a fossil state. The structure of the animal, though simple, is more complicated than in the case of the Rhizopods.

There is a group of animals often ranked among what are called sea-weeds, and called by naturalists *Hydrozoa* (Greek: *hydor*, water; *zoon*, an animal), of which an example is seen in the genus *Sertularia* (Greek: *sertum*, a wreath), whose cup-like cells are arranged alternately on a kind of stalk, like the stems of a bunch of currants with the fruit removed. This form of animal life is represented in very old rocks by a fossil called *Graptolite* (Greek: *graptos*, written; *lithos*, a stone), so named because some of the stones containing these fossils seem as if they had been scrawled or written over (*see* fig. 14, Nos. 5, 6, p. 78.)

The true corals, or Polyps (Greek: *polys*, many; *pous*, foot), come next in order. They are abundant now, and have been so probably at all times. The animals belong to the group *Radiata*, so called from having a star-like structure radiating from a centre. The polyps are compound, a central mass being connected with a large number of individuals, so that their growth is continuous and perpetual. The animal is in many cases attached permanently to the rock or sea bottom, but is always capable of travelling when young, and thus young individuals become attached to distant rocks and various floating substances before fixing for life. Some species are permanently free. The larger corals grow to enormous size, flourishing most where most exposed to the beating of the waves of a great ocean. These build hundreds of miles of reef, and surround innumerable islands and groups of islands in the Pacific with stone walls. Similar animals have worked in the same way from time immemorial, and the limestone cliffs and hills of many parts of England are the reefs built by coral animals in ancient times. The skeletons or structures of the modern coral animal differ only in detail from those that have been added to the solid substance of the earth within the present century.

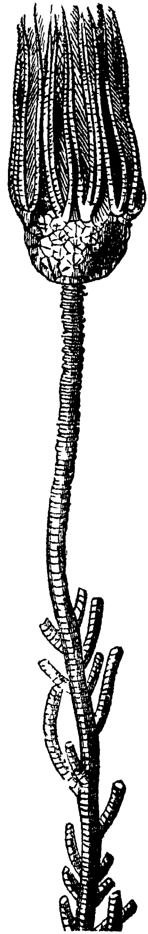


FIG. 4.—Lily Encrinite.

Star fishes, sea eggs, and sea urchins belong also to the Radiata, but to another division. They are called *Echinodermata*, from the Greek word *Echinus*, which refers to the spiny skin characteristic both of the hedgehog and sea urchin. They are not rare in a fossil state. These animals dwell at the bottom of the sea, and some of them, at any rate, are not limited in depth, as they have been brought up from more than a thousand fathoms water in a living state. Their value, as fossils, is considerable, and the extinct species include many forms that have not yet been found in a living state. A remarkable and very beautiful fossil species is represented in fig. 4.

The group of animals that succeeds the Radiata in Natural History arrangement is that of *Mollusca*, or soft animals (Latin: *mollis*, soft). Most of them, although soft, cover themselves with a stony shell. There are two principal divisions, of which that which is least complex in structure consists of animals so much like sea-weeds in appearance, as to be commonly ranked with them. These are compound animals, or *polyzoa* (Greek: *polys*, many; *zoon*, an animal), because in them a number of individuals are grouped together to form a complete animal, having a defined shape. Others are simple, each individual being distinct. These molluscoids, or coralloids (for they may be called either, as they resemble, in some respects, molluscs of the ordinary kind, and in others the corals [the termination is Greek: *coidos*, like]), are common enough alive on our own shores, and also common in our rocks. Some of the forms are inexpressibly elegant.

The ordinary Mollusca are very familiar to all. Most of the groups of animals hitherto described are marine, and all are aquatic; but many of the Mollusca are regular inhabitants of the land. Among them are the snails. Still, most of the Molluscs are water animals. The most abundant and best known modern groups do not seem to be those that were most common formerly, and we find, on examining carefully into the distribution of such animals in time as well as space, that certain natural series appear to belong more to one period, and others to another; but that, on the whole, it is not at all reasonable to assume that there has been any great advance in complication of structure.

Shells with two parts or valves, one moving on the other by a hinge, and those of one piece without hinge, are both common in a fossil state, and both include a large number of lost or extinct species. Of these, again, some groups are incredibly abundant fossil, but apparently rare now. Others are very abundant now, and rare in a fossil state. The group of *Brachiopoda* (Greek: *brachion*, an arm; *pous*, a foot)—so called because of certain appendages proceeding from the region of the mouth, bringing food, and once thought to be organs of locomotion—is rich in extinct forms. Now there are but few known. The form of the shell, and an idea of the peculiar structure, will be obtained by examining carefully the annexed cut, fig. 5. The group of shells containing the oyster, the mussel, the cockle, &c., all of which have two valves *(Bivalves)*, and that containing the snail, whelk, &c. (*Univalves)*, are well but not so richly represented in the ancient seas.

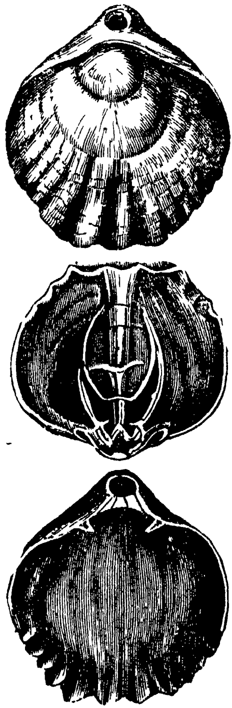


FIG. 5.—Terebratula.

The most complex of the Mollusca form a singular group called *Cephalopoda* (Greek: *cephalos*, head; *pous*, foot), from the position of the feelers, which serve to help the animals to move at the bottom of the sea. Most of these animals (like the shark among fishes) seek their food generally by browsing, mouth downwards, on the animals thickly congregated at the sea bottom. Of these animals there are whole groups of species altogether unknown at present, but whose remains are infinitely abundant in various rocks. They are found in the rocks of a very early period, low down among the strata, and covered with thousands of yards of accumulated water-worn material. They occur also in modern rocks. The Nautilus is the shell of the most familiar modern representative. The *Orthoceras* (Greek: *orthos*, straight; *ceras*, a horn) is one of the earliest forms,

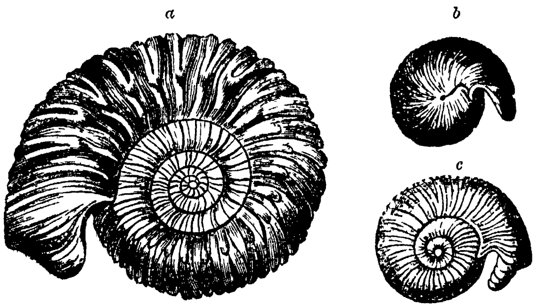


FIG. 6.—GROUP OF AMMONITES.
a. A. Brackenridgii (great Oolite). b. A. Herveyi (great Oolite).
c. A. bullatus (lower Oolite).

and is little more than a straight nautilus, or nautilus unwound. The *Ammonite* (fig. 6) presents hundreds of species of an intermediate character. It is impossible for any fossil remains to be found more characteristic than these, or more useful to the geologist and palæontologist. They are peculiar and easily recognized, abundant and of good size, of sufficiently high organization to be sensitive to changes of condition, and the structure of the animal is sufficiently dependent on that of the shell to enable naturalists to group them conveniently. Few shells have attracted greater attention, or are more frequently referred to.

Of higher general structure than the Mollusks are the *Articulata* (animals with joints or articulations). Of them there are two divisions, the more simple including the worms, the other the crustaceans (crabs and lobsters) and insects. There are no fossil worms actually remaining, for worms are soft animals; but there are plenty of indications of such animals in the sandstones. Many crustacean remains occur of all ages, including large groups very richly represented by numerous varied species in former times, but now without a single representative. The whole group of Trilobites must be mentioned as of this kind. In the older rocks many strange forms referred to this curious type have been found and are very abundant (*see* fig. 7, fig. 14 No. 6, and fig. 15).

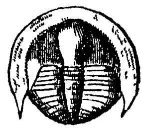


FIG. 7.—Trinucleus.

We come now to the upper division of animal life, represented by animals having back-bones, and a single nervous centre, called the brain, which is contained within a bony box, or skull, for the purpose of security. It is needless to say that they form four natural orders represented by quadrupeds, birds, reptiles, and fishes. Of these the fishes, being entirely water animals, are likely to be most abundant in a fossil state; and this is in fact the case. Their scales, the bony plates that sometimes replace scales, the teeth and palate bones, and in some, though few species, the bones, are buried in the mud at the bottom of the sea, and are retained there little altered. There are certain kinds, as usual, now common and formerly rare, and other kinds formerly rare and now common. The fishes encased in bone were among those very largely distributed in the earliest periods. They are still found, but are comparatively few in number, as the fishes whose bones are more solid, and external defences fewer, now preponderate greatly. Fishes' remains occur to a greater or less extent in all rocks, except those of the very earliest date, and in them the absence of such fossils is not to be regarded as proof that the animals did not live.

Reptiles come next to fishes among animated beings. They are of many kinds, the least highly organized being frogs and salamanders. Next are the serpents, then lizards, then crocodiles, and highest of all, turtles and tortoises. The ancient world contains examples of all the great natural groups, and besides them, contains a variety of strange and new forms, some inhabiting the sea exclusively, some confined entirely to the land, some provided with vast wings, and capable of flying freely through the air. The singular richness of various rocks in remains of this kind, suggests the probability that the land near the deposits containing them resembled rather the islands of the Indian Archipelago—the present metropolis of reptiles—than the wide continents and small islands with which Europeans are most familiar.

Birds, except waders, are little likely to leave varied or abundant indications of their existence in the mud and sand of the ancient sea shores. There is quite a sufficient number and variety, however, to show that throughout very extensive deposits of long duration, such animals lived. Most of the remains of these, as of the reptiles and fishes, indicate peculiar species, some gigantic in size, others very peculiar in structure.

The highest order of animals, named by naturalists *Mammals* (or Mammalia) because they give suck to their young (Latin: *mamma*, a teat), includes all the quadrupeds and monkeys, and man himself. Of these there are as many remains found fossil as could reasonably be expected. Such animals chiefly inhabit the land, but there is also an important group (whales, &c.) specially organized to dwell in water; and for the most part remains of their bones, buried in mud and sand, are soon and easily destroyed. But there is another reason why their remains are rare, for, as we have already seen, the actual accumulation of matter, by a whole tribe of large animals, living on the same spot for many generations, is nothing compared to that effected by a group of minute beings hardly visible to the naked eye, each of whom is adding perpetually to the stock by a positive permanent contribution, however small, whose life endures only for a few hours, or days, but of which the numbers are multiplied at such a rate that they can fill up in a very short time every available spot of land or water within range. A few large bones and some teeth of a large quadruped, who has lived a score of years, or a century, to complete its skeleton, are all that can be retained as a permanent indication of so much vital force exerted for so long a time. During the same time, the solid secretions of a mass of coral animals or oysters, originally not larger than the quadruped, would certainly be many times the amount, and far more durable. Thus it is that while the remains of the animals of higher organization are more interesting and instructive when we do get them, they are always rare, and generally in imperfect condition.

It is true that once, in the course of discovery, whole carcases of elephants and other large quadrupeds were found buried and locked up in ice, on the shores of the Arctic Ocean. Now and then also have been found, in certain gravels, or in caverns, so much of the remains of the same individual, or at least of the same species, that the whole skeleton can be built up again, and put together. But these are not ordinary events in Palæontology. Much more frequently we learn the existence of an animal by a few bones and teeth. Sometimes only a single tooth, or a fragment of a bone, is the sole indication from which the naturalist judges of an animal, and decides its relations with other animals. Occasionally a whole history has been told by the fragment of a bone. Some years ago, before the existence of extinct races of large birds in New Zealand was known, a person called on Professor Owen, and produced a fragment of bone, that was of the size and something of the shape of a beef bone. Most people to whom such a bone might have been shown, would have laughed at the idea of giving a price for such a fragment, and placing it in a museum. But the great comparative anatomist was not easily deceived. He saw in the specimen enough to justify him in purchasing it, and examining it very closely. He then confidently stated that he had before him, in this one broken piece of a leg-bone, sufficient and satisfactory evidence that in the island of New Zealand, whence it was obtained, there had lived a bird very much larger than the largest ostrich—a bird, in fact, with a leg-bone as large as an ox. Years elapsed, and other bones of similar gigantic birds were discovered. Tradition also came in aid, and it is now known that many races of such birds have, in comparatively recent times, dwelt in those beautiful islands, and have only recently become extinct. Their complete skeletons can hardly be said to be very uncommon.

Remains of plants are found in considerable abundance, but only in certain formations. In some cases, as in coal, they make up whole strata; but the plant character is generally lost in these masses of vegetation, and we can only find marks of the organic substances that compose it in the clays and sandstones adjacent. All parts of plants have been found fossil; the trunks, roots, and leaves of trees, and even the flower and fruit. The leaves are especially abundant in coal, and prove that a large and varied flora already existed on the earth when those important stores of fuel were in preparation. A group of leaves of one of these trees is represented in the annexed cut, and other varieties of leaves, besides views of the trunks, will be found in other pages. (*See* figs. 24 to 27, p. 100 *et seq.*) Most of the known coal plants were allied to ferns.

FIG. 8.—Asterophyllites. A plant of the coal period.

Fossils are found in various states. The teeth, bones, scales, shells, and other hard parts, and even the excretions of animals, and the leaves, fruits, and trunks of trees, are sometimes, and not very rarely, dug out of the earth in a state hardly altered. Some rocks are made up entirely of whole and fragmentary shells and corals, cemented together by water containing salts of lime. Others, though not made up in this way, contain them in vast abundance. In some, again, fossils are exceptional. Where the shell or bone is not in the state in which it belonged to the living animal, it is often converted, in a more or less complete manner, into stone. It is sometimes said to be *petrified* (Latin: *petra*, a stone; *fio*, I become), and is called a *petrifaction*. This term is, however, seldom met with in scientific books. The extent to which change takes place before the conversion of animal or vegetable matter into stone, varies in different cases. Sometimes each atom of the original texture is removed, and replaced by stony matter, so that the most careful examination under the microscope can detect no flaw. In some fossils, the work is only half done, and it may even happen that one half a body, once organized, is changed into limestone, and the other half into flint. The laws that govern these changes are not very well known, but of the fact that what is called "organic matter"—matter that has been arranged by the help of life—is easily converted into mineral matter, retaining its form, there is no doubt.

Besides actual unaltered remains, and those which have changed their original material for stone, there is another class of fossils, less complete, and often almost indeterminable, consisting of casts of the original. These sometimes consist of the material that has filled the interior of shells, or parts of shells, and other bodies, having the form of the interior. Sometimes casts showing the exterior of the shell are produced. In all these cases it is clear that nothing beyond the filling of the mould is necessary to secure the object. There are however many cases of chemical change, in which each particle of the organic substance has been replaced by a particle of mineral, such as flint or limestone, so that the minute structure can be detected by aid of the microscope.

Perhaps the most curious and unexpected class of fossil remains consists of the marks made on exposed surfaces of wet sand, by animals moving upon them under favourable conditions. These footprints or markings are sometimes very numerous and clear. They include a few footprints attributed to birds, many scratches apparently made by fishes or crustaceans, numerous marks of the paws of a large animal like a gigantic salamander (*see* fig. 9), and singular marks attributed to ancient species of worms. Even rain marks are not uncommon.

FIG. 9.—Fossil Footprints.

CHAPTER IV.

DISTURBANCE AND ARRANGEMENT OF ROCKS.

Rocks, as we have seen, must have been formed generally at the bottom of water; but we find them now not only in the plains and valleys above the general level of the sea, but lifted high in the air on the flanks or at the summit of great mountain chains. Measured by the distance between the supposed deepest part of the sea, and the known greatest elevation of mountains, there is a shell some 80,000 feet in thickness (about fifteen miles) within the range of human observation, and fairly called the earth's crust, as including the whole of the solid part of the globe with which we are concerned. About half the thickness (three-fourths of the area) is under water, and cannot be examined at all. Here chiefly deposits are being now made, and new rocks formed. The remaining fourth part, all above water, but at levels varying from a few feet to 30,000 feet, is that which yields a large part of the material for the newly forming rocks, and represents deposits that have been made when these parts were under the sea, and when perhaps part of the sea-bottom was dry land. The student will see that we assume a large amount of change to have taken place, in the way of upheaval and depression. Some of the rocks now at and beneath the bottom of the sea, must have been at one time dry land, for otherwise we could not account for the quantity of sand, clay, and mud removed to form the rocks that are now above the level of the sea. There must also have been depression or subsidence, carrying down, in some cases many thousand feet, the rocks whose upper parts were swept away to make the deposits which are now the foundation of our land. These rocks, of whatever kind, were formed beneath water, and in most cases beneath the sea, for they contain remains of marine animals. They must therefore have undergone elevation.

Thus, the history of rocks, prepared and arranged as they now are, and as we may observe them in every cliff, railway cutting, quarry, and mine, is a history of movement. Parts of the earth have sunk, and other parts have been lifted up. This kind of movement must have affected whole continents. It has apparently been going on during all time, and its results are seen everywhere. There is no rock whatever of which we can say positively, "This rock has been here from the beginning of the world." There are, in literal geological language, no "everlasting hills;" just as there is, in the correct language of science, no "perpetual snow." Change is the law of nature, and change of a kind and to an extent that is very startling to those who have been in the habit of looking at the earth as an emblem of stability, and whose best idea of permanence and durability is connected with terrestrial things.

It is necessary to impress this truth on the student at an early part of his study of geology, and the more so since in many works on geology the idea of some primitive or primeval condition is still retained. It was one of the natural but false notions of early geologists that they could read in the rocks they examined the whole history of the world from its commencement. Their imagination could see, looking back into the past, a vision of the time when the earth was still a chaotic mass, and even when it left the hands of its creator as a vast ball of gases in a state of intense ignition. They could point out the first results of cooling in certain granites that they would call primitive. They could see the first result of the grinding up of these granites in certain beds of gneiss, and they would say of some rocks—these are *azoic* (Greek: *a*, without; *zoon*, life), or *hypozoic* (Greek: *hypo*, under; *zoon*, life). They were the deposits before there was life on the earth. They would proceed to show where life first appeared, and what form it took, and call certain rocks *protozoic* (Greek: *protos*, first; *zoon*, life), or *primordial* (Latin: *primus*, first; *ordo*, order). All these, however, are assumptions unsupported by proof, and ought not to have been made. They are even in a certain sense mischievous, for when learnt they have had to be unlearnt and forgotten. The words primary, primal, primitive, primordial, protozoic, have no place in a geology based on sound practical views. They are words that infer a theory at present insufficiently proved.

The student should be aware of the state of geological theory with regard to this matter. Some modern geologists still believe that the disturbances and disruptions to which rocks have been subjected were in former times much greater than at present, and that sudden and complete destruction of the whole surface, or very large portions of it, have taken place at intervals, if not frequently, producing in each case an entire change in the inhabitants. These belong to the school of *catastrophists*, or believers in catastrophes and sudden destruction. Another class of geologists do not see in the history of rocks any necessity to resort to this system of catastrophes to explain the condition of rocks or fossils. These are called *uniformitarians*, as believing in the sufficiency of the rate of change going on now to explain the changes that have taken place, if only sufficient time is allowed. There is a third school of geologists whom it has been proposed to term *evolutionists*, who believe that in the changes, whether of the earth's crust or of the races of plants and animals living on it, there is evidence of the working out of a great law of progress, advancing from a definite beginning through various stages towards an end. This latter view commends itself entirely to every philosophic mind; but even those who admit it may still hold that there is at present no sufficient proof of the oldest rocks known having been the first rocks formed, or that the animals whose remains are found in these oldest rocks were among the earliest created—still less that they were alone on the earth.

The student will perhaps ask whether he is therefore called on to believe that there was no beginning, and that the whole history of the world runs in an endless circle. No idea can be more opposed to sound philosophy, or more offensive to the instincts of a thinking and rational mind. Without in any way bringing religion into the question, it is clear to any one who considers for a moment that the question at issue is one of fact. The fact is that every rock we can examine may have been—and we assume, therefore, that it probably was—formed out of the fragments of other rocks, which must of course be of still older date. These have been altered, and in some cases melted, and have been so thoroughly changed, by heat and chemical forces, that all mark of fossil contents is lost. But this is the case with the newer as well as the older altered rocks, and all granites and porphyries, as well as lavas and basalts, are of the same general character. There are, therefore, no special kinds of rocks necessarily previous in date to other kinds. Thus, while we accept, in its fullest sense, the statement that "in the beginning God created the heavens and the earth," we do not accept the supposition that we can find in the records of creation presented to us by examining the rocks and fossils, either the original rock or the first created form of life.

All that can be certainly learnt by the study of rocks is the order of succession in different parts of the world, so far as the evidence will enable us to trace it. We do this first by following out in the same country the sequence or succession of all the rocks there presented; secondly, by identifying in different and distant countries some well marked and characteristic rocks; and, lastly, by connecting in this way all that we can learn of all rocks throughout the world, and comparing the results. In doing this fossils are of the greatest use, as serving to identify certain rocks in distant countries, and thus making out what are technically called "geological horizons."

The elevation and subsidence of rocks has taken place in various ways. Large tracts of thousands of square miles in extent have sometimes been so slowly and evenly upheaved or depressed as to suffer little apparent change. The rocks originally deposited in a position nearly horizontal, are as nearly horizontal after movement as before, and nothing but the fact that what was formed under water is now above water, would suggest that a great change of level has taken place. But this kind of elevation, examples of which are common enough on a large scale in Northern Europe, Northern Asia, and the great plains of South America—probably also in Africa and Australia—is by no means universal. Besides, and connected with the plains, we have also the mountain chains. Here we find the strata thrown up, often at a high angle, broken asunder in various places, lifted up on one side of a fracture or depressed on another, and exhibiting inclinations very different in amount, sometimes opposite in direction, within very small areas. Often we find, breaking out between elevated strata, or laid bare by the removal of parts of strata, those rocks of igneous origin already described as basalt or granite. These also have sometimes influenced the strata and caused them to assume an altered form. Where great change of position and inclination has been produced, it is sometimes not easy, by merely following the rocks, to identify them. Where this is the case, and the surface is masked and covered up by soil, gravel, or other superficial accumulations, the difficulty is still greater. Thus it becomes necessary to study the mechanical position of rocks, with a view to learn the history of their succession.

The simplest evidence of disturbance of rocks is seen when strata or beds, of whatever material, that must, from the nature of things, have been deposited nearly horizontally on a level sea bottom, are shown at an angle of 20°, 30°, or even 45°, or more, these angles being far beyond those at which any accumulation of material will stand in the air or in water. The rocks in such case are said to *dip*, a term in common use among geologists, and one whose meaning must be learnt. Any plane surface, as a child's slate, if held parallel to the ground, is said to be horizontal. It cannot be said to lie in any particular direction, and has no dip. But if this slate be tilted it at once has a direction and a dip. The direction is that of any horizontal line drawn on its surface, and the dip is the angle which a line at right angles to this makes with the horizon. The same is the case with inclined strata. The direction of any horizontal line in them is the direction of the strata, and is called the *strike* (German: *streichen*, to extend), or extension of the stratum in length. This is easily found, where the strata are exposed, by the assistance of a spirit level; or, if this is not at hand, the eye will serve as a good indicator if a straight stick be laid on the bed and turned about. The direction of a line at right angles to this is that of the dip. It may easily be determined, if the bed is laid bare, by pouring water on it, and noting the point of the compass to which it flows. The amount of dip is measured by a graduated arc, and a simple instrument is easily procured or made which will answer the purpose. Such an instrument is called a *clinometer*. In order that a deposit may be examined, it must come to the surface, and it generally does so, covering or being covered by some other rock. Its first appearance is called its *outcrop*. (*See d*, fig. 11, p. 61.)

The determination of the dip and strike of the strata seen at the surface is the first and simplest geological observation in the field that can be made. It is one which every student should immediately endeavour to make for himself, for until this is done, there is no real understanding of geological phenomena. A series of observations of this kind, each result being marked down on a tolerable map, will give a general idea of the way in which the strata lie, near the surface of a country, and will be the foundation of a geological map. The strike, or bearing of the beds, where they are seen near the surface, being made out, the next object should be to draw on the map, as correctly as possible, a line connecting the various points where any particular rock ends. Such lines being drawn for two or more strata, other lines may be drawn at right angles to them. Lines of this kind indicating the direction of dip by an arrow, and the number of degrees of dip by a small figure, will enable the observer to prepare what is called a geological section, and in this way to obtain an idea of the relative position, and, in some measure, the actual total thickness of the deposits. This is not, in many cases, nearly so great as the apparent thickness, made by rough observations in the field, would seem to show ; because beds are often repeated, and the thickness increased in appearance by the tilting and breaking of the beds. The student must learn the principles on which many of the most important geological inferences are derived. Among these must be reckoned an estimate of the thickness of those beds that can be seen and measured only at the surface, and of which there are no means of obtaining an actual measurement, by sinking or boring through them.

It is only in the case of tilted beds that we can expect to see any connected series, or obtain the thickness by ordinary observations at the surface ;

but in point of fact, beds are so generally tilted, that the condition of absolute horizontality is altogether exceptional, especially in a country like England, at the extremity of a great continent. Generally speaking, the extremities of land, and land in the direction of mountain chains, not far from the mountains, exhibit beds considerably tilted; the beds in intermediate plains parallel to the mountains, and at a considerable distance from them, are often flat. But this flatness is only approximate, for it is seldom that the strata show a large extent of surface so level that water will not more readily run in one direction than any other. A slope so small that it cannot be noticed by the eye is yet quite sufficient to enable us to measure thicknesses. An incline of one in forty is of this kind; but if we have to traverse scores of miles of country, with rocks of the same dip, this is sufficient to indicate miles of thickness. A sensible slope is often seen in a quarry, but such a slope affecting a breadth of ten or twenty miles of country would involve a vast thickness of strata. Practically, we find that the slope is very seldom uniform for considerable distances. It is constantly changing—now in amount, now in direction; not unfrequently the direction is reversed. Thus, the measurement of thickness is a matter of great nicety, as a single neglect of change of direction might increase the apparent thickness enormously. The error in estimating thickness is almost always in excess; but still, making all allowances, there is no doubt that we have to deal with tens of thousands of feet, in calculating the whole thickness of various deposits open to examination in our own and other countries.

The general appearance of tilted rocks in a railway cutting, a sea cliff, or a quarry, must be familiar to every one who has made use of his eyes, in travelling through any part of England. But the special peculiarities arising from what may be called accidents in elevation or depression, are not perhaps quite so easily recognized. One of these is the production of fractures during movement, by which the broken beds have been lifted up or depressed more on one side of the crack or fissure than on the other. Such

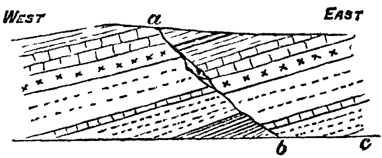


FIG. 10.—Fault.

a condition is called by geologists a *fault* (fig. 10). When faults or fissures are wide cracks, they are sometimes filled up with other rocks. If this is lava, modern or ancient, a *dyke* or wall is formed (*see d*, fig. 12). If the fissure is filled up with crystalline rock or spar, it is called a *vein* (*see a*, *b*, fig. 10). If there are stones rich in metals, these stones are called *ore*, and the vein is a "metalliferous vein," or *lode*. All these terms are in common use in geology. It is an important guide in tracing and identifying rocks on opposite sides of a fault, to know that when the angle which the strata make with the direction of a fault is greater than a right angle, the beds are lifted or *heaved* on the other side of the fault, and must be looked for accordingly.* When the angle is less than a right angle, the strata must

* In fig. 10, the rocks on the left hand are seen displaced by a fault, marked *a*, *b*, which may also represent a vein. The direction (underlie, or hade) of the fault being east, the rocks are thrown up to the west.

be looked for at a lower level, being thrown down by the disturbance. The direction of a fault is called, in mining language, its *hade* or *underlie*. Faults are sometimes called *slips* or *throws*, these being local and mining terms. The student should be aware that these movements of strata, accompanied by fracture and displacement, are of all possible magnitudes. Some of them do not displace the beds more than an inch, or a few inches; others amount to a thousand yards. Neither are all parts of the same fault movements to the same extent. On the contrary, a very great fault at one place will tail off, and be gradually smaller and smaller, until it ceases altogether. These matters depend on the nature of the elevatory movement.

The larger movements that take place in rocks seem to have been caused generally by elastic forces, like steam, acting from below and thrusting upwards—acting sometimes at a point, sometimes along a line, and sometimes pretty equally over a very large space. Such forces have acted sometimes suddenly and with great violence, producing an explosion, and terminating in the escape of the gases and steam, with large quantities of melted rock, such as we are familiar with in volcanic districts; but often they have acted slowly, and generally very slowly, thrusting up large spaces at the rate of a few inches only in a century. These slow upheavals, on a gigantic scale, acting along a line whose length is nearly half the circumference of the globe, and continued sometimes steadily, sometimes spasmodically, have been the causes of the elevation of the great mountain axes of the Old and New World. Their result is seen in many ways, and they explain several conditions, to describe which it is found necessary to employ new terms. The most simple of these is called an *anticlinal* or *synclinal* axis. An anticlinal axis (*a*, fig. 11)

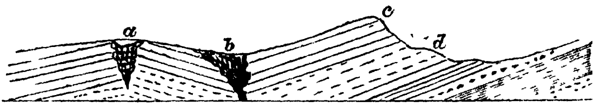


FIG. 11.—ANTICLINAL AND SYNCLINAL AXES.
a. Anticlinal, or saddle. *b*. Synclinal, or trough. *c*. Scarped cliff. *d*. Beds cropping out.

is the disposition of strata in opposite directions from a ridge. The position is that of the slates on the roof of a house. The term *saddle* is used instead of anticlinal. A synclinal axis (*b*, fig. 11), or *trough*, is the reverse. In this the beds dip down towards a line instead of from a line. In the former they diverge, in this they converge. Both are common in hilly countries, but in mountains the summit line of a mountain chain is more often a synclinal than an anticlinal. This results from the wearing away of the rocks after elevation. Rocks elevated into an anticlinal can hardly fail to be broken, and, being broken, are easily washed away. The highest ridges of mountain chains are thus not unfrequently connected with synclinals, or troughs; and as great mountain chains are usually compound, consisting of several parallel chains, it is often possible to trace, very distinctly, the marks of removals of large portions, showing in what way the existing condition of the range has been produced.

In the natural and regular order of succession, beds must be deposited nearly parallel to one another; but it is by no means to be supposed that deposits proceed without interruption during very long periods of geological time. Much more frequently the deposits continue for a certain time in regular order in the same spot, and are then stopped, either because they have attained the level due to the cause that produces them, or because some diversion has taken place in the current that supplies the material. A long pause may then occur, during which the beds already deposited are consolidated and subjected to movements of upheaval or depression. A part, perhaps a large part, may be pared off, and help to supply newer deposits at a great distance. At length, circumstances are again favourable for deposit, and new strata are thrown down upon the surface thus altered. The result, generally, must be that the new strata are not parallel to the old, and this important fact is expressed in geological language as a case of *unconformable stratification* (*see* fig. 2, p. 5). This phenomenon is exceedingly common, and may be repeated more than once in the same section. It must always be suspected when the fossils of the lower and overlying beds do not agree.

The washing away of parts of strata already deposited by the weather, by rivers, or by the sea, is a process that has always been carried on, and that belongs to the ordinary course of nature. It is called *denudation*, or laying bare (Latin: *de*, and; *nudus*, bare) (*see a*, *c*, fig. 12). Most rocks show marks of it, and many have been so far acted upon that little of them remains. When, from a series of beds, once continuous, some parts have been removed, leaving detached fragments behind, these fragments are called *outliers* (*see b*, fig. 12). When on the other hand

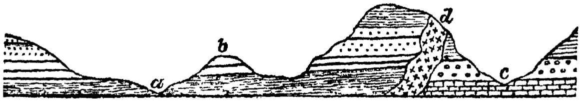


FIG. 12.

a. Denudation. *b*. Outlier. *c*. Inlier. *d*. Dyke.

the effect of denudation has been to expose underlying rocks within an area that has once been covered by newer deposits, the exposed part is called an *inlier* (*see a, c*, fig. 12). These expressions are both in common use in geological works. Denudation may be either *aqueous* — performed entirely by and under water—or it may be *aerial*—carried on, that is, under the influence of rain and exposure to wind and frost in the open air. Both are very influential, the latter much more so, perhaps, than is generally believed. Enormous quantities of material are removed from high and exposed land, and sea and river cliffs—in cold countries and during winter by the agency of frost and rain; in warm countries by heat and rain. Both frost and fire act in something of the same way, splitting rocks by their expansive power, and thus helping the rain which, when it falls, soon causes the removal of the rock that has been loosened.

There are many complications of all the causes that disturb rocks, and some of these are not uncommon and not unimportant. But in a notice of geology such as we here give, it is not desirable to puzzle the student with minute or difficult questions, some of which require a considerable knowledge of mechanics to understand them. It is sufficient that he understand the nature of upheaval and depression, and some of their almost invariable consequences. He must early and thoroughly learn what is meant by "dip" and "strike," by "faults," by "anticlinal" and "synclinal" axes, and by "unconformable stratification." The rest will come afterwards, and will be sure to attract attention when he goes into the field on his own account.*

Besides the results of upheaval and subsidence, as shown already, some very similar appearances are caused in certain brittle rocks, by the contraction that takes place when material accumulated with water parts with a large portion of this water as it consolidates into a rock. This contraction produces numberless small cracks, and some large ones. It even causes small heaves, and sometimes, where hollows are left, there may be depressions. The elevation that must follow the consolidation before the rocks become visible at the surface, naturally tends to affect all these cracks. Some it widens, some it closes, some it fills with crushed rock.

The effect of elevation is very different on brittle rocks, such as completely formed limestones, altered marbles, hard grits and sandstones and granites, and on soft rocks, such as unformed limestones, and marls, clays, and soft sands. What is broken in the former, is squeezed in the latter. When also the

* Among other text-books of Geology, the reader may refer to the "Elementary Course of Geology, Mineralogy," &c., by Prof. Ansted. 2nd edition, re-issue, 1869. He will there find the subject of the present chapter explained at greater length.

elevation is prevented from producing its full effect, owing to various parts being tied down by the pressure of mountains, contortion or twisting is not uncommon. The rise being interfered with by tight squeezing on one or more sides, the softer rocks are very much twisted, and are so far altered in texture that pure clays thus become slates, and gritty clays, clays and small stones, or clays mixed with sand, become converted into schist. The results are mechanical, and are due to pressure; but such rocks, when elevated thus, split in directions parallel to the plane of elevation, not parallel to the bedding, as they would do in any other case.

The rocks that belong to any particular country, as England, cannot be expected to afford examples of the whole series of rocks belonging to all time and distributed in all lands. It has, however, been mentioned already, that our island includes a large and useful series, including many groups highly characteristic, and indications of many others elsewhere more completely developed. And the various rocks are to a great extent illustrated by their respective fossils. Thus to a certain extent English or British geology is a type to English geologists, and there are few, if any, parts of the world where there is so much useful variety in so small a space. It is also remarkable, with regard to England and British geology, that there is in most cases a nearly average extent of the various formations. Of course some are wanting, and some badly, or very slightly, represented; but, on the whole, the student of British geology has great advantages over his continental neighbours. In teaching geology in England, the attention of the student may with advantage be directed chiefly to such English examples as are likely to be familiar.

To render more easy the reference to the various deposits, it is necessary that they should be collected into groups, each group being marked in some definite and convenient manner. The fossils belonging to it, and in some sense peculiar to it, are universally regarded as the most useful and trustworthy of such means, for a natural group of strata is always recognizable by a definite group of organic remains. This does not mean that there are none but special and distinct species, though each group of strata almost always presents some species found nowhere else; but it rather refers to the general aspect of the group, taken in connection with the inference derived from the study of it in a large sense, in reference to the circumstances of deposit. The characteristic appearance of the fossils is called technically its *facies*, and the group of species is the *fauna* or *flora*, or both, of the time when the strata were deposited. These terms, derived from the Latin, are of common use in Palæontology (*facies*, aspect; *fauna*, the gods of the field and of animals; *flora*, the goddess of flowers). We shall see, in subsequent chapters, something of their meaning and value; but at present the student must accept the statement of the fact.

The number of groups of strata possessing a fauna, and, where the deposits have taken place near land, a flora as well as fauna, is large, even in England. Each one is also in most cases a series of considerable magnitude and economic importance. To give the student some idea of their nature, we may instance the chalk as one very large series of strata of nearly the same mineral composition throughout. The chalk is several hundred feet thick, and was probably formed in the same way from bottom to top. It has certain fossils, very abundant, which may be regarded as those belonging to the special conditions and time of the deposit at the bottom of a deep sea. Besides these are others indicating the general inhabitants of the whole sea at the time. These are in moderate abundance, but are not universal. There are others that point, though rather vaguely, to the land of the period. These are very few and rare. When we compare its fossils with those found in strata below and above, we find a few common to the chalk and beds below, but the greater proportion not so. The *facies*, however, is not dissimilar. Hardly any are common, however, to the chalk and the deposits above it, and the *facies* are totally dissimilar. The strata are sometimes conformable to the underlying deposits, but more often unconformable. The lower beds in some places seem to have lost part of their substance by denudation before the upper were superimposed. This is especially the case when there is a marked difference in the nature of the organic contents.

Judging from indications of this kind, it is inferred that, so far as England and Western Europe are concerned, there is a very broad line of separation between the chalk and the beds lying over it, and a line well marked in some respects, but by no means strongly marked, between the chalk and the beds below. The former is an example of a very wide separation—the widest, indeed, known; the latter of a very small separation, often completely bridged over. The one is a case in which the interval that elapsed must have been exceedingly great, and the conditions of deposit altogether different. In the latter, the deposits may have been continuous, but the conditions had changed.

Of great divisions, such as that between the chalk and the beds that overlie it, there is only one other known. The whole series of rocks is thus divided into three main groups. Of smaller divisions the number is very large, and these again are collected into other groups.

For the sake of convenience, and not as involving any theory, the three principal groups of rocks are generally denominated respectively PALÆOZOIC (Greek: *palæos*, old; *zoe*, life), or older; MESOZOIC (Greek: *mesos*, middle; *zoe*, life), or middle; and CÆNOZOIC (Greek: *cænos*, recent; *zoe*, life), or later periods. The *Mesozoic* period was formerly and still is called by most geologists "Secondary," and the *Cænozoic* "Tertiary." The Palæozoic rocks were once called *Primary*, but this expression has very properly been abandoned by most geologists. In old geological books the word *Transition* is also applied to them. The middle and newer series together are sometimes called NEOZOIC (Greek: *neos*, new; *zoe*, an animal).

It is difficult to draw very exactly the line that separates the various subdivisions. Some of the most important among them are called series, but the principal groups of the various strata are generally marked by distinctive names derived from some peculiarity or some place where they are well seen. All the divisions are more or less arbitrary, and must be regarded as more mechanical than real. They often indicate the lapse of time, whether really proved or presumed. They almost always indicate change in the conditions of deposit, which in many instances must have affected very large areas.

The following skeleton list of series, formations, periods, or by whatever name the various groups are described, will be found useful for reference, and will help to accustom the reader and student to names, many of them unfamiliar. They are arranged in order of superposition, the oldest and lowest being at the bottom, and the newer (those higher in the series) in regular order above them. The rocks quoted refer in all cases where it is possible to recognized and familiar representatives.

ARRANGEMENT OF BRITISH STRATA.

(1.) Recent, Pleistocene, or Quaternary Deposits.

TERTIARY OR CÆNOZOIC PERIOD.

(2.) Pliocene series, or Newer Tertiary.
- Newer.—Older drift and Boulder clay.
- Older.—Crag (Upper and Lower).

(3.) Eocene or Nummulitic series. Older Tertiary.
- Upper.—Leaf beds (*Miocene*). Isle of Wight beds.
- Middle.—Bagshot beds.
- Lower.—London clay, and Bognor beds, and Thanet sands.

SECONDARY OR MESOZOIC PERIOD.

(4.) Upper Cretaceous series.
- Upper.—Chalk and Chalk marl.
- Middle.—Upper green sand.
- Lower.—Gault.

(5.) Lower Cretaceous or Neocomian series.
- Upper.—Lower green sand.
- Middle.—Weald clay and Hastings sand.
- Lower.—Purbeck beds.

(6.) Oolitic or Jurassic series.
- Upper.—Portland rocks and Kimmeridge clay.
- Middle.—Calc grit, Coral rag, Oxford clay, and Kelloway rock.
- Lower.—Cornbrash, Bradford clay, Bath oolite, Stonesfield slate, Yorkshire oolitic coal, Brora oolitic coal, Inferior oolite.

(7.) Liassic series.
Upper.—Shale and clay.
Middle.—Marlstone.
Lower.—Clays and limestone.

(8.) Rhætic series.
Upper.—White lias.
Middle—Bone beds.
Lower.—Marls.

(9.) Triassic series.
Upper.—Keuper and Dolomitic conglomerate. Salt-bearing marls of Cheshire.
Middle.—(*Muschelkalk*, absent).
Lower.—Bunter sandstone and conglomerate.

PALÆOZOIC PERIOD.

(10.) Permian series.
Upper.—Red marls and magnesian limestone.
Middle.—Marl slate, copper slate.
Lower.—Red sandstone and conglomerate.

(11.) Carboniferous series.
Upper.—Coal measures.
Middle.—Millstone grit.
Lower.—Carboniferous limestone.

(12.) Devonian or Old Red Sandstone series.
Upper.—Yellow, white, and red sandstones. Marwood and Petherwyn beds.
Middle.—Green and red shales. Caithness flags.
Lower.—Red shales and conglomerates.

(13.) Silurian series.
Upper.—Tilestones. Ludlow series. Wenlock series. May Hill sandstone.
Lower.—Caradoc series. Llandeilo series. Tremadoc slates. Lingulella flags.

(14.) Cambrian series.
Upper.—Harlech grits.
Lower.—Llanberis slates.

(15.) Laurentian series.
Upper.—Cape Wrath gneiss.
Lower.—

The Laurentian rocks are apparently made up of fragments of still older sedimentary rocks, greatly changed by the action of time, and by exposure for a long period to high temperature and enormous pressure in the interior of the earth. They pass downwards into gneiss, clay-slate, mica-schist, and granitic and porphyritic rocks of unknown age, but generally metamorphic.

Of the actual time, as measured by years, that has been required for the accumulation of the vast mass of deposits referred to in the above list, it must always be impossible to form any accurate estimate. Even a small part of any one amongst them, when we examine closely into its history, appears to have required so long a time that the imagination is fatigued in endeavouring to realize it; and when an attempt is made, as has been done sometimes, to assign a limit within which the work might have been completed, the result is unsatisfactory, owing to the absence of important elements required for the calculation. If we take only one example and endeavour to estimate the time-interval between the historic period and the date of deposit of those rocks which were accumulated while Northern Europe was occupied by the reindeer, the hairy elephant, the gigantic Irish deer, the rhinoceros, &c., we soon find that the difficulties in the way of any accurate measurement of years can hardly be overcome, although the period is so recent. Much more is this the case with the older rocks.

CHAPTER V.

OLDER PALÆOZOIC ROCKS AND FOSSILS.

THE oldest known rocks—those lowest in geological position among the long series of rocks in different parts of the world—are called *Palæozoic*, as containing the oldest known fossils, or the remains of the earliest forms of life of which we possess evidence.

From time to time, as observation continues and investigations are carried on more and more minutely, discoveries are made of fossils under circumstances up to that time totally unexpected, and in rocks at one time supposed to be entirely without such remains. No rocks could seem more unpromising or more hopelessly barren than the complicated schists and gneiss, greatly altered and contorted, found at Cape Wrath, in Scotland, and developed on a large scale in Canada. Yet even some of these have yielded proof of life, entangled among strata which have since been converted almost entirely into marbles and serpentines. The oldest stratified rocks, and those most changed, were formed not only after life had been introduced on the earth, but when there existed a sea containing calcareous material capable of supplying the inhabitants of the deep with shelly matter. Other older rocks had probably preceded these, provided, it may be, with other fossils; but our history carries us no farther back than this either with regard to fossils or rocks. The deepest and oldest rocks are the most changed, and in granite and porphyries we fail to discover any indication of mechanical deposit or of organic existence.

LAURENTIAN SERIES.

The palæozoic rocks, or rocks containing the remains of the older forms of life, are collected into many groups, of which the lowest and most ancient is best seen on the banks of the river St. Lawrence, in Canada. It is also represented in Scotland. The series in Scotland consists chiefly of gneiss, and the rocks are believed to belong to the upper part of the series. The lower members in Canada include several stages of gneiss with interstratified limestone. In Bavaria there are rocks of the same age. The estimated thickness of Laurentian rocks in Canada is 30,000 feet.

At present only one species of fossil has been detected in these greatly altered rocks. It is called *Eozoon* (Greek: *eos*, dawn; *zoon*, life), exhibiting what is assumed as the dawn of life on the globe—an unfortunate name, involving a theory which has little foundation. A future discovery in yet older rocks will render it inapplicable, as are so many names that have been given under the same assumption that the earliest discovered species, at any given period of discovery, is the first created species of animal or plant.

The Eozoon, as now known, belonged to the natural group of Rhizopoda, of which the simple forms of life now abundant at the bottom of deep water, yield innumerable examples. It secreted chambers connected by small orifices, and belonged, therefore, to the Foraminifera. It probably attained a large size by simple multiplication of the cells.

CAMBRIAN SERIES.

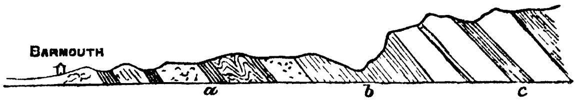


FIG. 13.—SECTION ACROSS THE LOWER SILURIAN AND CAMBRIAN ROCKS OF NORTH WALES.

a. Cambrian rocks. *b*. Lingula flags. *c*. Llandeilo and Caradoc beds.

Very extensive deposits, comprising in the lower part 3,000 feet of poor slates, well shown at Llanberis (N. Wales), and there covered with gritstones which in some places (in the Longmynd in Shropshire) swell out to a thickness of 20,000 feet, form the base of fossiliferous deposits in Wales and Shropshire, and are older than the oldest fossiliferous rocks, except Laurentian, in other parts of Great Britain. Being originally described by Professor Sedgwick from these Welsh localities, they have been called "Cambrian rocks" (*Cambria*, Wales), and form a distinct series. Over the Llanberis slates are the *Harlech grits*, generally consisting of about 6,000 feet of gritstones and poor flags. The position of these rocks is seen in fig. 13.[1] The lower members of the Cambrian series at the Longmynd are schists, sandstones, and pebbly beds, very poor in fossils, but with occasional bands of anthracite or stone coal, and occasional exudations of bitumen. They are associated with grits of volcanic origin, interstratified with them. They contain marks of worms, fragments of a kind of Trilobite, and markings, apparently of sea-weeds. Their bitumen is probably of organic origin. In rocks of the same age in Ireland (S. and S.E. of Dublin) are remains of a Zoophyte allied to Sertularia, a modern genus of Hydrozoa. The *Alum schists* of Sweden, and the *Huronian sandstones* of North America, are representatives of the Cambrian series.

The Cambrian fossils, though very rare, and poor in number of species discovered, are sufficiently varied to prove that the cause of their rarity could hardly be that there were few examples of living species in the ancient seas. The Trilobites and worm casts show that the class of animals was by no means limited to those of simplest organization. Some recent observations in Sweden seem to show that there existed at this period land plants allied to the grasses and rushes of the present day.

CHARACTERISTIC FOSSILS.—Fucoids. Impressions and burrows of worms (Annelides) called *Arenicolites didyma*, found on sands with ripple marks. Zoophytes or Corallines (perhaps Sertularia) called *Oldhamia*. Crustaceans of the Trilobite tribe called *Paleopyge Ramsayi*.

SILURIAN SERIES.

The rocks of this series form a singular contrast to the rocks below them, as being on the whole eminently fossiliferous, while the Cambrian and Laurentian series have proved hitherto exceedingly poor in fossils. Unlike the Laurentian, the Silurian series, though exceedingly well developed in many other parts of the northern hemisphere, is nowhere more interesting than within the British Islands, where it was first examined by Sir R. Murchison, and whence its name is derived. (*Silures*, an ancient tribe inhabiting the country where these rocks occur.) In Wales and Shropshire and the adjoining counties there are two very well marked divisions of this great series, both admirably illustrated by fossils. Similar divisions are recognized elsewhere. The following statement of the arrangement of the rocks will be useful to the English student, and is even available as a type series elsewhere. The divisions and thicknesses given are according to the development of the series in England.

			Thickness.
Upper	Ludlow	Ledbury shales or Tilestones	300 feet
		Upper Ludlow rocks	900 ,,
		Aymestry limestone	150 ,,
		Lower Ludlow rocks	900 ,,
	Wenlock	Wenlock and Dudley limestone	150 ,,
		Wenlock shale and Denbighshire grits	1400 ,,
		Woolhope and Barr limestone	50 ,,
		Tarannon shale and May Hill sandstone	1400 ,,
Lower		Llandovery bed (lower)	1000 ,,
		Caradoc and Bala beds	7000 ,,
		Llandeilo beds and Tremadoc slates...	7000 ,,
		Lingula (Lingulella) flags	5000 ,,

Marked physical features generally have some reference to the geological structure of every country, and thus, although there is no lofty chain of jagged mountain tops, nor group of hills of strange shape rising suddenly out of a plain, there exists, in the border country between England and Wales, a singular and striking ridge, terminated with projecting masses of hard rock, called the Stiper stones, which are landmarks for Silurian geology as well as for the geography of England. "Wending in a broken mural line from N.N.E. to S.S.W., these stony masses appear to the artist like insulated Cyclopean ruins, jutting out upon a lofty moorland ridge, at heights varying from 1,500 to 1,600 feet above the sea. On reaching the summit of this barren height, the traveller sees below him, to the west, a rapid slope, and beyond it a picturesque hilly tract, the strata of which are laden with Lower Silurian fossils, and diversified by rocks of igneous origin."* These stones are the remains of siliceous sandstones, resting on dark-coloured schists, which occupy the valley and hill country to the west, and are the lowest strata of the Silurian series. They are called *Lingula* (or rather *Lingulella*) *flags*, for a reason that will be given presently. They are light grey schists and shales, in which a small fossil shell, of a horny, rather than calcareous substance, shaped like a tongue (Latin: *lingua*), is very abundant. It is an interesting fact that this shell is so closely allied to a still existing genus of shells (*Lingula*) that it has only doubtfully, and for convenience, been separated from it under the name *Lingulella* (*see* fig. 14, No. 2). Besides this shell, marks of worms and remains of crustaceans, not unlike a shrimp, are common. The former indicate animals of large size. Fucoids, or sea-weeds, have also left their mark in these beds, especially in foreign beds. The fossils, in various places, abound to such an extent that millions might be obtained within a small space, and from the variety already named, and the complex organization of many of them, there is no doubt that the general conditions of life were fully established, at the time of the deposit of the oldest

* *Murchison's Siluria*, 4th ed., p. 37.

Silurian rocks, pretty much as they now are. The same grouping of animals is observed in rocks of this age in America, Scandinavia, Belgium, Spain, and Bohemia, as that already traced in England and Wales.

The Stiper stones belong to what is called the *Llandeilo formation.* It is an important series, well marked by peculiar fossils, called *Trilobites* (*see* fig. 7, p. 43; fig. 14, No. 1; and fig. 15, p. 80), and also by *Graptolites* (*see* fig. 14, Nos. 5, 6), both of which

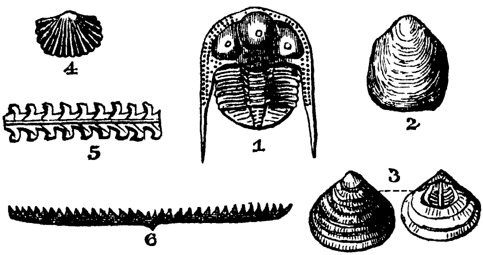


FIG. 14.—GROUP OF LOWER SILURIAN FOSSILS.

1. Trinucleus seticornis. 2. Lingulella Davisii. 3. Obolella plumbea. 4. Orthis calligramma. 5. Diplograpsus nodosus. 6. Didymograpsus geminus.

belong chiefly to the Silurian strata, and are represented by many curious varieties of form and structure. It is also important as containing lead ore in the fissures or veins. The rocks vary, but grits and flagstones, passing into shales, prevail. In certain places are large quantities of volcanic ash, accumulated during the eruption of the volcanoes of this very ancient period. The ashes are called volcanic grit, and sometimes resemble green slates. Basalt, the lava of the ancient volcanoes, is not wanting. Some of the flagstones (black trilobite flags) contain so many trilobite remains as to be black with the organic matter of the animals. Other beds are called *graptolite schists*, owing to the extreme abundance of graptolites in them. Some of the flags are calcareous. The *Skiddaw slates* in Cumberland, which also contain much interstratified igneous matter, and have a thickness of 7,000 feet, are of the age of the Llandeilo flags.

Attention has been directed to the abundance of graptolites and trilobites in the lower beds of the Lower Silurian series. The fossils thus named are particularly valuable to the working geologist, inasmuch as they are well marked, easily recognized, and for the most part certain species are limited to particular geological horizons. Graptolites (species of the genus *Graptolithus* and allied genera) represent certain modern zoophytes, common enough on shores, and called by naturalists *Sertularia.* Some of the forms they present are shown in fig. 14, Nos. 5, 6. They are generally limited to deposits of a muddy nature, and they may have inhabited deep water. They have a jagged appearance, sometimes on one side, sometimes on both sides. They are often branched, sometimes rounded, and sometimes angular.

Trilobites are so named from the division of the body into three parts, or lobes. They are not known in any rocks newer than Palæozoic, and certain forms are peculiar to particular groups of rocks. The lowest Silurian rocks contain species in which the plate covering the head has long appendages on each side, but there are indications of many great varieties of form among the earliest species. The size of the species found in the Silurian rocks is not very large, but many of them, such as the *Paradoxides* (fig. 15), and some species of *Asaphus*, attained fair dimensions.

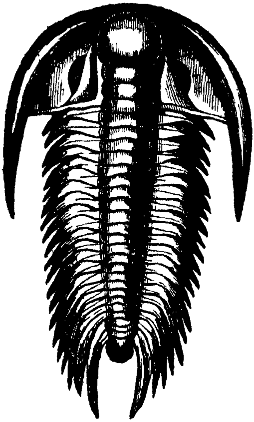


FIG 15.—Paradoxides.

The shelly sandstones of Caer Caradoc, in South Wales, exposed in a thickness of several thousand feet on the slopes of the igneous and altered rocks that make up that range, have long been known under the name of *Caradoc sandstone*, and may be regarded as forming the upper member of the Lower Silurian series. They are represented in North Wales by the *Bala beds* situated on the flanks of Snowdon. These are not very thick, owing to the absence of the igneous rocks; but they are equally well developed so far as fossils are concerned. Among the deposits of the Caradoc and Bala series are impure limestones, good enough for burning, and many of the sandstones are sufficiently soft to be used as freestones.

The beds of the Caradoc formation reappear in Cornwall and on the other side of the channel in Brittany. They are also found in the north of England, overlying the Skiddaw slates, and are there rich in fossils; and in Scotland they are exhibited as calcareous sandstones, with shales, mudstones, conglomerates, and limestones. In Ireland they are recognized in County Fermanagh. Scandinavia and

Russia both contain rocks of this age. The *Utica slates* and *Hudson River group* of North America are also equivalents.

Many Zoophytes and Polyzoa occur in Caradoc beds, and are accompanied by a variety of radiated animals, including peculiar forms of Encrinites. Among them are curious globular species, whose body was coated with plates of solid stone (*Cystideans*) and some true star-fishes. There are many shells, of which some species of *Orthis* and some of *Strophomena* (fig. 16) are highly characteristic. Both these genera were largely developed during this period, although they extend upwards into the Upper Silurian rocks. Some of the forms are very peculiar, but in a general sense they represent the Terebratulas of existing seas.

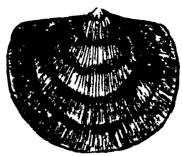


FIG. 16.—Strophomena.

There are Silurian species of bivalve and univalve shells, some allied to well-known living species, and others connecting the oldest with the newer rocks. Forms of *Orthoceras*, a straight chambered shell of which the inhabitant probably resembled the Nautilus, are not uncommon.

CHARACTERISTIC AND REMARKABLE LOWER SILURIAN FOSSILS.—(1) Sponges—*Protospongia* is common. (2) The double graptolites (*Didymograpsus* and *Diplograpsus*) are Llandeilo. (3) Polyzoa—Of these *Ptilodictya* (resembling *Eschara*) is chiefly Caradoc, and *Fenestella*, with some others, are both Caradoc and Wenlock, but chiefly the latter. There are several species. (4) Corals—Several genera and species. *Halysites*, *Heliolites*, *Favosites*, and *Petraia* are common. Among them the chain coral (*Halysites catenularius*) is found throughout, though chiefly in the upper rocks. *Favosites fibrosus* is common. *Petraia* is common throughout. (4) Radiata—The

Cystideæ are characteristic, and there are star-fishes very much resembling existing species. (6) Brachiopodous shells—Species of *Lingulella* and *Lingula* are characteristic of certain beds. Of *Orthis* there are many species peculiar and many common. The following are abundant:—*O. Actoniæ*, *O. calligramma* (fig. 14, No. 4), *O. striatula* (Llandeilo), and *O. vespertilio*, *O. flabellulum* (Caradoc). *Strophomena* is closely allied to Orthis and Leptæna, and very characteristic of Lower Silurian. *St. expansa*, *St. tenuistriata*, and *St. grandis* are universal. *St. depressa* (*Leptæna depressa*) is common, but extends upwards. The genus *Spirifera* (*S. plicatella*) first appears here. *Crania* and *Discina* are both Lower Silurian. (7) Ordinary bivalve shells—Several species in Caradoc beds, especially *Pterinea*, resembling the modern Avicula, and *Ctenodonta*, resembling Nucula. (8) Univalves—There are some extinct genera resembling Turritella and Trochus (*Murchisonia* and *Cyclonema*). *Bellerophon* (doubtfully placed) was a common shell, with characteristic species. (9) Pteropoda—*Conularia*, *Theca*, and *Pterotheca* are abundant. These animals were simply organized mollusca. (10) Cephalopoda or chambered shells—The straight and curved forms, *Orthoceras* (straight), *Cyrtoceras* (slightly curved), and *Lituites* (more curved, but with one end free), are Lower Silurian. (11) Annelides—There are indications of sea worms, both track marks and burrowing holes. *Tentaculites* and *Cornulites*, common Caradoc fossils, probably belonged to animals of this kind. (12) The most highly organized of the Lower Silurian fossils yet found belong to the Articulata. Of these, Trilobites of various genera are common and characteristic—*Olenus*, *Agnostus*, *Paradoxides* (Lingula Flags), *Asaphus* (*A. Tyrannus*) *Trinucleus* and *Ogygia* (Llandeilo), and *Trinucleus* (Caradoc).

Over the Caradoc beds, and forming a kind of passage bed into the Upper Silurians, are the *Pentamerus beds*, now called the *Llandovery rocks*. The Pentamerus (Greek: *penta*, five; *meros*, a part) is a bivalve shell divided into five chambers. It is particularly well developed in the Llandovery rocks, in which the Caradoc forms are mixed with shells only found elsewhere in Upper Silurian rocks. These Llandovery rocks contain also several shells of the Terebratula type, peculiar to them. The upper rocks are well seen at May Hill, about nine miles south of the Malvern Hills, and round the flanks of the Longmynd, in Shropshire. The *Coniston grits* of the Lake district are of the same age.

The Upper Silurian rocks form two well marked groups, the Wenlock and the Ludlow. Both are admirably developed in the typical Silurian district, and both are rich in fossils. Between the Llandovery rocks and the Upper Silurian, as usually recognized, are thick beds of pale shale and grit (*Tarannon shales* and *Denbigh grits*), poor in fossils, over which come shales containing bands of limestone. These are the *Wenlock shale* and *Woolhope* or *Lower Wenlock limestone*. Like some of the older Silurians, these are mixed deposits derived from volcanoes, alternating with the shales and limestones, and altering them. An exceedingly interesting geological section is represented in the valley of Woolhope (fig. 17), across

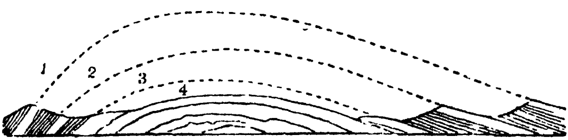


FIG. 17.—SECTION ACROSS THE VALLEY OF WOOLHOPE.

1. Upper Ludlow shale. 2. Aymestry limestone and Lower Ludlow. 3. Wenlock limestone and shale. 4. Upper Llandovery rock, covered with Lower Wenlock limestone and shale.

a dome-shaped elevation, resulting in what is called a "valley of elevation." The whole series of the Upper Silurian rocks may be recognized at the same time by an observer placed on a depressed hill at

Haugh Wood, a few miles east of Hereford. The beds wrap round the hill, and the upper rocks have been pared away by the action of the water.

Calcareous beds are very prevalent in the Upper Silurian rocks of England. The Upper Llandovery rocks are calcareous, and in the Wenlock shales above are bands of hard blue clayey limestone, some of them nearly ten feet thick, containing a peculiar species of Trilobite. Among the shales are the Lower Woolhope limestones, occasionally absent, and above the whole series the true *Wenlock limestone*—crystalline and pale—forming an ornamental marble rich in fossil corals and encrinites. It is quarried in many places. Much of it is concretionary, and abounds in nodules, called ballstones. These are crystalline and valuable, and occur among shales rich in fossils. Near Dudley, to the north, the limestone forms domes or rounded hills, and in a hill called the "Wren's Nest," the phenomena of Woolhope are repeated.

The Wenlock limestone is very rich in fossil corals, which are particularly beautiful and well preserved. Encrinites, shells, and trilobites also abound in it. One, the *Calymene Blumenbachii*, is especially abundant. It is called locally "the Dudley Locust," and has long been familiar to fossil collectors. Species of *Orthoceras* are also very abundant. Worm marks and tubes are common.

The Wenlock series of Silurian shales and limestones is covered at Ludlow by greyish shales and impure limestones, loaded with Trilobites, and rich in other fossils, among which are fragments of the shell of a very remarkable crustacean of the genus *Pterygotus* (Greek: *pteron*, a wing; *ous*, *otos*, an ear), resembling a lobster seven or eight feet in length (*see* fig. 18). There are also numerous star-fishes,

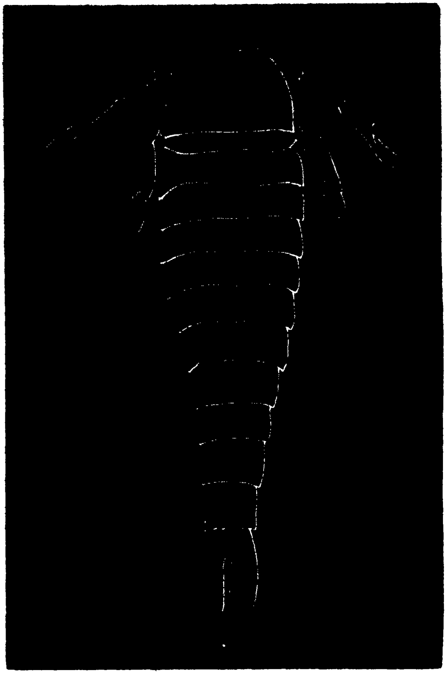


FIG. 18.—The Palæozoic King-Crab, or Pterygotus. (Restored outline).

closely resembling existing species, and remains of a fish of the genus *Pteraspis* (Greek: *pteron*, a wing; *aspis*, a shield), resembling modern Siluroid fish. Above these impure limestones are the solid dark grey limestones of Aymestry (*Aymestry*, or *Lower Ludlow limestone*), passing into or replaced by calcareous flagstones, also rich in shells and corals, among which a species of *Pentamerus* (*P. Knightii*), a bivalve shell, is highly characteristic. Then follows the *Upper Ludlow rock*, having at its base a shelly band of fossils, chiefly a kind of Terebratula (*Rhynchonella navicula*), and consisting chiefly of grey clayey limestones, called mudstones. Fossil shells abound in it, but corals are rare. Stems of Encrinites, looking like seaweed, large Orthoceratites, and some Trilobites and large Crustaceans, but, above all, abundant remains of fishes collected into a bed extending for some distance, and some remains of land plants, are the most interesting. The bed in which these remains are found is generally black, from the quantity of animal bitumen it contains.

The Upper Ludlow rock is occasionally covered by easily splitting flags, locally called Tilestones. These are passage beds connecting the Upper Silurian with the Lower Devonian strata. Their thickness is not more than forty or fifty feet. They appear to have been deposited in shallow water, probably in an estuary, land being near at hand.

The Upper Silurian rocks generally are represented in the Lake district by the "Windermere rocks," containing Lower Ludlow fossils, and in Scotland by hard schistose strata in the Pentland Hills, Lanarkshire and elsewhere, generally in a very contorted state. Magnificent specimens of the curious Crustacean *Pterygotus* (*see* fig. 18) have been obtained from Lanarkshire. In Ireland rocks of this age occur in the Dingle promontory. Scandinavia and Russia contain Upper Silurian deposits, and in North America there are numerous and important series of the same age.

The fossils of the Silurian series, in all parts of the northern hemisphere where they have been determined, indicate generally a marine origin, although towards the uppermost and newest parts there are land species. As a rule, the species and natural families are by no means remarkable for simplicity of organization. They are many of them high in the ranks to which they belong, and although fish remains are only found in the newest rocks, the kind of fish there found are by no means those that most nearly approach the lower class of invertebrate animals. Many are of strange and unfamiliar forms, many others so like existing species that they might almost be mistaken for them. Throughout the somewhat wide range of these rocks the fossils correspond closely enough to render it probable that uninterrupted sea extended where we now have the lands of the north temperate zone; but it does not follow that there may not have been at that time extensive lands with their inhabitants in other parts of the world, or that other seas may not have abounded with other fishes than those whose remains alone have as yet turned up. The evidences of adjacent land in the upper beds are distinct.

CHARACTERISTIC AND REMARKABLE UPPER SILURIAN FOSSILS.—(1) Sponges—*Stromatopora*, *Spongarium*, and *Tetiagonis*, all common. (2) Graptolites—The single forms, *G. priodon* especially, are very abundant in Wenlock shale and Lower Ludlow. (3) Polyzoa—There are few species; but fragments of *Ptilodictya* and *Fenestella* are very common. (4) True corals are much more abundant than in Lower Silurian. *Favosites* and *Heliolites* are very common. So are the chain-coral and *Syringopora* with the cup-shaped species (*Cyathophyllum*, &c.). (5) Radiata—Fragments of stems of Crinoids are very abundant (*Periechocrinus moniliformis* especially), and also of true star-fishes (*Palæaster*). (6) Brachiopoda — *Pentamerus* is characteristic of the lower or passage beds (Llandovery); *Strophomena* (*St. depressa*, *St. euglypha*, &c.), *Orthis* (*O. elegantula*), *Rhynchonella* (*R. borealis*, *R. navicula*), are the abundant genera and species. *Spirifera* (*Sp. exporrecta* and *Sp. sulcata*) are common in Lower Wenlock. (7) Bivalve shells—The genus *Pterinea* (Avicula) is rich in species, and common. Mytiloid shells (those resembling the common Mytilus or mussel) are very common. *Cardiola* (resembling Cardium, the cockle,) is most abundant (especially *C. interrupta*). Shells resembling Nucula and Arca seem to have been characteristic of the period. (8) Univalve shells—Of these *Euomphalus* and *Platyschisma* are the most important genera. Spiral shells are common. *Bellerophon* is common in Upper Ludlow. (9) Of the Cephalopoda, *Orthoceras* is the most important. (10) Crustacea—The Trilobites are the chief. *Calymene* (*C. Blumenbachii*) is the most abundant of all. *Phacops*, *Homalonotus*, and others, are common; but the variety of generic forms and species is much less than in the Lower Silurian. Small two-valved Crustaceans (*Beyrichia*) are very abundant. There is, also, a kind of shrimp (*Ceratiocaris*). The most remarkable genus is *Pterygotus*. Specimens are numerous and very varied. (11) Fishes—*Pteraspis*, *Onchus*, *Auchenaspis*, &c., were shagreen-skinned fishes, predaceous, but of small size. There were many others.

DEVONIAN SERIES, OR OLD RED SANDSTONE.

Overlying the Upper Silurian rocks in Herefordshire, and in the district generally where the Silurian rocks were first carefully observed, there is a great thickness of shales, sandstones, and conglomerates, containing occasionally calcareous concretions, but on the whole poor both in lime and in fossils. These cover a large extent of country, and rise into hills of considerable height. They have long been described as the "Old Red Sandstone." Followed northwards, the series becomes more of a conglomerate, and is exhibited in a somewhat lofty mountain chain in Caithness, N. B. It includes also in this part of Scotland some remarkable flagstones, rich in fossil fishes. The whole series yields occasionally sea-weeds, a few Crustaceans, a few shells, and many fishes, referred to nearly a hundred species, some of them of very singular forms, being coated with bony plates and scales, something in the manner of the sturgeon, but of very different forms and proportions. With these are unquestionable land plants, consisting of leaves, twigs, and trunks of coniferous trees.

Cornwall and Devon contain between certain rocks whose fossils prove them to be Silurian, and others clearly belonging to the Carboniferous series, which elsewhere overlies the Old Red Sandstone, a large and important series of shales, schists, and grits, inter-stratified with fossiliferous marbles and black lime-stones. These are now grouped into three divisions, as the "Devonian series;" and from their geological position they evidently represent the Old Red Sand-stone. They are in some parts rich in fossil remains, not corresponding, however, very closely with those of Herefordshire and Caithness, inasmuch as the former belong chiefly to shells and corals and the latter to fishes; but not without occasional specimens com-mon to both. Among the shells are many genera that have not yet been found in any Silurian rocks. There are also occasional remains of land plants.

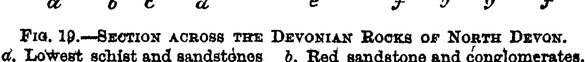


FIG. 19.—SECTION ACROSS THE DEVONIAN ROCKS OF NORTH DEVON.
a. Lowest schist and sandstones *b*. Red sandstone and conglomerates. *c*. Schist and Stringocephalus limestone *d*. Quartzose schists (Plymouth) *e*. Baggy sandstones. *f* Clymenia limestone and Mar-wood beds. *g*. Trough of culm on Posidonia limestone.

The annexed cut will show the way in which these beds arrange themselves in North Devon, where the order of the rocks and their position were first ascertained by Sir R. Murchison and Professor Sedgwick. The following is the series in Devonshire:—

Upper.—Marwood and Petherwyn beds.
Middle.—Plymouth, Ogwell, Ilfracombe, and Combe-Martin beds.
Lower.—Linton and Fowey beds.

All these deposits are essentially marine; whereas those of Wales and Scotland are probably freshwater. It is probable that land was gradually rising during the Silurian period in our latitudes, and that at the close of that period there were already tracts of land of considerable magnitude, from which were obtained the coarse grits and conglomerates of the Old Red Sandstone, which are estimated at not less than 5,000 feet in some localities. The thickness, however, is irregular. In the Devonshire series, limestones attain the thickness of 60 feet in some parts; but they are generally poor and thin. The yellow sandstone of Ireland is Upper Devonian.

Devonian rocks, possessing something of the true Devonian and something of the Old Red Sandstone type, cover a region, in the vast empire of Russia larger than the whole of the British islands. They occupy most part of the Waldai Hills, where they combine the shells of Devon with the fishes of Caithness. There are in Russia three divisions or stages of these rocks: the lowest and uppermost consisting of sandstones and shales, poor in shells, but with many fishes; and the central part containing limestones, some pure and some magnesian, loaded with fossils chiefly of marine shells. In some places the fossils are mixed.

The "Eifel limestone," a characteristic rock in the Rhenish provinces of Prussia, is a highly fossiliferous limestone in the Eifel mountains, occupying the place of the middle rocks of the Devonian series. It rests on the "Spirifer sandstone" and "Wissenbach slates," also fossiliferous, and containing a peculiar broad-winged Spirifer (a shell belonging to the Terebratula group), and it is covered by the Clymenia and Goniatite limestones, also crowded with characteristic fossils. In this part of Germany the Devonian succession of rocks is best exemplified. There is, however, a marked difference in the general character of the species of fossils when compared with the English types.

Besides the Rhine district, Devonian rocks occur in Germany in Franconia and the Hartz, in France near Boulogne and in Normandy and Brittany, in Belgium, in the Asturias in Spain, in Turkey near Constantinople, and they have been identified in South Africa and Tasmania. In North America there are several well-marked groups of rocks representing each division of the Devonian series. They contain various species of shells and Encrinites, some of gigantic size, some Trilobites and star-fishes, a few fishes, and many plants, including ferns and trees like those found in the coal measures above. In Gaspé and New Brunswick these are comparatively numerous.

Among the peculiar fossils of the Old Red Sandstone the most remarkable are the fishes. Of these the *Pterichthys* (wing-fish), *Cephalaspis* (shield-head), *Coccosteus* (berry-bone), and *Holoptychius* (all-wrinkle), have long been known and frequently described. They are all exceedingly curious.

In all of them the body is covered with large bony plates, coated with enamel instead of scales. The bones themselves of such fishes are soft, and their enclosure of bony plates, fitting each other, forms in some cases a true and very solid skeleton. These fishes—the Holoptychius especially, whose plates are covered with deep furrows or wrinkles—must have attained considerable size, some of them approaching twelve feet in length. Their teeth were not unlike those of crocodiles. Other teeth, resembling those of ordinary fish, are found in the same rocks.

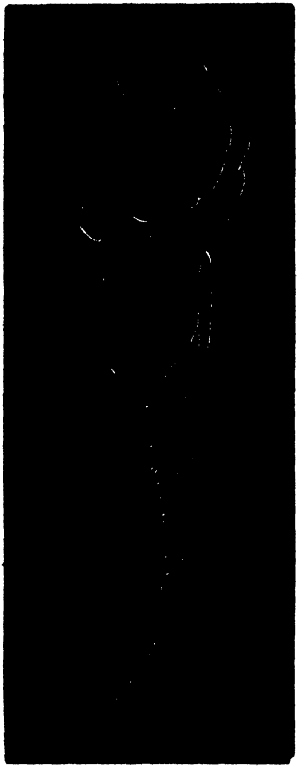


Fig. 20—Coccosteus (restored outline).

The *Coccosteus* (fig. 20) was a fish of moderate proportions, with a large broad head, high and nearly circular in shape, enclosed in a complete box of enamel, like the head of the sturgeon. The head was attached to the body more in the way in which the heads of some insects are attached than like that of most fishes. The jaws were powerful and strong. The upper part of the body was covered by a bony plate, but the lower part was undefended.

The body was long, and the tail both long and strong.

The very remarkable Crustacean family of *Pterygotus*, found in the Silurian rocks, was continued into the Devonian by other gigantic Crustaceans of the same type. These animals resembled the *Limulus*, or King-Crab of the West Indies. They combined the peculiarities of several families of Crustaceans. Besides them there were examples of many others of the same class, having little resemblance in form or structure to known species.

CHARACTERISTIC AND REMARKABLE FOSSILS.—(1) Plants: *Lycopodites*, *Lepidodendron*, *Cyclopteris* (in Ireland). (2) Corals: Chiefly cup-corals, as *Cyathophyllum*, of which there are many species; but also *Favosites* and *Heliolites*. *Pleurodictyum problematicum* is characteristic of the lower beds. *Calceola* was probably a rugose coral, and is common. Species of *Tentaculites* are common. (3) Brachiopoda. *Orthis* is rare, *Spirifera* common. The large broad-winged Spirifers (*S. disjuncta*, etc.) are characteristic. *Atrypa reticularis* ranges from Silurian through Devonian. *A. desquamata* is very common in England. *Lingula* occurs in the Tilestones. (4) Bivalve shells. Of these there are many. *Megalodon*, and species of *Cucullœa*, are typical. (5) There are a few Univalves of the genus *Murchisonia* and a few Cephalopoda, of which the most characteristic are *Clymenia* and *Cyrtoceras*. There is also a *Goniatite*. All are in the upper beds. (6) Of Crustaceans the Silurian forms are rare. In the place of these are species of *Brontes*, *Harpes*, *Trimerocephalus*, &c. (7) Fishes. Of these the number is large. In the older part we have the Silurian forms, then *Cephalaspis* and *Pteraspis*, afterwards *Coccosteus*, *Asterolepis*, *Dipterus*, *Pterichthys*, *Glyptolepis*, *Holoptychius*. In the uppermost we find some of these, with *Dendrodus* and *Glyptopomus*.

CHAPTER VI.

NEWER PALÆOZOIC ROCKS AND FOSSILS.

CARBONIFEROUS SERIES.

We have seen in the Laurentian, the Cambrian, and the Silurian rocks and fossils indications of deep sea deposits over a large part of existing land in the northern hemisphere, interrupted here and there by tokens of land within moderate distance, and terminating in the Tilestone and Old Red Sandstone, including large deposits first of estuary, and afterwards of fresh-water origin. We come next to the consideration of rocks, also of great extent and wide range, in which the proofs of the near existence of land are more precise, and where we find indeed every indication of large tracts of land clothed with peculiar but abundant vegetation.

These newer deposits, like the others, extend widely in longitude, and range also for very great distances in latitude. In the lowest determined stratified rocks limestone in an unaltered form is unknown. It is converted into marble, or mixed up with magnesia in serpentine, and almost all trace of fossil is lost. It occurs also there in veins, not beds. In deposits less ancient, where there has been a smaller extent of metamorphism, the limestones are muddy and not sufficiently cleared of clayey matter.

Very often they are in lumps enclosed in mudstones or shales. But they are generally fossiliferous, and sometimes almost entirely made up of fossils. The limestones are, however, nowhere in very large masses. So also in the older part of the Palæozoic period, although in Ireland there are some bands of anthracite, and here and there land plants and fucoids, there is nowhere a large accumulation of vegetable carbon. We now come to what is expressively called the *Carboniferous series.* In it carbon everywhere occupies a prominent place. In the lower part as limestone (carbonate of lime), in the middle part as coal to a small extent, and in the upper part in various ways, both as carbonate of iron and in vast accumulations of coal, carbon is everywhere characteristic. This is the case especially in England, where the name was originally given, and where it is retained with some show of reason. At any rate it is certain that in most other parts of the world the largest and best deposits of fossil fuel or coal are still obtained from this series, and thus the "Carboniferous series" remains as a fit title.

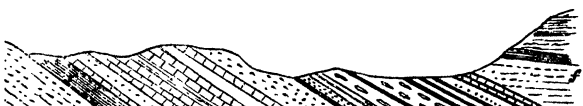


FIG. 21.—SECTION ACROSS THE CARBONIFEROUS ROCKS OF ENGLAND.

a. Old red sandstone. *b.* Lower limestone shale. *c.* Carboniferous limestone. *d.* Millstone grit. *e.* Coal measures. *f.* Permian rocks.

The following subdivision of the Carboniferous series in England will be found useful in reference to the descriptions and details that follow:—

UPPER DIVISION.
Coal measures (all estuarine).
Ardwick series.
Pennant series.
Gannister series.

MIDDLE DIVISION.
Millstone grit (marine).

LOWER DIVISION.
Carboniferous limestone.
Upper limestone shale, or Yoredale series (marine).
Mountain or scar limestone (marine).
Lower limestone shale (estuarine).

The Lower Carboniferous rocks are exhibited in England on the margin of the South Welsh coal basin, in Derbyshire, in Yorkshire, in Northumberland, and elsewhere. They are thin and poor in Wales, but expand as they advance northwards. Generally shaly, they include sands and calcareous grits. In Scotland they form calciferous grits, and in Ireland carboniferous slate is the representative. The general character of the rocks and their contents varies, however, but little. The Burdie house limestone is the most interesting Scottish rock of this period.

The *Carboniferous limestone*, sometimes called *Mountain limestone*—owing to its frequent development in many parts of England in table lands and hill country—is an important mass of semi-crystalline limestone loaded with fossils. Very often, indeed, it consists of them almost exclusively, and with the fossils so large a proportion of corals is included in some localities as to induce the idea that the rock itself may be an altered coral reef. In this state it is presented in Derbyshire, where it is the cause of the extreme picturesque beauty of the valley scenery.

Something of the same kind is seen in Somersetshire, near Wells, and in some of the Yorkshire valleys. In all these cases, and indeed generally in the British islands, the limestone is metamorphosed, and passes into a kind of semi-marble, valuable for ornamental purposes. In Yorkshire it forms two groups—the *Scar limestone*, so called from the bold steep rocks or *scars* (an old English word) in which it is generally presented, and above this the *Yoredale rocks*, a series of limestones, freestones (of sand), and flagstones, attaining in some places a thickness of 1,000 feet. Some of the sandstones are so compact as to become quartzite. Bands of coal are not unknown among the rocks of this series. They are generally thin, but sometimes of fair quality.

In districts away from the typical region the lower members of the Carboniferous Series are still very generally recognized, although in a peculiar form. In Devonshire the limestones are black, and are associated with sandstone and shales, a very poor coal called *culm* being common among them. In Ireland there are two principal limestone bands, and an intermediate slaty deposit called *calp*. In Scotland the *Calciferous sandstone* is the base, and the carboniferous limestone is represented by sandstones, shales, coal, and ironstone. These beds are rich in encrinital remains from top to bottom, but there are only a few bands of limestone.

The carboniferous limestone reappears in Belgium, and extends into Westphalia, resting on shales. In these countries there is a very large proportion of semi-marble and limestone of a deep jet black colour, due to the abundance of carbonaceous matter derived from animal and perhaps vegetable organisms. The same general character is continued as far as Russia, except that in the great mass representing the carboniferous limestone of England the dark colour becomes gradually paler. Coal occurs with the middle beds in Southern Russia. In North America the base of the system consists of sandstones and conglomerates, but limestone is generally found in some parts of the series.

The Lower Carboniferous Series is very widely extended, and is for the most part easily recognized. It abounds in fossils, including almost all the great natural groups contained in the older rocks, but rarely identical species. The corals, shells, crustaceans, and fishes are all highly interesting, and many whole groups are special. There are Foraminifera and Radiata. Among the latter are many Encrinites, whose stems sometimes make up whole beds of stone. A characteristic species is figured in the annexed cut (fig. 22). There are also remains of many shell-bearing animals, among which those of the large and important groups, *Cephalopoda* and *Brachiopoda*, are the most abundant. Among the Cephalopoda is a genus of chambered shells of the kind already alluded to as resembling the Nautilus. The carboniferous type is called *Goniatite*, from the angles (Greek: *gonos*, an

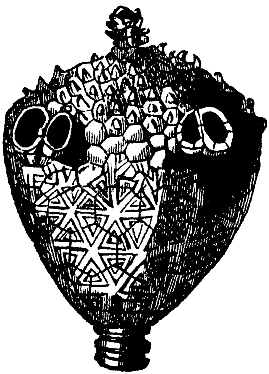


FIG. 22.—Actinocrinite.

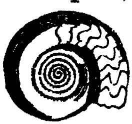


FIG. 23.—Goniatite.

angle) made by the chambers with the shell (*see* fig. 23). Singular crustaceans have been found, some extremely remarkable. There are also many varieties of fishes, resembling more or less the Devonian, and including some nearly allied species; but in addition to these are many others unknown in the older rocks. The fossils of this period are very similar in distant countries.

The *millstone grit* is so called from its composition in many parts of England, where the beds over the carboniferous limestone consist largely of rounded pebbles and small angular stones mixed with sand, hardened into stone. It is valuable for making millstones. It is by no means so widely expanded as the beds below and above. In some places it contains coal, and often alternates with shale, but is generally almost without marks of life. In Northumberland, Yorkshire, and Lancashire it is important, and contains a large quantity of useful building stone, but out of England it can rarely be identified. Near Buxton it attains a thickness of 1,200 feet, but in North Staffordshire it is reduced to 200 or 300 feet. In Scotland it is called the *Moor-rock*, and is a group of white sandstones and grits. A millstone grit district is generally marked by long lines of terraced or steeply scarped hills.

Over the millstone grit, or, if that is absent, lying upon the uppermost beds of carboniferous limestone, we find in many parts of the world, and to so large an extent as to deserve especial notice, a series of grits and shales alternating with that peculiar form of altered vegetable matter known under the name of coal. These beds, as a group, are called *Coal-measures.* They are often crowded with fragments of plants, and contain many peculiar fossils of animals. Occasionally (*see* fig. 24) the complete stem of a tree is found bedded in the sandstone accompanying coal. The coal in these rocks is of the greatest economic value, and it was long supposed that only in rocks of the same age could valuable beds of true coal be expected. Although recent observations have shown that there is no monopoly of true coal in the coal measures, it is at any rate certain, that in the whole history of deposits at present known there is no approach to a repetition of coal to so great an extent or of such excellent quality.

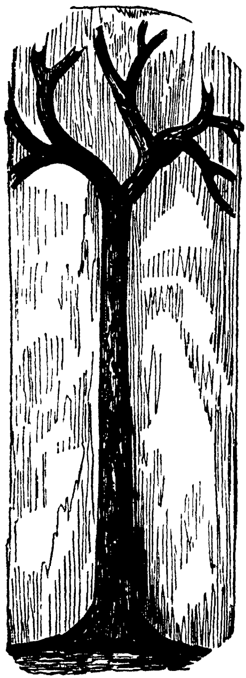


FIG. 24.—Fossil Tree imbedded in Stone.

The productive coal-fields are by no means everywhere in the same part of the coal measures, and even where most productive it should be understood that the coal forms but a small percentage of the whole thickness of the rocks. The very greatest total thickness of all the seams of coal in a coal field nowhere exceeds 200 feet, while there are in some places two or three thousand feet of unproductive grits and shales. On the whole, the middle and lower members of the series are the richest.

As a general rule, it may be considered that the coal measures have been formed near land in water rarely salt, sometimes brackish, and sometimes fresh. There are a few limestone bands associated here and there in the series, but grits discoloured by carbon, shales, often blue, dark blue, or black from the same cause, and lumps or nodules containing a large percentage of iron, are the chief minerals. In some districts, or coal fields, the coal almost invariably rests on stiff clays loaded with the rootlets of trees, but in others it lies on nearly pure sand. Occasionally, as in the case illustrated in fig. 24, there is distinct proof of the growth of vegetation having taken place on the very spot. The series has every appearance of having been formed rapidly, and the quantity of vegetable matter entangled and preserved before decay commenced is beyond all question enormously large, and difficult to explain by comparison with operations of the same kind now in progress.

Three divisions of the coal measures are recognized in Lancashire. They are as follows: 1. Upper, or Ardwick series, comprising 2,000 feet of grey shales and sandstones, with thin limestones at Ardwick, near Manchester, and some coal; 2. Middle, or Pennant series, 3,000 feet of purple and grey shales, with all the thick coals of the formation; and, 3. Lower, or Gannister series, 1,800 feet of micaceous grits and shales, with thin coal. The coal measures have been subjected to partial elevation and frequent fracture, resulting in some places in faults or displacements of the strata to the extent of many hundred, or even thousand feet. Some good cannel coal, very rich in gas, occurs in this field. There are coal fields of the same general nature in Flintshire, and the Yorkshire coal field contains all the varieties of coal, and is very extensively worked near the great manufacturing towns of the West Riding. It connects with the Derbyshire and Nottinghamshire coal fields, and though the total thickness of coal is not very great, the facilities of working are considerable.

The Newcastle coal field, containing some of the finest qualities of coal for household use and gas manufacture, has been much more worked than any other. The associated beds consist largely of sandstones, which are especially abundant in the upper members, but there are many shales.

The South Wales coal field forms two basins, the western consisting chiefly of anthracite and the eastern of bituminous coal. There is also a large quantity of steam coal intermediate in quality. Besides these, there are coal fields in many other counties of England, each exhibiting some peculiarity. The most important are the South Staffordshire, where there is a seam of coal forty feet thick, the Cumberland and Westmoreland, the Warwickshire and Leicestershire, and the Somersetshire and Gloucestershire. In the latter the beds are very thin, but numerous.

Scotland presents a large area occupied by coal measures, besides the coal-bearing strata belonging to the millstone grit and carboniferous limestone. Sandstones of considerable importance in an economic sense alternate with coals and with shales rich in bituminous matter, given off in abundance by slow distillation. The Ayrshire coal field and the centre of the Mid-Lothian coal fields are examples. The uppermost beds in Scotland are of red sandstones and marls.

Coal occupies a geological position nearly similar to that in England, in many parts, not only of Europe but North America. It is even traced to some much more distant lands. The coal measures of Belgium, those of France, in a number of detached basins, those of Rhenish Prussia, of Bohemia, of Silesia, of Hungary, of Southern Russia, and parts of Turkey, as well as others found in Spain, all belong to the same period. In Nova Scotia, New Brunswick, and Cape Breton, in the vast coal districts of the Ohio and the Alleghanies, of Illinois and the basin of the Missouri, in Melville Island in the Arctic zone, in the isthmus of Panama, in the tropics, and in Chili and Peru in the Southern hemisphere, we have almost all varieties of geographical position. All, however, offer many points for comparison, and few important differences. Some of the deposits are of greater extent, but none have hitherto been so closely examined, or so thoroughly worked as the English. China, India, Australia, and New Zealand carry the horizon of the coal measures eastwards, and across the Equator, in the eastern hemisphere as well as the western, the coal brings into relations of close uniformity positions not now presenting any similar forms of vegetable life ranging throughout the whole. Both South Africa and Brazil have yielded true coal plants.

The one great characteristic of the coal measures is the presence of workable beds of coal. But it must not be supposed that coal is everywhere to be found in these rocks, or that it is the only material in them of economic interest. They contain generally a large quantity of iron ore, sometimes consisting of oxide of iron, but more commonly, and to a much greater extent, of carbonate of the oxide, mixed with clay, and called argillaceous, or clayey carbonate of iron, or more commonly "clay ironstone." It is this mineral which has yielded, and still continues to yield, a large part of the iron of commerce, and till lately the coal measures of England have been among the largest suppliers of it. The deposits called coal measures generally consist of many alternations of coal shale, more or less rich in carbon, and of large quantities of iron ore, often in the state of bands and connected lumps; but there are also numerous and thick beds of sandstone of all degrees of hardness. The shales are sometimes so completely made up of the rootlets of trees, buried in and helping to form the coal, that it is clear they formed part of the old soil. They are then called *underclay*.

Coal is altered vegetation, and there are sufficient indications of the nature of organic life preserved among the strata associated with the mineral fuel, to enable us to form a tolerable notion as to the flora of the time and place. It appears from them that the plants must have grown in extensive marshy jungles, sometimes near salt water, but more generally in estuaries, and where the water was fresh. Forest trees of the kinds with which we are familiar in temperate climates, were rare, and the trees and plants that abounded have been called *Lepidodendron*, *Sigillaria*, *Calamites*, &c. There were also many varieties of ferns, and some curious extinct pine trees, not unlike the Araucaria of New Zealand. There is nothing requiring us to suppose that the climate was tropical, but the conditions must no doubt have been such as to provide the warmth and moisture needed for the vegetation alluded to.

The characteristics of the chief varieties of coal plants may be thus described. The *Lepidodendron* (Greek: *lepis*, a scale, *dendron*, a tree) owes its name to the scaly exterior of its bark (*see* fig. 25). It was a large tree, branching trunks of it as much as fifty feet long having been obtained in coal mine workings. Cones of this tree, and leaves attached to the bark, serve to show its general relations, but also remind us of the little resemblance it had to any modern types of tree. The number of species already determined is very large. The *Sigillaria* (Latin: *sigillum*, a seal) is so called also from the markings on the trunk, which resemble the impression of a seal. A large proportion of the coal appears to have been obtained from vast forests of this tree, the roots of which, named *stigmaria* (Latin: *stigma*, a mark), are commonly found in the clay under many of the principal coal seams. This tree grew to the height of seventy feet, and sometimes much more. The stem was cylindrical and fluted, and in some specimens was five feet in diameter. The markings, from which its name is given, were the scars left by fallen leaf stalks. The interior of the trunk must have been succulent, and easily destroyed by decay, so that often nothing remains of the tree but a mere shell filled with sandstone, or crushed quite flat.

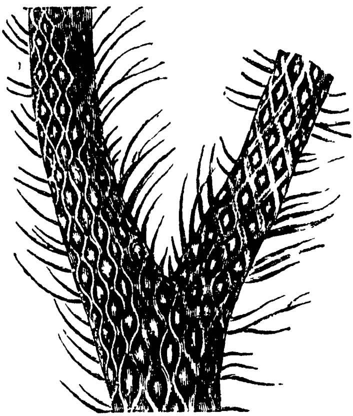


FIG. 25.—Lepidodendron.

The *Calamite* (Latin: *calamus*, a reed) was also a tree attaining large size, and appears to have had some relation to the recent *Equisetaceæ*, or Mare's Tails, but belonged to an extinct tribe of plants nearly confined to the Carboniferous Period. The foliage was very peculiar, the leaves diverging like stars from the joints of the branches. The fruit was also peculiar. There are many names of coal plants mentioned in works on geology, which we cannot here allude to, but most of them belong to the groups above mentioned, or to the great family of ferns, among which the tree ferns appear to have been exceedingly common. Some of these are represented in figs. 26, 27. Numerous cases are recorded of large groups of trunks of trees and of fragments, with the roots attached, in the very soil in which they grew (*see* fig. 24, p. 100). There are other cases in which it is probable that the woody material was drifted.

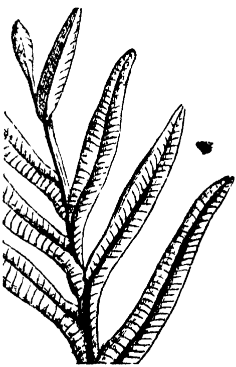


FIG. 26.—Pecopteris.

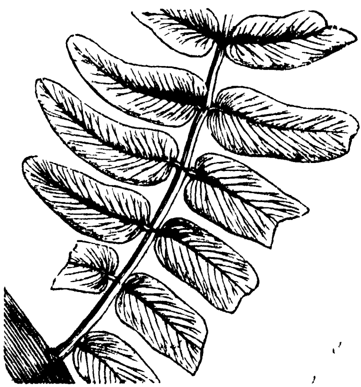


FIG. 27.—Neuropteris.

Remains of animals in the true coal measures are not abundant, but neither are they very rare. They possess extraordinary interest, as they include not only many insects (spiders, scorpions, centipedes, &c.), crustaceans of peculiar forms, and various shells, but very many varieties of fishes, and a considerable group of reptiles. Many of the fishes are of large size, and their teeth indicate reptilian and highly predaceous habits. Megalichthys (*megale*, great, *ichthys*, fish), and Holoptychius (*see* p. 91), were associated with shark-like forms belonging to the group of Cestracionts or Port Jackson sharks. Remains of reptiles, though only recently discovered, are already very numerous. Footsteps of large reptiles have been found on coal sandstones in America, and of small reptiles in Scotland. Bones of eight or ten species have been found in Nova Scotia, representing various types of reptilian life. England and Ireland, as well as Scotland, have yielded other forms, some small, others of considerable size, some batrachian, resembling the salamander, others crocodilian or lacertian; one is believed to form a connecting link between reptiles and fish. No less than eight genera allied to the salamander have been described by Professor Huxley, from Ireland alone.

The vast stores of carbon buried in the earth during the newer carboniferous period are further exemplified by the quantity of petroleum which has of late years been discovered by boring into the coal measures in North America, and by the thick and widely extended strata of bituminous shale in all the principal coal fields of England and Europe. Whatever may have been the cause of the natural distillation by which the mineral oil was obtained, it is impossible not to recognize the dependence of these enormous supplies on organization, whether they are due to animal or vegetable life. It is more than probable that large accumulations of fishes buried in certain localities may have helped to supply the material.

It will be evident, from the account here given of the contents of the rocks at the upper part of the great carboniferous series, that there must have been large tracts of well-peopled land in all those parts of the world where the coal occurs, and that this includes districts now separated by wide and deep oceans.

CHARACTERISTIC AND REMARKABLE FOSSILS.—(1) Plants—Many are found throughout the Carboniferous series, though by far the great majority are in the upper part. The trees are *Lepidodendron* (with its fruit *Lepidostrobus*), *Sigillaria* (with its root *Stigmaria*), *Calamites*, *Sternbergia*, *Ulodendron*. The tree ferns, *Neuropteris*, *Alethopteris*, *Pecopteris*, *Sphenopteris*, *Cyclopteris*. (2) Radiata—Of Polyzoa, *Amplexus*, *Cyathophyllum*, *Syringopora*, *Lithostrotion*. *Heliolites*. Of the higher groups, *Archæocidaris*, *Palæchinus*, *Actinocrinus*, *Poteriocrinus*, *Cyathocrinus*, *Pentremites*. (3) Brachiopoda. *Spirifera trigonalis*, *S. glaber*, *Producta antiquata*, *P. gigantea*, *P. Scotica*, *Terebratula hastata*, *Pleurorhynchus*. (4) Bivalves. *Anthracosia* and *Anthracomya* (resembling Unio), *Avicula papyracea*. (5) Univalves—*Pleurotomaria*, *Euomphalus*. (6) Cephalopoda—*Goniatites Listeri*, *Orthoceras*, *Discites*. (7) Articulata. Of Trilobites : *Edmondia*, *Phillipsia*, *Griffithsia*. They are of small size and rare. There are genera allied to *Limulus*, *Bellinuria*, and *Prestwichia*, and some of larger size. There are also many insects. (8) Fishes—The mountain limestone yields many palatal bones and teeth of *Psammodus*, *Orodus*, *Helodus*, *Diplodus*, *Cochliodus*. Several genera are found in the coal measures, as *Megalichthys*, *Rhizodus*, *Cœlacanthus*, *Amblypterus*, *Palæoniscus*. (9) Reptiles—*Archegosaurus*, *Ichthyerpeton*, *Anthracosaurus*, *Ophiderpeton*, *Pholidogaster*.

PERMIAN SERIES.

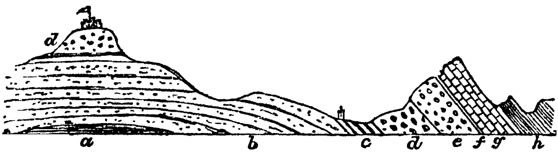


FIG. 28.—SECTION ACROSS THE PERMIAN SERIES IN GERMANY.

a to *e*. Todt-liegende (Rothliegende and Brandschiefer). *f*. Kupferschiefer. *g*. Zechstein. *h*. Bunterscheifer.

Overlying the coal measures in the British Islands we generally find red and yellow sandstones, and conglomerates poor in fossils, passing upwards into marly shales and magnesian limestones, sometimes of considerable extent, which again are covered with red sands and marls. They are best seen in the counties of Durham, York, and Nottingham, where they cover the upper coal measures, and are themselves covered by other sands and marls. A general section of the whole, as seen in Würtemburg, where the series is more complete, may perhaps be useful to the student, and is given in fig. 28.

There is little in these rocks in our own country to justify separate classification, and the early accounts of English rocks regarded all these sands and marls and the magnesian limestone as one series, coming in between the palæozoic and secondary, but belonging to the latter. But England, though very rich in formations, does not possess all in the same perfection; and it was found in 1844, by Sir R. Murchison, while visiting Russia, that there existed a natural group of rocks, overlying the carboniferous series (there well developed), and quite distinct from the sands and salt-bearing marls, immediately above. These rocks, being exhibited on a large scale in the ancient kingdom of Perm, in the east of Russia, he named *Permian*, a title which has since been adopted by geologists universally.

The Permian rocks are conformable to the carboniferous, but differ from them sufficiently. They are well represented in Germany. The whole group is characterized by one type of animal and vegetable life, and this clearly brings it within the boundary of palæozoic formations. The following arrangement of the rocks, bringing into comparison the English and German representative strata, may be useful for reference:—

	England.		Germany.
1	Red gypseous marls. Magnesian limestone.	1	Bunterschiefer. Zechstein.
2	Marl slate.	2	Kupferschiefer.
3	Red sandstone and conglomerate.	3	Rothliegende. Brandschiefer.

The conglomerates and red sandstones at the bottom contain vegetable markings and fossil plants often difficult to distinguish from coal measure species. Sandstones capable of being used for building purposes, and marls, sometimes bituminous, are associated with these sandstones. They are not generally of much thickness, and on them rest beds of magnesian limestone, made up, almost entirely, of corals and shells, but only occasionally yielding fossils of which the species can be determined, owing to the great alteration and metamorphism due to the change from carbonate of lime to a mixed carbonate of lime and magnesia. The limestone is full of cells, and sometimes of very curious texture. The more perfectly crystalline parts are called *dolomite*, and of this there is a considerable quantity in some localities.

A marly slate found in Durham, and connecting the magnesian limestone with the underlying beds of sandstone, contains numerous fossils, especially of fishes. In this way, this part of the series has been identified with the German *Kupferschiefer*, or copper-slate, a remarkable bed, worked for copper ore at Mansfeld, near the Hartz Mountains. The overlying magnesian limestone thus represents the *Zechstein* of Germany, which also contains much dolomite. These beds seem to have been deposited partly in the sea, partly in estuaries.

Permian rocks are found in Ayrshire, in Scotland, where they have been disturbed by volcanic ejections, and they are believed to exist in Devonshire. They have been recognized in the south of France, and in the southern States of North America. They probably extend into Asia. In some localities, they are comparatively rich in fossils, but generally this is not the case.

The fossils, however, that characterize the formation are essentially palæozoic, though the species, both of plants and animals, are almost all distinct. Russia and Germany yield a large flora, extending to nearly 200 species. They include calamites, lepidodendron, many ferns, and many coniferous trees. The animals present the same general resemblance. The species include a large number of minute animals, some of low organization, others much higher. Among them are foraminifera, one of which (formerly called a serpula) is infinitely abundant. Some of the corals are peculiar. Many of the shells are very characteristic, and there are radiata and crustaceans, all more or less clearly palæozoic. The fishes, which are very abundant in certain localities, and very characteristic, all resemble in general structure the older, rather than the newer types. Reptiles have been discovered, though their remains are not common.

CHARACTERISTIC AND REMARKABLE FOSSILS.—(1) Plants—Many new species of the carboniferous genera of tree ferns, as *Neuropteris Huttoniana*, *N. salicifolia*, *Odontopteris Permiensis*, *Pecopteris Gœpperti*, *Sphenopteris lobata*, etc.; also *Ullmannia*, *Nœggerathia*, etc. (2) Foraminifera—*Dentalina*, *Textularia*. (3) Polyzoa — *Fenestella retiformis*, *Acanthocladia*, *Synocladia virgulacea*. (4) Brachiopoda—*Producta horrida*, *Terebratula elongata*, *Spirifera alata*, *Athyris pectinifera*. (5) Bivalve shells—*Bakevellia*, *Cardiomorpha*, *Schizodus*, *Pecten pusillus*, *Monotis speluncaria*, *Byssoarca striata*. (6) Univalve shells—*Turbo helicinus*, *Pleurotomaria antrina*. (7) Cephalopoda — *Nautilus Frieslebeni*. (8) Fishes—*Palæoniscus elegans*, *P. varians*, *Acanthoda gracilis*, *Pleuracanthus Decheni*. (9) Reptiles—*Zygosaurus*, *Protorosaurus*.

CHAPTER VII.

Older Secondary Rocks and Fossils.

The close of the Older or Palæozoic Period, and the commencement of the Secondary, is marked by a decided though not always prominent change in the facies or general aspect of the plants and animals whose remains are buried in the respective rocks. This is the more remarkable, inasmuch as the nature of the rocks differs but little, and, as far as England is concerned, the rocks succeed each other with too little change and interruption to allow us to decide readily and in all cases, by mere inspection, where one ends and the other begins. Sandstones and conglomerates are the prevailing rocks. In the Permian as in the Triassic series, the sandstones are mixed with so much clay, and discoloured so generally by irony stains, the marls are so frequently accompanied by salt and gypsum, and the fossils of every kind are so few, that great obscurity is the result. It is only when we obtain fossils, and can apply to them a thorough knowledge of Palæontology, that a distinct conclusion is arrived at when disconnected deposits are under consideration. But even when the rocks are alike, there may often be detected a want of conformability between the newest Palæozoic and oldest Secondary Strata.

TRIASSIC SERIES.

England is not more rich in the distinctive rocks that commence the Secondary System than it is in the newest and highest of the Palæozoic. It contains them, indeed, in both cases, and they can be made out, but recognition is difficult without the help of foreign representative forms. The series we have now to consider consists, in England, of little more than a succession of marly sandstones, rich in rock-salt in certain districts, and often containing much gypsum (sulphate of lime). It certainly does not deserve the peculiar name *Trias*—divided into three parts—by which, notwithstanding, we are obliged to designate it. We must cross the sea and visit Germany to see its full development. We there find a distinct series, consisting of conglomerates and coloured or variegated sandstones at the bottom, a peculiar fossiliferous shelly limestone of considerable thickness in the middle, and an overlying series of marls and shales, with some grits, often containing deposits of rock-salt and yielding salt springs. The student will recognize a general resemblance in Germany and England, with the intervention, however, in the former country of the very characteristic limestone, altogether wanting here.

So much more distinct are the continental representatives of these rocks, that the German names are now in common use among English geologists in speaking of them. We possess the lower member, called in Germany, *Buntersandstein* (*bunter*, variegated), and in France, *Grès bigarré* and *Grès de Vosges*. The middle calcareous member, called *Muschelkalk* (shell limestone), is absent, and the sandstones, clays, and salt-bearing marls of the upper series, called in Germany *Keuper*, or copper, are so called also by us, although certainly copper has very little to do with them, except in a few localities in Germany. With us the lower member, although present and pretty widely distributed, is of little interest. Its sandstones are not often useful for building, and its conglomerates are still less available. The sandstones are soft and whitish, the conglomerates often made up of quartz pebbles and loose sand. The thickness of these beds is considerable, amounting in places to 600 feet. Such is the Bunter as an English formation.

The Keuper is more interesting, more varied, and more valuable. Its base is very generally marked by compact laminated sandstones, holding back water, and technically called *waterstones*, because when reached by boring, or when cropping out at a hill side, water is generally obtained among them. They attain in the middle of England a thickness amounting to 400 feet, and they are covered by strata that are especially saliferous. In these the rock-salt deposits occur. Many of the marls of the Keuper, even when the salt is absent, are recognized by crystalline forms in the sand, filling up the place of crystals of rock-salt. The salt is chiefly worked in Cheshire, where there is a total thickness of 1,700 feet of salt-bearing strata, including many deposits of gypsum, some of which are crystalline, and are called alabaster. These saliferous beds extend very widely in Europe on the same geological horizon. They extend even beyond Europe, and may, perhaps, mark some peculiarity of climate. They have, perhaps, in most cases, been deposited from inland salt lakes, evaporated either to saturation or to actual dryness. Similar deposits are now going on in the Dead Sea, the Salt Lake of the Western States of America, and some others. In all these cases, they combine the conditions of the interior of a continent with the vicinity of a geographical or mountain axis. In the Mendip Hills, Somersetshire, the Keuper is represented by a peculiar conglomerate containing magnesian limestone, called the dolomitic conglomerate. At Elgin, in Scotland, there is a sandstone, recognized by its reptile fossils as Triassic. The continental representative of the lower or Bunter sandstone is sometimes (but rarely) rich in fossil plants, and (still more rarely) in marine shells, indicating the vicinity of land. These plants are unmistakably different in their general aspect from those of the coal measures. On the whole they may, perhaps, be regarded as indicating a drier climate.

The *Muschelkalk* is almost everywhere a limestone, but varies a good deal in colour and texture. The lower members alternate with the upper Bunter, and pass insensibly from them. Some of the limestones are bituminous, and yield a sulphurous smell on being struck. The fossils are numerous, varied, and very characteristic. They include a peculiar encrinite (*see* fig. 4, p. 39), a peculiar form of ammonite (*see* fig. 29), one of a succession of links connecting the nautilus with the true ammonite, several fishes' teeth and palatal bones, and some curious reptilian fragments. Many of these have

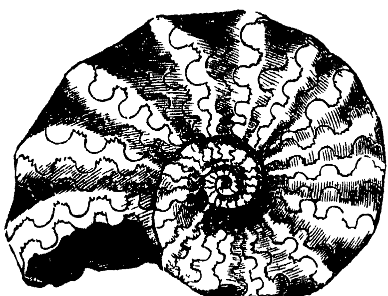


FIG. 29.—Ceratites nodosus.

been obtained from Würtemburg and adjacent parts of Germany.

The *Keuper* of Germany, and the *marnes irisées* of France, are red, grey and bluish mottled marls, passing into sandstone. Rock-salt and gypsum occur abundantly, keeping up the saliferous or salt-bearing character of the deposit, though rock-salt is not mined. Many brine springs exist wherever this rock is at or near the surface. Fossils are also found, though not very commonly.

Triassic rocks have been found in considerable abundance in North America, where they sometimes contain valuable and workable beds of coal. The most important deposits are near Richmond, Eastern Virginia, U.S., and in North Carolina ; but rocks of the same age are found in Connecticut and Massachusetts. A similar series is found in India, especially at Nagpur and its neighbourhood. Even in South Africa, at various points, these rocks recur, and are marked by fossils very characteristic. Almost all these localities are remarkable for brine springs.

One of the most interesting peculiarities of the triassic series, so far as fossils are concerned, consists of the numerous impressions of the feet, tails, claws, and other parts of animals that have moved over the surface at a time when the sands were part of a seashore and before the rocks were formed. The footprints (*see* fig. 9, p. 49, and fig. 30) represent animals of various size—some certainly four-footed, others apparently two-footed. The former are believed to have been impressed by reptiles, some more or less like the salamander, though enormously larger (*see* fig. 30), others more or less like turtles, and some of very singular structure, hardly yet fully understood. There were also lizards. Some of the smaller marks may have been made by quadrupeds of which bones have also been found. Those belonging to two-footed animals were probably made by birds. The frequent

FIG. 30.—Labyrinthodon.

discovery of the bones of reptiles has cleared up some of the obscurity that naturally attached to the markings when the animals were only recognized by their footmarks, and the discovery of bones of similar species of the same genus (if not of identical species) in England, India, and South Africa has afforded unexpected evidence of a probable extension of almost uninterrupted land between these distant countries, at and after the close of the Palæozoic Period. It is interesting to know that this land was peopled by small marsupial quadrupeds, if not by other and larger tribes not yet discovered. The absence of deposits as well as fossils connecting Palæozoic with Secondary deposits is accounted for by the existence of this land. Connecting links must be sought where there was water, and certainly not where the surface was being laid bare, instead of being covered up. The most important fact is, that the vegetation, of which there are many indications, gradually changed during this interval, the newer plants reminding the botanist of the flora of modern South Africa, while the flora of the Carboniferons Period more resembled that of Norfolk Island. The Permian flora, as has been already stated, offers a somewhat intermediate type.

CHARACTERISTIC AND REMARKABLE FOSSILS.—(1) Plants—*Voltzia, Equisetites columnaris.* (2) Radiata—*Encrinites moniliformis.* (3) Bivalve shells—*Avicula socialis, Posidonia minuta.* (4) Cephalopoda—*Ceratites.* (5) Crustaceans—*Estheria minuta.* (6) Fishes—*Palæoniscus, Acrodus, Hybodus, Gyrolepis, Saurichthys.* (7) Reptiles—*Labyrinthodon, Telerpeton, Hyperodapedon, Staganolepis, Rhynchosaurus, Dicynodon.* (8) Birds—Footprints.

RHÆTIC SERIES.

Large and important deposits, containing numerous fossils in some parts of the Austrian Alps and Lombardy (the ancient *Rhætia*), have been found to intervene in central Europe between the Trias and the Lias, which latter bed was long supposed to connect directly with the Keuper. These beds, known on the Continent as the "Kössen," and partly as the "San Cassien" beds, are also present in England and Wales. They are well seen in the cliffs at Penarth, near Cardiff, and are called in the English Survey Map, the *Penarth beds*. They include with us a hard and fine-grained calcareous variety of the lias, called the *white lias*, a group of marls, a thin but very persistent fossiliferous bed of black shale, loaded with fossil bones of fishes, reptiles, and even small quadrupeds, and long known as the *bone-bed*, and some marls below. Overlying the Keuper is a series of grey marls that have yielded the tooth of a small quadruped, of the nature of a kangaroo, but not larger than a rat. Then comes the typical "bone-bed," with bones chiefly of reptiles and fishes, a few oysters and some other shells, and then a considerable series of marls and sandstones containing a peculiar and characteristic fossil, the *Avicula contorta.* Above this is the white lias, which is still believed by some geologists not to belong to the true Rhætic series. *Avicula contorta* beds have been found in Ireland, at Lisnagrib and also near Belfast.

CHARACTERISTIC AND REMARKABLE FOSSILS.—(1) Shells—*Avicula contorta*, *Cardium Rhœticum*, *Pecten Valoniensis*, *Axinus*, *Chemnitzia*, *Pleurophorus*. (2) Fishes—*Gyrolepis*, *Hybodus*, *Acrodus*, *Saurichthys*. (3) Reptiles—*Pterodactyl*. (4) Mammals—*Hypsiprimnopsis microlestes*.

LIASSIC SERIES.

The Liassic Series is very well marked in England, and has long been known. It is still included by many geologists as a part of the Oolitic, or Jurassic Series. There are three divisions of lias, the lower consisting of shales, blue clay, and occasional limestone bands or bands of limestone nodules, valuable for cement. The middle member is generally called *Marlstone*, as being more decidedly stony and calcareous. The upper member is for the most part shaly and less calcareous. It is often of dark colour, and possesses bands of poor coal and bitumen passing into jet. Clay preponderates throughout, and the name lias is understood to be a local and provincial corruption of *layers*, owing to the stratified appearance of the rock in bands of different colour. Sand and sandstone are rare throughout the series in England, and the sandstones that occur are marly.

The lower lias shales (600 feet in thickness in some places) rest on the white lias, and pass into it. They commence with some beds remarkably rich in the fossil remains of large aquatic reptiles, apparently almost marine in their habits, and as the skeletons of these animals have been found not only abundantly, but in admirable condition and of large size, they long since attracted great attention, and have been admirably described. So complete are the remains, that in some cases the contents of the stomach and the digested matter that has passed through the stomach and reached the lower intestines may be studied. The fossil dung of these animals is called *coprolite* (Greek: *copros*, dung; *lithos*, a stone). With two very distinct genera of these marine reptiles are associated the remains of a third genus of reptiles, organized for taking extended flights in the air, and capable also of swimming (*se* fig. 36, p. 130). These animals are now so familiar to all who visit museums, or make collections, that their names must be learned and carefully remembered by the student. The largest of the marine reptiles, resembled the porpoise. It is called *Ichthyosaurus* (Greek: *ichthys*, a fish; *sauros*, a lizard) as having

FIG. 31 -Ichthyosaurus.—(Restored outline.)

combined the external characters of fish and lizard or crocodile in a remarkable degree (*see* fig. 31). The

FIG. 32.—Plesiosaurus.—(Restored outline.)

next in size, exceedingly remarkable in many species for the length of its neck, and compared by its first discoverer to a serpent strung on a turtle, is called *Plesiosaurus* (Greek: *plesios*, near; *sauros*, a lizard), as being more reptilian than fish-like (*see* fig. 32). The third, whose strange proportions are not in any way paralleled even by the most singular of the bats, or flying lizards, is called *Pterodactyl* (Greek: *pteron*, a wing; *dactylos*, a finger), from the mode in which the bones, representing those of the fingers, were lengthened out and connected with membrane to form wings (*see* restoration, fig. 36, p. 130).

The *Marlstone*, well exhibited near Cheltenham, is there rich in fossils, and attains a thickness of 200 feet. The beds of limestone, from which its name is derived, are impure, but workable. The marlstone in Cleveland, in Yorkshire, is exceedingly rich in iron ore, which is now quarried and dug very largely to supply the numerous foundries of that district. The fossils include many shells of various kinds, radiated animals, and a few corals. Among the shells those of animals more or less nearly allied to the squids, calamaries, and cuttle fish—the *cephalopoda* of naturalists—are beyond measure abundant, and are exhibited in a singular variety of forms. Of these the *belemnite* (Greek: *belemnon*, a dart, *see* fig. 33) was the skeleton of a squid, having an ink-bag like existing species. Its stony case and appendages were more complex than those of existing squids, and these are exceedingly common in a fossil state, not only in the lias but the rocks above, to the end of the Secondary

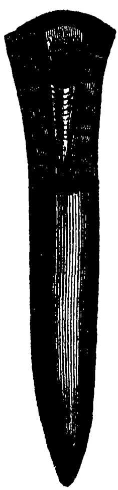


FIG. 33. Belemnites canaliculatus.

Period. The complete animal of another kind, closely allied to the calamary, has also been found. These creatures seem to have been especially abundant in the muddy bottoms that have since become lias, and, owing to their toughness and to the nature of the clay they were buried in, they have been admirably preserved.

It is chiefly the *Ammonite* that characterizes the lias and the secondary deposits above it. The shell thus named belonged to a kind of nautilus, feeding chiefly at the sea bottom, with a chambered shell containing much air and supporting the animal in the water. No doubt the animal, like that of the nautilus, may also have been capable of rising to the surface. As in the nautilus, the shell was divided into numerous cells left filled with secreted air, when the animal grew too large for the last chamber it had constructed. The continuous growth of all animals inhabiting shells requires a constant increase in the size of the shell. In many the shell becomes wider rapidly, and the old shell is nearly, or quite enclosed, or partly absorbed in the new one. In others, the animal builds an additional chamber time after time, leaving a wall of partition between the outer or new chamber and all the rest. These then serve as a float, enclosing air, and assisting in the movements of the animal.

In the nautilus now, and in ammonites formerly, this has often resulted in the construction of a long succession of chambers, a tube passing through a hole in each chamber and connecting the animal with the first. The walls of the outer shell are intersected by each inner wall built by the owner and inhabitant. In the nautilus the body at the extremity where the new wall is built is smooth, and the intersection is therefore a straight line. In the rocks of the Older (Palæozoic) Period there is a little divergence, and an angular line is produced. This is the *Goniatite* (Greek: *gonos*, an angle: *see* fig. 23, p. 98). In the Trias the angle becomes a series of easy curves, and the shell is called *Ceratite* (Greek: *ceras*, a horn: *see* fig. 29, p. 116). In the lias, for the first time, the junction of the wall of the chamber with the wall of the outer shell becomes complicated, and resembles a parsley leaf, the pattern, however, differing in each species. These are the true *Ammonites*, the name of which is derived from the resemblance of the shell to the horn in the statues of Jupiter Ammon. Ammonites are arranged in six sections, according to the form of the back of the shell; and into 15 groups, chiefly according to the form of the intersections of the wall. The extreme importance of the ammonites as characteristic shells throughout the Secondary Period, and the fact that representative forms of the great extinct family of Cephalopods, of which the ammonite is the best known example, afford the main clue to the determination of subdivisions of secondary strata, render it desirable that the student should, as far as possible, understand the nature of the differences that exist between species, genera, and tribes of these shells. But so detailed an account is hardly consistent with elementary instruction in Geology.

The upper lias, besides containing beds of jet, abounds with these peculiar fossils, and contains also univalve and bivalve shells of various kinds, crustaceans and radiata, as well as reptiles and fishes. These differ only in detail from those which characterize the lower and middle parts of the series. The band containing the jet (which is a kind of lignite) is a hard and highly bituminous shale, in which are fragments of bituminized wood, separating the lowest from the uppermost beds of this member of the series. The total thickness of the upper lias is 300 feet, of which the hard bed measures sometimes 30 feet. There are small deposits of this period in Ireland.

On the Continent the lias exists in a tolerably well-marked form, though not always like the English type. In many places, as at Luxembourg, the clays are replaced by hard sandstones, valuable as building stones. In the Jura there is a want of conformity between the lias and the overlying oolites. In Westphalia and Bavaria the lower lias is sandy. There is lias in India.

CHARACTERISTIC AND REMARKABLE FOSSILS.—(1) Plants—Species of *Zamia* and coniferous plants and trees. (2) Radiata—*Pentacrinites Briareus*, *Diadema*, *Ophioderma*. (3) Brachiopoda—*Spirifera Walcotii*, *S. Münsteri*, *Rhynchonella variabilis*, *Terebratula Edwardsii*, *T. puncta*, *Leptæna Moorei.* (4) Bivalves — *Lima* (*Plagiostoma*) *gigantem*, *Gryphæa arcuata* (*incurva*), *Hippopodium crenatula.* (5) Cephalopoda—*Nautilus truncatus*, *Ammonites bifrons*, *A. planorbis*, *A. obtusus*, *A. Bucklandii.* (6) Insects and crustaceans—Among the insects are beetles, crickets, and dragon flies. (7) Fishes—*Lepidotus gigas*, *Acrodus nobilis*, *Hybodus reticulatus*, *Chimæra monstrosa.* (8) Reptiles—*Ichthyosaurus communis*, *I. platyodon*, *Plesiosaurus dolichodeirus*, *Pterodactylus crassirostris.*

OOLITIC OR JURASSIC SERIES.

As the lias is especially characterized in England by its laminated clays, of which there are parallel bands, some more and some less calcareous, but all chiefly argillaceous; so the overlying rocks are marked by an enormous preponderance of limestones, which in many cases put on a peculiar form, occurring in small round grains like the roe of a fish, and hence called *Oolite* (Greek: *oon*, an egg; *lithos*, a stone). The name oolite was introduced very early in the history of Geology, and is well understood even where this peculiar structure is altogether absent. Owing to the existence of a large and important series of strata in the Jura mountains, not at all oolitic in any sense of the term, but corresponding with our oolites in age and fossils, and with the continental rocks in general character, the name Jurassic has been found more convenient on the Continent. Thus the two expressions *Oolitic* and *Jurassic* are now used indifferently—the former, usually in England; the latter, almost universally out of England.

The oolitic series is eminently English. There is nothing of it in Wales, little in Ireland, and not much in Scotland. The rocks occupy in England a broad continuous belt of country, ranging north-north-east from the coast of Dorsetshire to the coast of Yorkshire. The whole series is conveniently subdivided into three principal groups, each consisting of several members. As main subdivisions they are retained generally throughout Europe; but the various members are altogether local, and it must not be expected that the same kind of rock will extend very far. The oolites of England suggest the idea of a sea receiving and distributing rapidly large accumulations of mud, and admitting of the secretion of much carbonate of lime during a time chiefly of subsidence, but occasionally varied by upheaval. The following is a general statement of the deposits:—

Middle	Upper calcareous grit		80 ft.
	Coral rag		
	Lower calcareous grit		
	Oxford clay, 600 ft.		
	Kelloway rock, 10 to 60 ft.		
Lower	Cornbrash, 15 to 80 ft.		
	Great oolite, 260 ft.	Forest marble.	
		Bradford clay.	
		Bath oolite.	
		Stonesfield slate.	
		Fuller's earth.	
		Lignites of Yorkshire and Scotland.	
	Inferior oolite, 230 ft.		
	Liassic sands, 60 ft.		

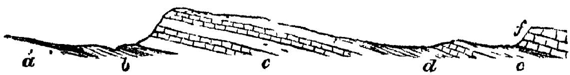


FIG. 34 —SECTION ACROSS THE LOWER SECONDARY ROCK.
a. Triassic or Rhætic beds *b.* Lias *c.* Great Oolite *d.* Calc grit, Coral rag, and Oxford clay. *e* Kimmeridge clay *f.* Portland series

The *liassic sands* consist of a loose sandy deposit, slightly micaceous, separating the upper lias from the inferior oolite; but they contain shells which are peculiar, and their thickness is sometimes considerable. Over them come the limestones (generally oolitic) of the *inferior oolite*, not very well adapted for building purposes, but often used. They contain some characteristic shells. Above the inferior oolite is sometimes a bed called *Fuller's earth*, but between are often interpolated certain bands of lignite or imperfect coal, some of fair quality known as the *Moorland coal* of Yorkshire; others the *Brora coal*, consisting of workable seams of coal found in Brora in

Scotland. Both are freshwater and estuary deposits. In Yorkshire, where the lignite beds overlie the lias, the strata include valuable seams of ironstone nodules, and only a few seams of poor coal, although some of them have been worked for many years. In Scotland, at Brora, there are seams more than a yard thick of fair quality.

The *Fuller's earth* is a band of clay of a peculiar nature, very absorbent of grease, and used in the manufacture of cloth in the process called fulling. It is covered or replaced by a thin-splitting calcareous stone used sometimes for roofing purposes, and called Stonesfield slate. A similar flag or tilestone is found at Colley Weston, in Northamptonshire.

These slates, flags, or tilestones (for they enjoy all these titles), are two in number, and are separated by a less compact rock of the same kind. In them was found many years ago the first indications of mammalian life in beds of the Secondary period. Since then the number of species has been greatly increased, and at present the limit with regard to such animals is found in the Trias. No doubt the time will come when we shall meet with them in Palæozoic rocks, for where there was any large extent of land, it is probable that there were quadrupeds of some kind. All these older forms of quadrupeds were marsupial, as indeed are all the native quadrupeds of Australia. All the species described were of small size, while the reptiles of the period were large in size and varied in form, many genera as well as species that then lived having since disappeared.

The *Bath oolite* is a series locally very important, owing to the large quantity of excellent soft building stone obtained from it. The beds consist of numerous bands of limestone, some coarse and shelly and full of fossils, others of fine texture and containing few or no shells. The finer limestones are generally oolitic, and each little grain is found to have for its centre some organic body; but this can only be made out by the microscope. Towards the north of England the limestones of this period are more compact and durable.

A thin band of clay, called the *Bradford clay*, containing a great abundance of a peculiar fossil, called the "pear encrinite" (*Apiocrinites*), overlies the Bath oolite near Bradford in Wiltshire. It is of a pale greyish colour, and encloses slabs of tough limestone. It is often absent or replaced by a calcareous bed of shelly marble, called *Forest marble*, semi-crystalline, and occasionally polished for ornamental use. In the north of England these beds are represented by black shales containing carbon. In Normandy there is a coral limestone of the same age, covering the well-known *Caen oolite*, a beautiful and valuable building stone representing generally the lower oolites of England. The *Cornbrash*, consisting of clays, sandstones and rubbly limestone, decomposing into good corn lands, caps the escarpment of the lower division of the oolites. All the beds between the Inferior oolite and the Cornbrash may be included under the name "*Great oolite*." The total thickness of the group in the West of England is about 260 feet, and we may consider that on the whole the various formations are estuarine, having been formed in water not very deep, near land, and perhaps not far from considerable streams. The land adjoining was inhabited by very large land and flying reptiles and very small quadrupeds. There may also have been large quadrupeds and birds, and small reptiles. Some of the reptiles whose remains have been found were of exceedingly large dimensions, and differed from all living reptiles by possessing long legs lifting them high above the ground. Of such we know two very distinct kinds, both gigantic. One was carnivorous and rapacious. It is called *Megalosaurus* (Greek: *megale*, great; *sauros*, lizard), and is known by its teeth, lower jaw, leg bones, and other bones. Of these there is a lower jaw, nearly a foot long, and a thigh bone, three feet long. Another animal, of which little more than the leg bones are known, was larger in size and stood higher. It was called *Cetiosaurus* (Greek: *cetos*, whale; *sauros*, lizard), from a supposed resemblance to a whale. It was, however, in all probability, a true land reptile. Its thigh bone was five feet four inches in length. There were also crocodilean animals, ranging from the very commencement of the Secondary Period, through all the various series of rocks, modified in some matters of detail, but representing both the land and fresh-water varieties. The flying reptiles, or *Pterodactyls*, were numerous, and were also continued through the whole period, though it was not till the latter part that those of largest size appear to have lived. They are known very completely by their skeletons. (*See* restoration, fig. 35.) The aquatic rep-

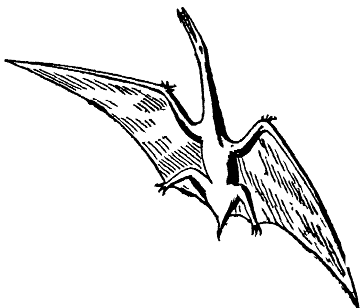
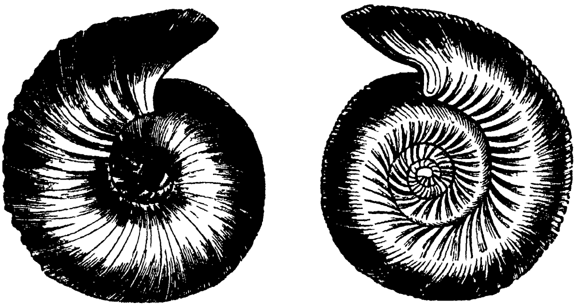


FIG. 35.—Pterodactyl.

tiles of the period differed only in detail from those of the lias, already described. The quadrupeds were small, but bones of many individuals have been found, and they show a variety of size and habits. It is even thought that one of them does not belong to the marsupial tribe. There is no evidence at present as to birds; but as they seem to have lived in the Triassic Period, they were probably not wanting later. Fishes' remains are common; and the forms, though retaining many peculiarities, approach nearly in some cases to existing tribes. The shells include ammonites and belemnites in considerable variety, besides many bivalve and univalve species, some characteristic. Of crustaceans there are several; but none of them remind the naturalist of the trilobites of the Palæozoic Period. Some, however, resemble the king crab (*Limulus*), of which various early examples exist, while others are closely allied to species at present common enough. There are many radiata, including a number peculiar to the formations in which they are found. There are also corals.

The middle oolites commence in the south-west of England, with a few feet of calcareous rock, called *Kelloway rock*, thickening towards Yorkshire. This is covered up by a thick bed of tolerably pure clay, called *Oxford clay*, which is developed in some parts of England to a thickness of 600 feet. It is generally a stiff clay, though not without much calcareous matter. It is also rich in fossils, but these are often merely the nuclei of ironstone nodules. It is surmounted by sandy beds with thin plates of clay and marly rock, called the *Lower calcareous grit*, apparently derived almost entirely from crushed shells and decomposed animal remains. The *Coral rag* comes next. It exists in some places to the thickness of thirty or forty feet, and forms a small coral reef, made up largely of a single species of coral, but partly of fragments of shells and other corals that have been mixed up with it. Parts of it yield a fair building stone. This coral reef ranges throughout England. The *Upper calcareous grit* is a mixed rock, partly a freestone, lying at the top of the Oxfordian



AMMONITES.

FIG. 36.—Ammonites Achilles Oxford clay. FIG. 37.—Ammonites Lamberti Coral rag.

group, or middle secondary rocks. The total thickness of the Oxfordian rocks in England does not much exceed 700 feet. In France a clay, called *Argile de Dives*, represents the Oxford clay in Normandy. In Switzerland the coral rag is the part chiefly developed. It there contains a turreted univalve shell, called *Nerinæa*, whence the whole group is called the *Nerinæan limestone*. There is also a valuable bed of iron ore.

The upper member of the oolitic series includes only two formations, the *Kimmeridge clay*, somewhat resembling the Oxford clay, and of the same thickness (600 feet), and the *Portland beds* (together about 180 feet), chiefly calcareous. The former is remarkable, as containing a lignite called the *Kimmeridge coal*, formerly much worked at Kimmeridge Bay, but now abandoned. There are three recognized divisions of Kimmeridge clay, distinguished by fossils. A kind of limpet (*Discina*) and ammonites are the most useful fossils. The Portland beds consist of thick, valuable, and well-stratified bands of limestone, separated from the Kimmeridge clay by intermediate bands of sandy rock mixed with green particles, called *Portland sand*. The limestone contains the best and most important of all the building stones of England. It is of a creamy white colour, slightly oolitic, and sometimes semi-crystalline in texture. On the Continent the beautiful lithographic stones of Solnhofen, in Baqaria, replace the Portland rock, and are exceedingly rich in fossils, including insects, crustaceans, fishes, and many shells. A few years ago remains of an animal provided with feathers, and therefore attributed to a bird, were found in these beds. There is still some doubt as to the nature of this curious animal. It was about the size of a rook. It had the backbone continued to the extremity of the tail, a peculiarity unknown in any bird. This is the more remarkable, as in the fishes of the older formations the same peculiarity is observed, the fins there being attached to the extremity of the

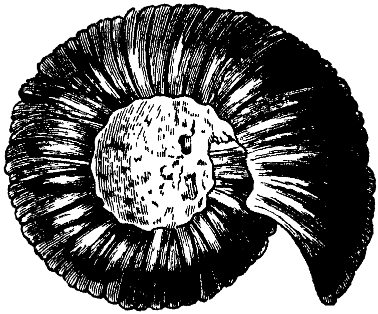


FIG. 38 —Ammonites biplex, Kimmeridge clay.

backbone, as the feathers were in the Solnhofen bird. It is a peculiarity also in each case that carries the structure of the very young animal into the subsequent growth, whereas in existing fishes and birds that structure is modified at a very early period.

CHARACTERISTIC AND REMARKABLE FOSSILS.—Of the lower division: (1) Plants—*Thuytes articulata*, Impressions of ferns, *Cycadeæ*. (2) Corals—*Eunomia radiata*, *Thamnastræa*, *Arbasia*, *Thecosmilia*. (3) Echinodermata—*Pseudodiadema*, *Arbacia*, *Acroselenia*, *Apiocrinites*, *Cidaris*. (4) Brachiopoda—*Terebratula fimbria*, *T. digona*, *T. intermedia*, *T. carinata*, *T. obovata*, *T. ornithocephala*, *Rhynchonella spinosa*, *R. Lycettii*, *R. cardium*. (5) Bivalve shells—*Pholadomya fidicula*, *Ph. Heraultii*, *Ph. carinata*, *Ostrea flabelloides*, *Lima Pontonis*, *L. duplicata*, *Pecten fibrosus*, *P. articulatus*, *Trigonia costata*, *Tr. striata*. (6) Univalves—*Pleurotomaria granulata*, *Pl. ornata*, *Purpuroidea nodulata*, *Cylindrites acutus*, *Patella rugosa*, *Nerita costulata*, *Emarginula* (*Rimula*) *clathrata*, *Nerinæa cyngenda*, *Cerithium*. (7) Cephalopoda—*Ammonites Humphreysiana*, *A. Braikenridgii*, *A. Murchisoni*, *A. Parkinsoni*, *Belemnites elongatus*, *B. giganteus*, *B. ellipticus*. (8) Crustaceans—*Glyphæa rostrata*. (9) Insects. (10) Fishes—*Aspidorhynchus*, *Pycnodus*, *Ganodus*. (11) Reptiles—*Ichthyosaurus*, *Plesiosaurus*, *Megalosaurus*, *Cetiosaurus*, *Pterodactyl*. (12) Mammalia—*Amphitherium*, *Phascolotherium*.

Of the upper and middle divisions: (1) Corals—*Thecosmilia arachnoides*, *Thamnastræa*, *Isastræa* (many species), *Stylina*, *Comoseries*. (2) Echinodermata—*Cidaris Blumenbachii*, *Hemicidaris intermedia*, *Pseudodiadema*. (3) Brachiopoda—*Rhynchonella varians*, *Rh. inconstans*. (4) Bivalve shells—*Trigonia clavellata*, *Tr. elongata*, *Tr. gibbosa*, *Ostrea gregaria*, *O. deltoidea*, *Gryphæa* (*Exogyra*) *virgula*, *G. bilobata*, *Perna mytiloides*, *Cardium striatulum*, *C. dissimile*. (5) Univalves—*Nerinæa Goodhallii*, *Phasianella striata*, *Discina*. (6) Cephalopoda—*Ammonites Jason*, *A. Comptoni*, *A. Williamsoni*, *A. athleta*, *A. Duncani*, *A. biplex*, *A. anceps*, *Trigonellites latus*, *Belemnites hastatus*, *B. Owenii*. (7) Fishes—*Lepidotus minor*, *Asteracanthus*. (8) Reptiles.

CHAPTER VIII.

Newer Secondary Rocks and Fossils.

LOWER CRETACEOUS OR NEOCOMIAN SERIES.

The newest and uppermost strata of the lower secondary series, comprising the beautiful beds of compact, heavy, and close-grained building stone known as "Portland," chiefly quarried in the Isle of Portland, are sometimes covered by estuary and freshwater limestones, marls, and other beds, called *Purbeck beds*, because chiefly seen in the Isle of Purbeck. Among the deposits are bands of black loam, formerly the soil in which grew trees whose stems and roots are still to be found. They are often called *dirt beds*, and range for a considerable distance. Except in the coal measures there is no other instance known in which the trees and the soil in which they actually grew are found together. The trees are very different in the two formations, although both are distinctly unlike the modern vegetation of the country. The Purbeck vegetation, like that of the older part of the Secondary Period, approached in its general character the vegetation of South Africa.

Over the dirt beds, and among them, is a coarse flaggy limestone, used as slate for common roofing purposes, and also a slaty clay, over which are compact limestones with bivalve shells, of kinds now living in fresh water. After this is the *cinder bed*, a mass of oyster shells, and then limestones valuable for building. Among them is a kind of half-crystalline mass of little univalve shells, like snails, called the *Purbeck marble*, often cut into pillars and polished, for use in the insides of churches and cathedrals. Most of these beds are fossiliferous. They have yielded not only insects, crustaceans, shells, and fishes, but a considerable number of bones, referred to many species of small quadrupeds not larger generally than rats, but marsupial, or pouched, like the quadrupeds of Australia.

The whole thickness of the beds recognized as Purbeck in the parts of England where they are best exhibited, may be about 300 feet, and it is clear, from all the attendant circumstances, that as a group of rocks the Purbeck is estuarine or fresh-water, land having been very near during the whole deposit. It has generally been thought that the direction of the land was towards the west, at least in great measure, and that there was a large estuary, connected perhaps with a considerable river, opening out in that part of England where we now have the counties of Sussex and Kent, and reaching across the British Channel to the neighbourhood of Boulogne. The rocks in

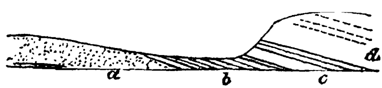


FIG. 39.—SECTION ACROSS THE UPPER SECONDARY ROCKS OF ENGLAND.
a. Chalk. *b*. Weald clay. *c*. Greensands and Gault. *d*. Hastings sand.

this tract of country are called by geologists *Wealden*, the name (which is modern) being given because a large quantity of forest (or wold) was left growing here after most of the forest lands of England had been removed.

The lower of the Wealden deposits is called the *Hastings Sand.* It is a thick mass of loose open-grained sandstone, well seen in the cliffs near Hastings, and covering a large portion of Sussex. The caverns excavated under Hastings Castle are in this rock. Above these soft sandstones are others of harder quality, formerly quarried at Tilgate, near Horsham, and called *Tilgate beds.* They are somewhat calcareous, and in the lower part are conglomerates, but the building stones are bluish grey grits. Remains of several gigantic land reptiles have been found in these beds, some carnivorous and some herbivorous, and remains of plants are also met with.

Beds of sandstone and shelly limestone, with clay ironstone, lie over the Hastings sands. Among them is a limestone called *Sussex Marble,* like the Purbeck marble, and made up of shells. Being semi-crystalline, it is capable of receiving a polish, and is used in churches. Some of the strata are a foot thick, but this is an exception. Above them is a thickness of 600 feet of clay, called *Weald Clay,* covering the Hastings sand on the outer margin of the Wealden district. It is generally blackish, and contains many fresh-water shells, and millions of shells of very minute crustaceans (*Cypris*), not so large as a pin's head.

Wealden deposits are found in the Isle of Wight and near Boulogne, and beds occupying the same geological position are found in the North of Germany, near Hanover. The latter, however, are chiefly thick beds of sandstone. There are no doubt marine beds of similar age, but these we shall consider presently, as they are not found in England near the Wealden district.

The reptiles of the Wealden and Purbeck include several species of turtles of the terrapin or fresh-water type; three (perhaps four) species belonging to genera of gigantic land saurians, several species of lizards, and several of crocodiles. Of these the great carnivorous reptile *Megalosaurus* has already been alluded to. It inhabited the land during the Oolitic Period, and continued to the Wealden. With it on the Wealden land was the *Iguanodon*, so called from the resemblance of its teeth (Greek: *odous*, a tooth) to those of the Iguana. This animal was a vegetable feeder, attaining enormous dimensions. Like the Megalosaur, its leg bones are so long that the creature must have stood very high above the ground, perhaps not less than ten or twelve feet.* The whole length of the animal could not have been under twenty-five feet. The feet were large and provided with claws. Another land reptile, called *Hylæosaurus* (Greek: *hylæos*, a wood, and *sauros*), the saurian of the wooded district or Weald, was probably fifteen feet long and taller in proportion even than the Megalosaur. Its habits are not known, as there have been no jaws or teeth found. The *Cetiosaurus*, as has been already observed, was a gigantic land reptile, without any real resemblance to the whale. There were also true crocodiles of very large proportions.

The Wealden deposits are well represented, and have yielded some of their most interesting and characteristic fossils, in a group of deposits at the back of the Isle of Wight, and there the overlying marine deposits which connect the Wealden with the rest of the older cretaceous rocks are also well shown. They are

* This is taller than a very tall elephant. Elephants rarely reach eleven feet.

known as the *Atherfield Beds.* These beds are essentially marine, and seem to indicate a considerable subsidence during or at the close of the deposit of the fresh-water clays of the Wealden. They contain fossils in abundance, chiefly shells. Very similar rocks, with the same kind of fossils, appear in Kent, where, however, the thickness of the deposit is small. Above them, near Hythe, are stone beds of some importance, known as the *Kentish rag* and *Bargate stone.* These are local, but interesting. Elsewhere whitish or greenish sandstones alternate with clays of the same age. After about sixty feet of such beds we come to about eighty feet of beds at Sandgate, covered by a similar series, somewhat thicker, reaching to Folkestone, where other beds of a newer period cover them up and conceal them. These together form the group of the "Lower Greensand" of the older geologists. The rocks were so called from grains of silicate of iron of a green colour pretty generally spread amongst the sands and sandstones. The green grains are often absent, but the name remains, and is convenient.

Many years ago there was recognized in Switzerland, not far from the town of Neufchâtel, an important and large group of limestones, between the Portlandian rocks of the Jura mountains and the beds recognized as belonging to the Chalk Period. These were called by Swiss geologists *Neocomian* (from *Neocomum*, the Latin name for Neufchâtel). The lower members of the great series here presented are now recognized as belonging to the period of our Weald, while the upper division represents the Lower Greensand of the Isle of Wight and the south-east coast of England. But it is not only on the Continent that such contemporaneous beds exist. On the Yorkshire coast of England there is also a nearly complete series of rocks of this kind extending upwards from the Kimmeridge clay into the upper Neocomian or Atherfield beds. A few words on this important coast section will be useful to the student.*

The junction of the Upper Oolites and the Lower Neocomian, though not conformable, is marked in this part of England by a layer of nodules of phosphate of lime and saurian remains, above which are about 250 feet of shaly clays with much pyrites distributed in three groups, each characterized by a peculiar species of ammonites. The number of other fossils is not large, but the species are important, and clearly identify the beds with the Lower Neocomian of Switzerland and France. The lower sands and sandstones of Lincolnshire, resting on the blue clays which there represent the upper oolites, are of the same age. So also is the *Carstone* of Norfolk and Cambridgeshire, an indurated mass of sands in the same position. Thus marine beds were being deposited in this part of England whilst the fresh-water beds of the Wealden were accumulated.

At Speeton, where these beds may be examined with advantage, we also have the Middle Neocomian, consisting of dark blue clays with bands of cement stones, overlaid by other clay beds. One of these is called the *shrimp bed*, as containing many remains of a small crustacean. A peculiar form of ammonite (*Ancyloceras*) is common in these beds, which are about 150 feet thick, and, on the whole, poor in

* Geologists are indebted to Mr. Judd for this work. *See* "Quart. Journ. of Geol. Soc., 1868," p. 218.

fossils. Next above them are dark-coloured clays 120 feet thick, with about thirty feet of septaria or nodules used for making cement. The fossils in this upper bed of this *Speeton Clay* series are those of the Atherfield beds in the Isle of Wight. The very important section at Speeton is of the greatest interest in connection with the lower member of the great Cretaceous series, and completes the English series in a manner equally interesting and unexpected.

Other examples of Lower Greensand in England are to be found in the lower part of the Greensand series in Devonshire, and the *Sponge gravel* of Faringdon in Berkshire. A bed called the *Plicatula clay* belongs to the upper part of the series. At Pondicherry in India and in South Africa fossils have been found which indicate contemporaneous beds. Remains of reptiles have been found in various deposits of this period, but they differ little from those of the Wealden.

The total thickness of the Lower Greensand, or Upper Neocomian, as developed in England, is not less than 1,200 feet, while the Wealden or Middle and Lower Neocomian yield 1,600 feet of fresh-water, or 350 feet of marine strata, according to position. These together are inferior in magnitude to the great series of yellow and white limestones of the same period in Switzerland and the South of France. In Germany, the beds called *Hilsthon* and *Hilsconglomerat* belong, the former to the Middle, and the latter to the Lower Neocomian. Extensive Neocomian deposits occur in Spain, Italy, Austria, the Crimea and Caucasus, Northern Africa and South America. In the latter continent there are fossils obtained from Bogotá identical in species with some of those from Speeton.

CHARACTERISTIC AND REMARKABLE BRITISH FOSSILS.—Of the Purbeck beds: (1) Plants—*Zamia*, *Cycas*, and coniferous trees. (2) Radiata—*Hemicidaris Purbeckensis*. (3) Shells, chiefly land and fresh-water—*Cyclas*, *Unio*, *Cyrena*, *Corbula*, *Pecten*, *Modiola*, *Avicula*, *Valvata*, *Lymnæa*, *Paludina*, *Physa*, *Planorbis*, *Melania*. (4) Crustaceans—*Cypris punctata*, *C. Purbeckensis*. (5) Fishes—*Lepidotus Mantellii*, *Microdon radiatus*, *Aspidorhynchus Fisheri*. (6) Reptiles —*see* Wealden. (7) Mammalia—*Plagiaulax Becklesii*, *P. minor*, *Triconodon*.

Of the Wealden and Neocomian beds: (1) Plants—*Coniferæ*, *Cycadeæ*, Ferns. (2) Fresh-water shells—*Cyrena*, *Cyclas*, *Unio*, *Melanopsis*, *Paludina*, *Tornatella Popii*. (3) Marine shells—*Perna Mulleti*, *Gervillia anceps*, *Trigonia caudata*, *Lima elongata*, *Corbis*, *Pleurotomaria gigantea*, *Nautilus plicatus*, *Ammonites Deshayesii*, *A. Neocomiensis*, *A. Nutfieldensis*, *Ancyloceras gigas*. (4) Crustaceans—*Cypris spinigera*, *C. Valdensis*, *Meyeria Vectensis*, *Palæochoristes*, *Hoploparya*. (5) Fishes—*Chimæra*, *Lamna*, *Lepidotus*. (6) Reptiles—*Pleurosternon*, 4 sp., *Chelone*, *Platemys*, 2 sp., *Iguanodon*, *Megalosaurus*, *Hylæosaurus*, several lizards, *Streptospondylus*, *Cetiosaurus*, *Pelorosaurus*.

UPPER CRETACEOUS SERIES.

There is generally a marked want of conformability between the upper beds of the Lower Greensand and the overlying deposits, and this extends to the fossils, which vary a good deal. The *Gault*, the lowest member of the Upper Cretaceous series, is shown in a characteristic manner at Folkestone, and may be traced thence to Cambridgeshire, where it is of some thickness. Beyond to the north it changes its character, and is represented by a red rock at the base of the chalk series at Hunstanton Cliff, Norfolk. It there overlies unconformably the Upper Neocomian rocks. The thickness of the Gault is in some places as much as 250 feet. It is a dark blue marly clay, very fossiliferous, but also very pyritous, and thus the fossils, easily obtained, rapidly perish on exposure to the air. In many places the gault is much used as brick clay. The name is local and provincial. In its upper part the clay contains many green particles of silicate of iron, and thus passes into the upper greensand.

The *Upper Greensand*, generally a calcareous sandstone, often a pure sand of deep red colour, but almost always in England containing particles of green silicate of iron, is well seen near Godstone in Surrey, where it is quarried for a useful kind of firestone. It is seen also in Bedfordshire. The harder bands come out at the foot of the chalk for some distance in Surrey, and are called *Malm rock*. The thickness diminishes towards the north, and is reduced to a foot or two in Cambridgeshire, but the rock is still traceable. In the Black Down Hills in Devonshire there are bands of hard chert, alternating with loose sand and rich in fossils, that appear to represent both gault and upper greensand. The fossils have been converted into chalcedony, and are often very beautiful. Parts of the stone are used for building.

Exceedingly valuable and important bands of phosphate of lime occur in the gault and upper greensand. They are abundant, and have been worked of late years to great profit for agricultural purposes near Farnham in Surrey, at Folkestone, near Cambridge, and elsewhere. They are not always organic, though obtained from organic substances. Many of them have been derived from the excrement of fishes and reptiles, but the exact cause of their presence in these deposits is not clear.

Beds representing the gault and upper greensand are found in France and Belgium, in the north of Germany (there called *Plänerkalk*), and in the canton of Glaris, in Switzerland. In the last-named locality the deposits are rich in remains of fishes. This part of the Cretaceous series has been identified in the north-west extremity of North America. The Upper Greensand is considered to be the equivalent of the *Lower Quadersandstone* of Germany.

Chalk is the name given in England to a soft, thick, widely spread formation, consisting to a very large extent of carbonate of lime in a peculiar form, traceable for a long distance along the south coast of England, and again at certain points on the east coast, and continuing across the Channel to Belgium and Denmark on the east, and to the French coast on the south and south-east. The narrow passage called the Straits of Dover is a deep cut in the great ridge of chalk that once continued from Dover to Cape Grisnez, and there is still in all probability a thickness of 400 feet of chalk below the present bottom of the sea.

Chalk is a nearly pure carbonate of lime, too well known to need description. It is of a creamy white colour, almost the same in texture throughout, and has numerous flint bands, and some detached fragments or nodules of flint distributed through it. Its thickness in England is estimated at about 1,000 feet. It ranges from the south coast through the eastern counties, and terminates on the Yorkshire coast. Where it reaches Denmark the white chalk is capped with a more friable limestone containing numerous corals, believed to be much newer than our white chalk. In many parts of England, where the base of the deposit is seen, the chalk is of grey colour and less pure in the lower part, terminating downwards in the *chalk-marl*, and a variety of chalk with many siliceous grains. This passes directly out of the Upper Greensand. The chalk is remarkable for its fine escarpments, a fresh face of rock being constantly exposed, owing to the readiness and rapidity with which it is acted upon by weather.

Out of England, there is chalk in France, but, although harder, the rock is similar to the English type. Part of it is somewhat newer. In Belgium, near Maestricht, are also upper beds. In the East of Europe, it appears in Poland, the south of Russia, and the Caucasus. There are contemporaneous beds in Germany, in the *Upper Quadersandstone*, a loose-textured sandstone. In New Jersey, U. S., are sandy beds and clays, in the Texas siliceous limestones, in South Africa dark sandstones, all of this part of the Cretaceous Period.

The chalk as exhibited in England is remarkable for an admixture of black flint, chiefly in the upper members, and always in nearly the same condition. The flint generally occurs in thin bands, parallel to the stratification. It is sometimes in layers of large detached lumps, each flint coated with chalk to a sensible depth below the surface. Sometimes cracks and fissures of the chalk, more or less vertical, are filled with flint. On close examination, even without the assistance of the microscope, it becomes evident that many remains of living beings, consisting of shells, or stony skeletons, have become entangled with the flint during the time of its formation. Sometimes half a shell (itself converted into flint) projects from the smooth surface of the flint, the rest being buried. Not unfrequently there are markings, which show that a structure like a sponge is entirely enclosed. Under the microscope, the minute structure is seen to be almost always organic, and even the texture of soft animals not provided with hard skeletons is not unfrequently preserved almost uninjured. Much difficulty has been felt in explaining this condition, but naturalists are generally agreed that the presence of life has had much to do with it. It is evident, that the origin and history of chalk must be understood before we are likely to see how the flints were placed where we find them.

Chalk, although having the same composition as hard limestones, is almost earthy in texture and easily broken up into a fine powder. The powder, when carefully examined, is found to be made up of fragments of various shells, and of millions of the very minute shells of foraminifera (*see* fig. 40). This is precisely the nature of the mud now forming at the bottom of the Atlantic, lifted during deep soundings, or by dredges, from hundreds of fathoms below the surface, far beyond all influence of currents carrying mud from the land.

FIG. 40.—Chalk Foraminifera.

Under favourable circumstances of temperature there would seem to be a large and never-failing supply of animal life at the sea bottom, and there can be no doubt that by the solid matter separated from the salt water by these animals, large deposits in deep water are constantly being made. Carbonate of lime is the material chiefly separated, and forms the great mass of the material added, but spicules of flint are also secreted, especially by sponges and other organisms of the simplest kind, and these are left behind when the animal dies.

Flint is capable of existing in a peculiar jelly-like state, almost dissolved in water, and in this state may accumulate in large quantity. Whether owing to the outflow of springs containing much silica, such as occur in volcanic districts, or owing to other causes less evident, an excess of silica may from timo to time have been deposited at the sea bottom, and the tendency in such caso would be to cover up all the living organisms and all such remains as were lying there. That there exists under ordinary circumstances a mass of organic matter at the bottom of deep water in a gelatinous state, ready to be converted into silica, is rendered probable by modern researches at the bottom of the Atlantic. What the organic matter may be—whether animal or vegetable, or of doubtful nature—is a question that cannot but interest the geologist, but it is not yet distinctly answered.

Flints abound with remains ot sponges and sponge-like bodies, some of which evidently grew to an enormous size, and were piled vertically one above another to a considerable height. Others were very minute. Whole columns of certain kinds (*Paramoudras*), converted into flint, have been found in the Norfolk chalk quarries. One common species is represented in the annexed cut (fig. 41, No. 6). Flint also contains many other organisms, curious in form, though simple in structure. Many of them appear to have been soft animals, though others may have had a partial skeleton of needle-like crystals of quartz.

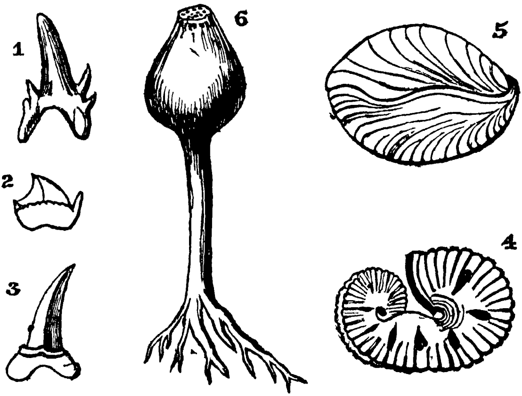


FIG. 41.—GROUP OF CRETACEOUS FOSSILS.
1, 2, 3. Teeth of sharks. 4. Scaphites æqualis. 5. Terebratula carnea. 6. Sponge (Siphonia).

Chalk, as has already been pointed out, abounds with shells of Foraminifera. Certain forms, now very common, are almost equally common in this rock. But chalk also contains many shells, both bivalve and univalve, and among them *Terebratula* (Fig. 41, No. 5). It contains many of the later forms of the Ammonite and Nautilus, as *Hamite*, *Scaphite* (fig. 41, No. 4), and *Ancyloceras*, and many Radiata, both star-fishes and sea-urchins. There are few true corals, but many Polyzoa, whose habitations are often described as corals. Fishes are abundant and characteristic. Many were scaly, and approach pretty closely to the existing species. Among the fossils, are many

Sharks' teeth (*see* Fig. 41, Nos. 1, 2, 3). Of Reptiles there are several species, some of them remarkable. They include the *Mosasaurus* (the reptile of the river Meuse in Belgium), a lizard-like reptile, twenty-five feet in length, supposed by Cuvier to have been aquatic. Its paddles were very large and long. Its jaws and teeth are crocodilian, and its habits were probably similar to those of the crocodile.

The upper cretaceous formations are singularly rich in those curiously organized flying reptiles called *Pterodactylus*. These have been already alluded to. The most remarkable specimens have been found in the upper greensand, and they include bones of individuals of size so gigantic as to bear comparison with the largest flying animals. A distance of as much as twenty feet between the tips of the expanding membrane that served as wings seems not to have been greater than belonged to these strange monsters. The head, portentous jaws, and serrated row of sharp teeth were fully proportioned to these extraordinary dimensions. The legs and feet seem to have been small in proportion, and although some of the species were perhaps capable of swimming, there can be little doubt that the air was their chief resort. It has been suggested that they belong to a group of animals intermediate between Reptiles and Birds. Several species of Ichthyosaurus, and Plesiosaurus; several new genera allied to these and to the Crocodile; some Turtles of large size, and a few curiously formed Lizards, complete the list. No remains of quadrupeds have yet been found in upper cretaceous formations.

As the beds at the base of the Upper Cretaceous series seem to indicate the vicinity of land in the clays and sands of the gault and upper greensand,

and their contents, so also the uppermost strata of chalk, especially in Belgium and Denmark, point to a similar conclusion from the study of their fossils. The intermediate stage, when the true chalk was deposited, involved a deep sea in most parts of Europe where chalk now appears. As, however, the American and some of the Eastern representative beds were of a different kind of rock, and the land that had disappeared here was in existence elsewhere, it is not extraordinary that there should be a considerable difference in the nature of the organic remains.

CHARACTERISTIC AND REMARKABLE FOSSILS.—(1). Amorphozoa—*Brachiolites, Chenendopora, Siphonia, Manon, Polypothecia, Paramoudra, Spongia, Ventriculites.* (2) Foraminifera—*Bulimina, Dentalina, Globigerina, Nodosaria, Rosalina, Rotalina, Textularia.* (3) Corals—*Parasmilia, Smilotrochus, Caryophyllia, Microbasia, Trochocyathus.* (4) Echinodermata — *Bourgueticrinus, Cidaris, Cyphosoma, Diadema, Marsupites, Ananchytes ovata, Micraster cor-anguinum, Galerites albo-galerus, Goniaster, Stellaster, Selenia.* (5) Brachiopoda—*Terebratula squamosa, T. striata, T. carnea, T. biplicata, Waldheimia, Terebrirostra lyra, Argiope, Rhynchonella octoplicata, R. plicatilis, Magas pumila, Crania Parisiensis.* (6) Bivalves—*Ostrea vesicularis, O. macroptera, O. carinata, O. frons, Lima Hoperi, L. globosa, L. spinosa, Pecten 5-costatus, P. Beaveri, Inoceramus.* (7) Cephalopoda —*Nautilus lævigatus, Ammonites auritus, A. Rhotomagensis, A. Mantellii, A. Lewesiensis, Hamites armatus, H. maximus, Scaphites æqualis, Ancyloceras gigas, A. spinigerum, Belemnitella mucronata, Belemnites minimus, Turrilites.* (8) Fishes (chiefly teeth)—*Oxyrhina, Lamna, Corax, Odontaspis, Otodus, Ptychodus, Saurocephalus; Dercetes, Beryx, Macropoma.* (9) Reptiles—*Chelone,* 3 sp., *Protemys, Raphiosaurus, Coniosaurus, Dolichosaurus, Mosasaurus, Leiodon, Crocodilus, Polyptychodon, Plesiosaurus, Ichthyosaurus, Pterodactylus,* 6 sp.

The true chalk, of which the uppermost member dies out at Faxoe, in Denmark, as a friable coral-bearing limestone, has generally been regarded as separated by a gap so wide and complete from anything lying over it as to involve the lapse of a vast period, and an entire change in the whole system of deposits. It seems probable that increased and minute investigation in various countries, and the comparison of deposits of the same period at distant points, may lay bare deposits of this intermediate period. Already there have been detected near Marseilles strata of strictly lacustrine character of the age of the upper chalk, developed in a series 1,400 feet in thickness, and covered by thick beds, also lacustrine, of the Older Tertiary Period. Important bands of lignite are worked in these strata. There are in other parts of Southern Europe foraminiferous limestones, apparently of the cretaceous period, but which, if so, belong to the uppermost cretaceous deposits, and may bridge over the interval. However this may be, we must still recognize the close of the Secondary Period as one of the great breaks in the geological series. Everything lying on the chalk and contemporaneous beds is geologically unconformable, and the life of the newer period is on the whole different from that of the old. In the Secondary, as in the Palæozoic Period, we have, in the parts of the world already examined geologically, long and large ranges of rocks, continuous and resembling each other over wide tracts, often connecting lands now separated by deep seas. At a later period the deposits are more isolated, and point more to continuous land. The land of the northern or land hemisphere was then disconnected where it is now connected, and there are peculiarities both in the faunas and floras of all the groups of rocks, especially the few that indicate the near presence of land, that render this very clear. The student of Geology must familiarize himself with the important truth that he sees only fragments of the geologic record; that of the great history he endeavours to make out, only a few chapters and parts of chapters are preserved at all, and that even these he can by no means understand thoroughly and appreciate fully.

It has been pointed out already that the Secondary series of rocks is generally well represented in England; and, indeed, there is not to be found in any part of the world yet known so much variety, and such a complete outline of the record, as in our little island. In proportion, however, to the fulness of the evidence up to the end of the deposit of the chalk is the blank that succeeds.

During this period the great geographical axis of the Old World, and perhaps that of the New World also, began to impress on the earth the features we now recognize. Before that there may have been open sea in the northern hemisphere, as there now is in the south, and there may have been land crossing the Atlantic, and connecting Europe with North America in temperate latitudes. The rising up of the great mass of the land that now forms the Old World may have produced first a string of islands and island groups, ranging east and west, gradually multiplying as more and more of the mountains and plateaux and hills rose above the waters. So long as the great plains remained under water there was no continent, there was much water of moderate depth, and conditions were favourable for deposit. At length the work was completed; the great plains rose out of the sea, and the expanse of land checked all marine deposits over millions of square miles. Then and in this manner terminated the Secondary Period—a period, so far as we can judge, of little convulsive movement, during which the conditions of life changed gradually, and during which it is quite possible that there was a very different state of things in the opposite hemisphere, about which we at present know nothing. The elevation of land parallel to the great mountain chains would form a perfectly effectual barrier to the communication of species by water in temperate latitudes and on opposite sides of a wide tract of land. This great and systematic elevation was no doubt accompanied by corresponding subsidence, so that the general features of the earth may have become altogether changed, and climates completely altered.

CHAPTER IX.

Tertiary or Cænozoic Rocks and Fossils.

OLDER TERTIARY SERIES.

The history of the earth is a history of perpetual change, large in amount between distant periods of time, but very slow in progress; rarely perhaps, if ever, convulsive on a large scale, but producing alternate elevations and depressions, sufficient to modify in time all the physical features of the land. Where in any district there is a distinct gap, either from an entire want of conformability, over a large area, of the newer on the older rocks, or where the fossil remains of two series of rocks in contact are exceedingly different in *facies*, or general aspect, as well as in species, it is impossible not to perceive evidence of a long lapse of time. In proportion as the life was different, the conditions of life must have been different, for conditions of life mean conditions of climate and position, and these only change with time. Thus very marked changes of this kind mean long intervals. A change of this kind has been noticed in the group of fossils, both animal and vegetable, in passing from the Palæozoic to the Secondary rocks, and now we meet with a similar change in advancing to the Tertiary. Throughout Northern Europe, or, rather, on the whole of the northern side of the great geographical axis of the old world, the tertiary rocks occupy what are called in geological language "basins,"—in other words, they appear to have been deposited in limited areas, each separate area having something distinctive. In the wide interval between the northern and southern ridges of the same great axis, we find the tertiaries more widely and uniformly spread, less basin-shaped, and more continuous. In the broad space on the eastern side of the great geographical axis of the new world, especially in the southern part, we find the tertiaries occupying long broad strips of country resembling, in this respect, the development of the secondary rocks in Europe.

By the word Tertiary, which is sometimes replaced by *Cænozoic* (Greek: *cænos*, new or recent; *zoe*, life), geologists generally include all rocks newer than the chalk, assuming that the chalk or contemporaneous rocks can always be strictly defined, and that the life of this newer period is also more modern and distinct in all important senses from the life of the Middle, *Mesozoic*, or Secondary Period. Practically, the line is drawn so well and so clearly in England and Northern Europe, that little difficulty is experienced. Near Marseilles, indeed, there appear to be passage beds, as already pointed out, and throughout large tracts in the old world, there is a deposit of limestone crowded with foraminiferous shells, parts of which may be marine representatives of the interval, although other parts certainly belong to the Tertiary Period, and even to a part not by any means the oldest.

The following general table of the distribution of some of the principal and best known tertiary rocks in England will be useful:—

Recent deposits, *Post-pliocene* or *Pleistocene*:—

Vegetable soils, shingle, and blown sand; river mud and peat; raised beaches; cavern deposits; glacial drift.

Upper tertiary deposits, or *Pliocene* :—

High-level gravels and old cavern deposits. Boulder clay.

Red and Norwich crag.

Suffolk crag and coralline crag.

Lower tertiary deposits, or *Eocene* :—

Leaf beds in Antrim and Mull.*

Sundry beds in the Isle of Wight, including (*a*) Hempstead, (*b*) Bembridge, (*c*) Osborne, (*d*) Headon beds.

London clay series, including (*a*) Bagshot sands and clay, (*b*) Barton clay, (*c*) London clay proper and Bognor beds, (*d*) Woolwich and Isle of Thanet beds.

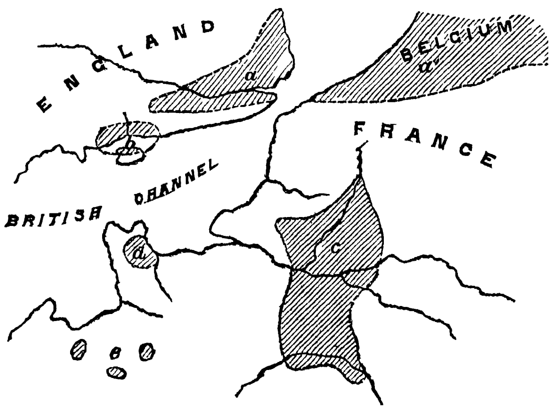


FIG. 42.—MAP OF THE OLDER TERTIARY BASINS IN WESTERN EUROPE.
a London basin. *a'*. Belgian older Tertiary basin. *b*. Hampshire and Isle of Wight basin *c*. Paris basin. *d*. Cotentin basin. *e*. Small basins in Brittany.

The annexed diagram will give a general idea of

* These beds belong to a part of the Tertiary series often regarded as forming a middle division, and named *Miocene* (less new), from two Greek words, intimating that they contain fewer recent species than the overlying beds, which are called *Pliocene* (more new). The oldest tertiaries were called *Eocene* (dawn of new), as indicating the commencement of a period when some species agree with those now living in adjacent seas. For the same reason the recent deposits are called *Pleistocene*, or "most new."

the geographical position and relative magnitude of the larger of the older tertiary basins in Western Europe. It will be seen that they are not extensive, and they present little appearance of having been at any time much more so.

The lowest of the British rocks of the Tertiary Period, being the oldest of the rocks that repose directly (but not conformably) on the chalk, consists of a group of sands and sandstones met with on a somewhat large scale in the county of Kent, and especially in the Isle of Thanet, and on the shore near Herne Bay, where they are generally based on a layer of angular chalk flints. These beds are called the *Thanet Beds.* They are sometimes ninety feet thick, and contain several bivalve and some univalve marine shells, regarded as characteristic. Similar sands, with the skull of an extinct bear, have been found near Beauvais, in France. Somewhat newer than these sands in England are plastic or pottery clays and sands with lignite, developed at Woolwich beneath the London clay, and found also at Reading, and in the Isle of Wight, in contact with the chalk. These are the *plastic clay beds.* In France, a similar set of deposits occupies the same geological position. They contain a mixture of marine and freshwater species of shells, and oyster beds are not uncommon. Remains of a wading land bird, as large as an ostrich, have been found near Paris, at the base of the plastic clay. Just above the Woolwich and Reading beds, are pebble beds containing also sand or loam. It has been proposed to call these the *Oldhaven beds,* or *Basement beds.*

We next come to the typical *London clay,* a tenacious brown and bluish-grey clay, with bands of concretions called *septaria*, worked for the manufacture of Roman cement. This bed covers a large part of the interval between the chalk hills north and south of London, and yields everywhere supplies of brick clay, of which the metropolis is built. This important deposit is repeated in France near Dunkirk, and is represented in England, on the coast of Suffolk, at Kyson, by a bed of yellow and white sand. It is also represented in France by sands, but very imperfectly. The true London clay, though in many places poor in fossils, is exceedingly rich in certain localities, as in the Isle of Sheppey, at Highgate Hill, and at Bognor in Hampshire. It is remarkable as yielding examples both of the flora and fauna of the period in a singularly complete manner. The flora represented by numerous fossil fruits, including those of palms and several species of custard apple (essentially tropical or sub-tropical at present), and various species of Acacia, indicates a warm climate.* With these are numerous turtles, a sea snake of large size, a true crocodile, and

* The following note by Dr. Bowerbank, who has figured and described the fossil plants from Sheppey, will give some idea of the riches of this flora :—"On a rough estimate, I should say I have at least from 300 to 400 species by me not yet described, and not less than 100,000 specimens beneath water, in bottles of various sizes. There are a great number of Palmacean fruits and a few cones. There are a considerable number of fruits closely allied to Schomberg's Snake nut. Seeds of two or three species of *Anana* are numerous, and fruits with the seeds imbedded on the surface, which have been either *Potentillas* or *Fragarias*, most probably the former. One small but decided specimen of *Cocos* is all I have yet seen of that genus. The resemblance to the fruits of the existing flora of warm and temperate latitudes is very strong throughout."—Morris's *Catalogue of British Fossils*, 2nd ed. p. 363.

fragments of birds and quadrupeds, all pointing in the same direction with regard to climate. Among the quadrupeds is a kind of tapir, and an opossum. The Spice Islands of the East Indies offer the nearest resemblance to the probable climate. The marine shells and fishes, of which there are many, also suggest a high temperature. The fishes include a sword-fish and a saw-fish.

The *Barton clay* (300 feet), the *Bagshot sands* and clay, and the *Brackleshan beds* (650 feet), are now regarded as the middle beds of the lower tertiary series, or "middle Eocene." These beds are very important, as they are the representatives in England of enormous deposits of limestone and other rocks, abundantly exhibited in the Alps and extending thence to the Carpathians, running far into India, repeated in North Africa and Egypt, and belonging also to the Pyrenees. Thus, the rocks of this part of the period form a large part of the great mountain axis of the Old World, and rocks of the same age are not less abundantly distributed on the Atlantic border of North America. Most of them are characterized by particular species of a

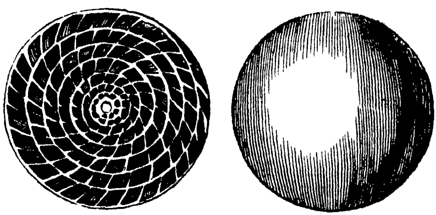


FIG. 43 —Nummulites.

fossil called *nummulite*, of which sometimes the limestones are almost made up. This group, so largely extended, and forming indeed the most important tertiary deposit of the Old World, is known as the *Nummulitic limestone.* It extends to the upper part of the lower division of the older tertiaries. It occurs in Thibet 16,500 feet above the sea, indicating not less than 20,000 feet of vertical elevation of the sea bottom that has taken place since the deposit of the London clay, and since the time, therefore, when the climate of England was so warm as to resemble that of the Moluccas and Philippine Islands.

The Barton clay itself, though not far from the London clay, has yielded more than 250 species of marine shells, not more than one in twenty being identical in species with those of the underlying clays. In actual contact with the London clay is a considerable group of siliceous sands poor in fossils, covering a large area near Bagshot in Surrey, and in the New Forest. At Bracklesham Bay, near Chichester, are sands richer in fossils. In France are certain beds of sand at Soissonnais, underlying the *Calcaire grossier* of Paris, which is now recognized as the equivalent of the Bagshot and Bracklesham series, and over the Calcaire grossier are the sandstones of Beauchamp (*grés de Beauchamp*). These all belong to one period, during which the climate must have been warm, though much less so than during the deposit of the London clay. Bones and teeth of sea serpents, gigantic rays, numerous sharks, and a singular variety of fishes of less familiar forms, are accompanied by a great variety of beautiful shells, and there is also a land flora and remains of quadrupeds. The calcaire grossier is especially rich, one spot alone having yielded more than 400 species of shells (bivalves and univalves), a large number of them indicating brackish water. There are also foraminifera of considerable interest, valuable as marking a geological horizon. The *miliolite*, a chambered shell like a millet seed, and nummulites are among those of chief value. The Barton clay also contains nummulites. The well-known fossil fishes obtained from Monte Bolca near Verona, in North Italy, are of this period.

The important and exceedingly interesting series of tertiaries exhibited on the north side of the Isle of Wight come next in order. They are repeated and further illustrated on the opposite or Hampshire coast, and the whole must be taken together.

Both at Hordwell (or Hordle) Cliff and in the Isle of Wight, the upper members of the Barton series consist of white sands used for glass-making, and upon them come the *Headon beds*, consisting of 200 feet of white and green marls and limestones. They occur both at Whitecliff Bay on the eastern and Headon Hill on the western extremity of the Isle of Wight, and the upper and lower members are fresh-water, the middle brackish and marine. They contain land and fresh-water shells, remains of turtles, alligators and land and sea snakes, several birds and several quadrupeds. There are also fish, among which is a bony pike. Over these beds is another small group called the *Osborne beds* (St. Helen's sands and Nettlestone grits), seventy feet thick, including a freestone quarried at Ryde. Some of these beds are brackish and some fresh-water. The Paris representatives are the beds there called *calcaire siliceux*, or siliceous limestone.

The *Pembridge beds* consist of about 120 feet of marls, clays, and limestones, partly brackish, partly fresh-water, and partly marine. They include, at Binstead, a good building stone, and form an important deposit, representing in England a gypsum formation at Montmartre in Paris, which yielded to Cuvier the remains of quadrupeds, whose description in an elaborate work first attracted general attention to this department of geology.

The Isle of Wight has also yielded similar remains, but in smaller quantity, and in a less perfect condition. Several of the animals restored by Cuvier resembled the tapir and rhinoceros, others were altogether distinct. All were new to science. The *Palæotherium* (Greek: *palæos*, old; *therion*, beast), and *Anoplotherium* (Greek: *ana*, without; *oplon*, a weapon; *therion*, a beast) are the best known. A restored outline of one of them is annexed. The gypsum beds of Paris are largely quarried for the manufacture of plaster; and besides about fifty species of quadrupeds, they contain remains of birds, of land plants, of crocodiles and other reptiles, and of fresh-water fishes. The skeletons are generally well preserved, and often complete.

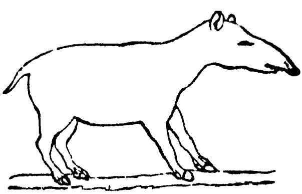


FIG. 44.—Palæotherium.

The *Hempstead beds*, which follow, include the lignites of Bovey Tracey, once worked as coal. The whole of the beds are about 170 feet thick, the lower part being carbonaceous, the middle fresh-water marls, and the upper marine sands. These terminate the deposits of the Older, or Eocene Period, as now known. They are represented in France by the Fontainebleau sandstones, an important group, containing a few land and fresh-water shells, covered with fresh-water limestones and marls. In Belgium, they are represented by very fossiliferous sands, clays, and marls, partly marine.

The Nummulitic formation has been alluded to as an important part of the Older Tertiary series. Under the local name of *flysch* there is found in the Alps an overlying series of dark-coloured slates, marls, and sandstones, with marks of sea-weeds, which belongs to the same period. These rocks are often crystalline and metamorphic. In the United States at Claiborne, Alabama, is also a lower Eocene formation, of which the lowest member is a foraminiferous limestone. Above it is a rotten limestone with many bones of a gigantic extinct whale, and still higher sands and marls rich in fossil shells.

These older tertiaries, wherever exhibited, are, on the whole, richer in variety of species and generic forms, both of plants and animals, than the rocks of the Secondary Period; and, as a whole, they unquestionably point to the existence of large tracts of land, well watered by considerable streams, which must have proceeded from elevated mountain chains, situated far from the coast line. There are proofs of estuaries, lakes, and river deltas; not, it is true, so large as those at present to be found in Asia and America, but larger and more important than those of Europe or Africa—much more so therefore than those of Australia. The land existing in these latitudes during the Secondary Period was apparently insular; while the land belonging to the Early Tertiary Period had already become continental, in the sense of resembling the two great natural divisions of land at present existing. But the direction of extension of the land was probably different; there was then no vast and elevated tract, such as that now forming Central Asia, and the mountain chains of Europe and Asia were by no means lofty. Thus the cold derived from this ridge of mountain and extent of plateau did not exist, and the warmth of the tropics extended much farther than it now does.

There is hardly any important group of plants or animals without some representative in the various deposits of the older part of the Tertiary Period, and of most of them there are many species. When regarded as a whole, they indicate, as we have already seen, a much warmer and moister climate than we have now in this part of the world, but by no means a tropical climate. This warm and humid temperature did not long continue, for even in the interval between the deposit of the oldest and newest of the Eocene rocks, a change had taken place of considerable magnitude, producing a gradual adaptation to present conditions. The important astronomical causes that may have produced a difference of climate to this extent cannot be properly considered in an elementary treatise like the present; and the student must, for the present, be contented to take for granted that there are many causes which can account for the changes that have taken place, without the necessity of assuming a gradual cooling down of the whole earth—a view which is opposed to the results of observation concerning the fossil groups of the Secondary, and even of the Palæozoic Period.

The uppermost members of the Older Tertiary

Period * are hardly represented in England. Volcanic disturbances were then taking place in some parts of our island, and among lava currents and volcanic ashes of the pericd, indicated in the magnificent and well-known basaltic rocks of Giant's Causeway in the north-east of Ireland, and in Fingal's Cave in Staffa and other similar phenomena in the islands of Scotland, we find a few remains of plants that enable us to refer the whole to this period. Certain irony sands also, on the surface of the North Downs, near London, are also regarded as of the same age. In other parts of the world—in Europe, Asia, and both Americas, rocks of this kind were being deposited on a large scale. In the west of France, in the cliffs or *faluns* on the banks of the Loire and Garonne; in the south of France, near Montpelier; and in Auvergne, in Central France; in Belgium; in Switzerland on a large scale; in the hills near Turin; in the basin of Vienna; in the Alps; and in Greece (at Pikermé), these deposits are abundant and exceedingly fossiliferous. They recur in India, on the flanks of the Himalayas, and in the Siwalik Hills; and they are found both in North and South America.

In Europe their fossils indicate lower temperature,

* These uppermost members of the Older Tertiary series include the rocks described by Lyell, and in many geological works, as *Miocene* or *Middle Tertiary.* It seems more convenient, in the present state of geological classification, to regard them, as has been done in the text, as Older Tertiary, recognizing only two divisions of this great period. The student should, however, be aware of the mode in which these important rocks are here regarded, and, also, that the difference is one of name only, not of the order of superposition.

a less warm climate than at present in the same latitude. In America they show also a change from the Eocene, or older condition, and an approximation to the existing climate and forms of life.

Among the fossils of this period, the plants are not the least important. They are particularly well exhibited in the Canton of Berne in Switzerland, and at Oeningen. On the whole, they present a mixture of forms. Species of fan-palm and other palms, tulip trees and cinnamon trees, are associated with hornbeam, buckthorn, cypress, fig, and some curious ferns. Many of the plants are nearest to species now confined to the Cape of Good Hope, others to North American species. A large proportion of the woody plants are evergreens, a characteristic of subtropical climate; but of the forest trees there are species nearly allied to the present trees of Central Europe. It has been estimated that the Swiss flora of this period implies the existence of some 3,000 species; the most abundant and characteristic forms being such as would bring America, rather than any countries of the Old World, into comparison. There are also species allied to Asiatic, African, and even Australian vegetation; but these are few, and less important.

There is also reason to suppose that the general aspect of the whole of the older tertiary vegetation in England, under whose shadow lived the Palæotherium, Anoplotherium, crocodiles, and turtles, is well made out. We recognize magnificent forests in this epoch, characterized by massive oaks, many species and varieties of large trees allied to the fig, elms, pines, nut trees, acacias, and others. An undergrowth existed of laurels, and other shrubs, many spice trees, and trees bearing gr ... soil was covered with a luxuriant herbaceous vegetation, and we find but few ferns. The ground was probably undulating, consisting of low hills, rising out of vast, dry, sandy plains, where grew many coniferous trees, and many leguminous plants. Later in the period there was more moisture, and there were then lakes, on which grew large water lilies. At a later period still the vegetation had entirely changed, and had assumed a North American, rather than an Asiatic character.

Reverting now, once more, to the uppermost members of the Older Tertiary Period, we find that the fossils of the animal kingdom are abundant and interesting, though confined to certain limited localities. The shells are exceedingly numerous, and include sufficient variety to justify the supposition that we have a fair idea of the general distribution of the group. There are also insects in great abundance and crustaceans, but few corals and polyzoa of great interest. But it is chiefly among the vertebrate tribes that we find the important evidence that warrants the conclusions drawn as to the state of the land, and the development of life. There are many fishes, especially in special beds, but exceedingly few reptiles. Birds, also, are poorly represented, but of quadrupeds there is a large and increasing list. In Western Europe, we have the *dinotherium*, a singular genus of gigantic pachyderm, probably aquatic, and provided with long projecting tusks in the lower jaw. With its remains are those of species of rhinoceros, hippopotamus, many large deer, and several animals of the whale tribe. With these, also, in Southern and Eastern Europe, are giraffes and apes. A vast expanse of grassy plains, with considerable rivers and some swamps, must then have extended in the Eastern Mediterranean, and probably connected Eastern Europe with Asia Minor and North Africa. At the same time, there was a repetition of these physical features on the northern side of the Alps, then probably but partly elevated, and certainly not yet sufficiently lofty to chill the air of Central Europe.

A great question has arisen among geologists as to whether the evidence of the fossil plants and animals of this period is sufficient to justify the probability of land then existing connecting Europe with North America. That many important groups of islands, if not continued land, existed in the North Atlantic, probably in the northern part of it, we may fairly assume from the former presence in the two countries of certain species of larger animals. There is, however, no evidence justifying the assumption of a vast continent where we now find deep water. However this may be, it is impossible to avoid concluding that Western Europe then enjoyed a climate far more nearly subtropical than it has done since, or does at present. At the same time, the preponderance of temperate forms is large, and marked enough to enable us to conclude that the early Eocene climate had already been modified, and that the tendency of change was towards a diminishing temperature and a less insular climate.

The Siwalik beds, containing a peculiar fauna referred to this period, range at intervals across

India. They are to a great extent boulders and shingle beds, with sands and marly conglomerate; all dipping at a considerable angle, and exposed on a breadth of six or eight miles. These beds include remains of large quadrupeds of all the principal groups now inhabiting India, besides giraffes and some new and very singular forms. All the species are extinct. One genus (*Sivatherium*) presents a curious mixture of the characters of the ruminating animals, such as the ox or deer, with the pachyderms, of which the elephant is the type. The rhinoceros accompanied it. There are also some remarkable land tortoises; one species, at least, of very gigantic proportions. With them are many quadrupeds, and some monkeys. Shells, and the remains of invertebrated animals generally, are less common. The Middle Tertiary, or close of the Older Tertiary Period, in Asia, south of the Himalayan Chain, thus had a large distinct fauna, very different from the present. We must repeat, however, that at this time the great geographical axis of the old world had not become a lofty mountain chain. The deposits containing the remains of these animals rest on the flank of the great chain, and are tilted up at an angle of 15° or 20°.

The older tertiaries of North America are tolerably extensive, especially in the Southern States of Georgia, Alabama, and South Carolina, and they extend into Virginia. The width of the deposits, which are chiefly marls, clays, and sands, not much above the sea level, amounts to more than 100 miles. Among the fossils there are some hundreds of species of shells; but the most striking are the bones of a large cetacean, or whale, whose length must have reached seventy feet. Extensive and important lower tertiary deposits have been described by Mr. Darwin in South America, both on the Atlantic and Pacific sides, but they have not yet yielded a fauna and flora of the period.

There are representatives in North America of the upper members of the Eocene series, but they are comparatively unimportant, and consist chiefly of gravel cliffs with shells. In South America parts of the great plains on the Atlantic side overlying the lowest tertiaries appear to belong to the upper member of the Eocene group.

CHARACTERISTIC AND REMARKABLE FOSSILS (in England).—(1) Plants—Fruits of *Nipadites*, *Anona*, *Favöidea*, *Tricarpellites*, *Leguminosites*, *Hightea* (London clay); leaves of *Ficus*, *Laurus*, *Cinnamomum*, *Andromeda*, *Nymphæa*, *Lastræa*, *Flabellaria*; *Sequoia*, *Platanus*, *Filicites* (upper beds); seeds of *Chara*, *Carpolithes*; rhizomes of ferns. (2) Foraminifera—*Globigerina*, *Nodosarina*, *Nummulites*, *Rotalina*, *Truncatulina*. (3) Corals—*Dasmea*, *Dendrophyllæa*, *Litharia Websteri*, *Stylocœnia*, *Turbinolia*. (4) Echinodermata — *Astropecten*, *Echinopsis Edwardsii*, *Hemiaster*, *Ophiura*, *Pentacrinus subbasaltiformis*. (5) Bivalves—*Terebratulina striatula*, *Lingula tenuis*; *Avicula papyracea*, *Cardita planicosta*, *C. acuticosta*, *Corbula longirostris*, *C. pisum*, *Crassatella sulcata*, *Cryptodon angulatum*, *Cyprina Morrisii*, *Cyrena cuneiformis*, *Cy. pulchra*, *Cy. semistriata*, *Cytherea incrassata*, *Leda amygdaloides*, *Lucina serrata*, *Modiola elegans*, *Nucula similis*, *Ostrea bellovacina*, *O. edulina*, *Pecten corneus*, *P.* 30 *radiata*, *Pectunculus brevirostris*, *Pholadomya margaritacea*, *Solecurtus Parisiensis*, *Tellina* (several species); *Teredo*. (6) Univalves—*a*. Marine and brackish water: *Calyptræa trochiformis*, *Cerithium concinna*, *C. elegans*, *C. plicatum*, *C. mutabile*, *Conus deperditus*, *C. dormitor*, *Cypræa Bowerbankii*, *C. tuberculosa*, *Melania costata*, *M. fasciata*, *M. inquinata*, *Mitra scabra*, *Phorus extensus, Rissoa Chastellii, Rostellaria ampla, Scalaria Bowerbankii, Scaphander lignaria, Terebellum fusiforme, T. sopita, Turritella sulcifera, T. multisulcata Voluta ambigua, V. athleta, V. luctatrix, V. nodosa, V. Rathieri, V. Selseiensis. b.* Land and fresh watêr : *Bulimus ellipticus, Helix labyrinthica, H. occlusa, Paludina lenta, P. orbicularis, Potamides cinctus.* (7) Cephalopoda—*Nautilus centralis, Aturia ziczac, Belosepia.* (8) Crustaceans—*Dromilites, Goniochele, Hoploparia, Thenops, Zanthopsis Leachii.* (9) Fishes—*Ætobatis, Carcharodon heterodon, Cœlorhynchus, Cybium macropomum, Edaphodon, Galeocerdon latidens, Lamna elegans, L. Hopei, Myliobatis striatus, Myriapristis Toliapicus, Otodus obliquus, Phyllodus.* (10) Reptiles—*Chelone* (11 species), *Trionyx* (8 species), *Platemys* (2 species), *Emys* (7 species), *Crocodilus* (3 species), *Alligator, Gavialis, Palœoptris* (4 species), *Paleryx* (2 species). (11) Birds—*Halcyonis, Lythornis.* (12) Mammalia—*Anoplotherium, Chœropotamus, Dichobune, Hyopotamus, Lophiodon, Palœotherium.*

CHAPTER X.

NEWER TERTIARY AND QUATERNARY ROCKS AND FOSSILS.

THE oldest and lowest portion of the newer tertiary deposits in England is generally admitted to be the crag of Suffolk (*Suffolk* or *Coralline crag*); a mass of about forty feet of sandy and shelly gravel, loaded with remains of shells, polyzoa, and corals, with thin stony bands, sometimes quarried. Above this, or occupying its place, is another crag, called *Red crag*, from its deep ferruginous colour. Besides a few shells, the red crag contains a singular mixture of mammalian fossils, generally in rolled fragments or nodules, rich in phosphate of lime. These must have belonged, for the most part, to large quadrupeds, whales, and fishes, partly, perhaps, of the date of deposit, but chiefly of earlier date, and often a mixture derived from several formations, almost all tertiary, though some of them not now remaining as strata. This crag appears to have been formed near shore, in water of no great depth. Most of the bone fragments are hard, heavy, and much mineralized, indicating change after deposit, and subsequent removal by the action of water. The fossils of the coralline crag are chiefly shells and polyzoa, with a few small corals. There are many concretions in the red crag, once supposed to be the fossil dung of large animals (coprolites, or dung stones); but most of them are not organic, except as having an organic centre. The most common mammalian remains are the ear bones of whales, teeth of large sharks and rays, crabs from the London clay, teeth of a kind of elephant (a *mastodon*, of a species found also in Italy), and bones of rhinoceros and tapir. There are some very characteristic shells, of which the *fusus contrarius*, or reversed whelk, is very abundant. Both the coralline and red crag are very local, and only developed to a small extent in England. They are represented at Antwerp by beds of the same general character, forming yellow, grey, and black crags, also containing shells.

Parts of the fossiliferous beds on the flanks of the Apennines belong to the same period as our crag, and are newer tertiary. The beds that are well known in the Alps, near Turin, in the hill of the Superga, are older, but the beds at Parma, those of the upper valley of the Arno, and certain blue marls at Sienna, are, judging from their shells, of the same age as the crag. Part, at least, of the great series in the Uralo-Caspian plains, in Western Asia, are contemporaneous.

A third crag exists in the eastern counties, known as the *Norfolk crag*. At Chillesford, near Orford, in Sussex, it overlies the red crag, but elsewhere it is generally found resting immediately on the chalk. At Cromer this is the case; and there we meet with a bed of lignite, apparently belonging to it. This bed is not seen under ordinary circumstances, owing to its position beneath the sea at the ordinary level of low water, and is chiefly known by fragments drifted to the shore after storms. At Bridlington, on the Yorkshire coast, near Flamborough Head, there is another small group of strata of the same age, but of different composition, consisting of flints, sand, and pebbles; but the fossils, of which there are many species, mark clearly the geological position of the deposit. Here, also, are characteristic shells, including bones and teeth of the larger pachydermata.

It is interesting to notice the prevalence of large elephantine quadrupeds in the tertiary strata, not only of England, but throughout Northern Europe, as belonging to this part of the period. The whole of the evidence from fossils, with regard to the older tertiaries in Europe, unquestionably points to a climate warm and insular, a climate with frequent rain perhaps, but in which the temperature varied but little from winter to summer. And on the whole there was much more warmth than is now to be found in any climate in similar latitudes. After the deposit of the Eocene strata, there seems to have been considerable depression in the temperate seas, but a rise of land, both in the north and on the line of the great geographical axis. Throughout Europe the temperature was gradually lowering as time advanced. The oldest tertiaries were warmer and more insular than those less old, and the newer members of the older group indicate, as we have seen, a distinct change in this respect. But the same *facies* is preserved. There still remained in these lands the elephant, the tapir, the rhinoceros and the hippopotamus of the older period. These animals became accustomed to the gradual change of climate, and, instead of being destroyed by any catastrophe, they became adapted to the changing condition brought about by the continued action of similar causes. It is even likely that some of them became clothed with hair and wool. We know at any rate that such was the case with the elephant of Tartary and Siberia, for remains of perfect carcases thus defended have been frozen into the gravel cliffs of the Arctic Ocean.

New animals were, however, introduced, and among them deer of the reindeer type of large dimensions and with branching horns of enormous span, especially organized to live in countries where there was heavy snow.

As we approach the existing period and historic times, we gradually find more and more evidence concerning the land animals, especially those whose bones were sufficiently solid to resist injury, and we are able to bring them into comparison with those of existing species. We also obtain larger groups of remains of some kinds among the lower animals. It has already been pointed out that the gradual elevation of certain parts of the land in the northern hemisphere, and the possible loss of considerable tracts of land in the Atlantic, are facts that explain this in some measure. There was greater variety of life on land, because the land was larger in extent and more continuous; there are more remains preserved and handed down to us, because there has been less time subsequently to destroy the evidence. But the student must not suppose that the deposits in distant places always correspond. The mere fact that land extended far in one direction would naturally tend to produce similarity of marine life along the sea coast, running in that direction, and great difference in a direction at right angles. Thus the rise of land on an east and west line in comparatively late times in the old world, would be accompanied by a constantly widening interval in the shells and other marine fossils in places very distant in longitude. On the other hand, the rise of land in the new world on a north and south line, would produce a similarity in the growth of species in coasts far distant in latitude. The general result seems to be, that whereas up to the newer Tertiary period there had been a tolerably uniform distribution of the larger quadrupeds throughout the land then existing in the temperate latitudes of the northern hemisphere; there was at the same time a very marked difference between the inhabitants of the northern and southern lands. The three tracts of land, the great continent America, and Australia, had a very distinct *facies* as regards the large quadrupeds, and that *facies* still exists, although almost all the most remarkable species have died out, and have long been extinct, or have become locally extinct, where before they were very common.

It is necessary that the student should know, that in parts of the world where changes of elevation have been experienced more rapidly than in England (though some of these are by no means of small amount) there are formations of great magnitude belonging to the period of the British crag. Thus in Sicily there is a vast deposit of marine limestone, covering half the island, in some places 3,000 feet above the sea, and nearly a thousand feet thick, representing these poor thin seams of shelly gravel. On the coast of Italy, occupying the same position with regard to Vesuvius that the Sicilian limestone does to Etna, there are deposits of the same age at the same elevation. Here, therefore, at any rate, we see an elevation of more than 4,000—

probably of 5,000 feet, since the deposit of our Suffolk and Norfolk crags, and a deposit of great thickness previous to elevation. Other parts of Europe, and important districts in Asia and America, tell the same tale.

The diminution of heat, gradual, as we know, by the continuance of life of the same species in the districts where climate was altering, but sufficient at any rate to modify specific forms; bringing down Arctic species of shells gradually towards central Europe, to intrude on, and ultimately replace, the southern forms that before prevailed, appears to have continued for a long time. By degrees the warm insular climate, which even in Greenland admitted of the growth of large forest trees, and in England was nearly sub-tropical, was lost; the mountains were gradually upheaved to their extreme elevation, and all the conditions favourable to warm climate disappeared; ice and snow crept down gradually to the plains from the northern lands, from the main chain of the Alps on both sides, from the Pyrenees, and even from some subordinate ranges (then perhaps loftier than they are now), such as the Cevennes, the Jura, the Carpathians, the Apennines, and the Balkan. The land of the Arctic circle not only reached the pole, but descended into the North temperate zone, and large tracts of country in the northern hemisphere, reaching perhaps nearer the equator than the Antarctic land now in the southern hemisphere, in latitude 65°, were then covered with ice. The mountains of Scandinavia, and even the lower mountains of Scotland, Wales, and Ireland, were also ice-covered; and the fragments broken away from the great ice fields of the north were drifted down loaded with the *débris* of many rocks, and were caught on shoals, depositing on them sand and pebbles, which are now converted into gravel and form what is called the *Boulder clay* formation.

Since that time, however, the shoals have become elevated into the plains of Northern Europe, or form hills and low plateaux, the gravel capping the hills. On the American continent there is ample evidence of the same kind of action. It has even been supposed that during this great change the ice reached within the tropics. This was the glacial period of geologists. It had advanced gradually, brought about no doubt by cosmical causes. Whether the earth's orbit and the position of our planet in its orbit were the cause,—whether our solar system was then passing through some cold region in space,—whether the sun, owing to some cause, did not communicate so much heat,—or whether, lastly, the great difference in the distribution of the land was sufficient—whatever may have been the cause, or whether (as it may be) two or more of these causes acted in concert, there would seem little doubt as to the fact. While the elephant and the rhinoceros still remained and roamed over the plains of Languedoc at the foot of the ice-covered Pyrenees, the reindeer had found the same valley a fit and convenient dwelling-place, and other deer of gigantic size and of similar habits occupied Ireland, England, and Belgium. Numerous specimens of a large bear accompanied them, hyænas (like those of the Cape of Good Hope, not those of Abyssinia and North Africa) were also abundant, and all these took shelter in the numerous natural caverns in the limestone rocks, wherever such rocks were at the surface and available.

The purely mechanical indications of this glacial period are neither few in number, small in amount, nor doubtful in their nature. Deep grooves and scratches in the rocks travelled over; large heaps of gravel marking the course of the glaciers; lakes now, where the tongue of the ancient glacier slowly advanced and rooted up the mud and earth; piles of angular blocks, mixed up with stones, earth, and sand; hills of gravel covering level plains; these are so common on the surface of Northern Europe as to conceal in many cases the natural strata. At Cromer, where, as we have seen, the Norwich crag rests on the chalk, and where are the stumps of Scotch and spruce firs and other trees still left in the ancient soil of the pre-glacial period, forming what is called the "forest bed," the glacial deposit of the *Boulder clay* may be seen resting on a tough blue clay, with recent species of shells, and presenting a mass twenty or thirty feet thick of mixed clay, sand, and angular blocks of stone of all sizes, including many transported from a great distance, scratched, striated, and polished on the surface that has been forcibly dragged over hard rock, drifted by marine currents, and bearing its share of the weight of hundreds of thousands of tons conveyed by the ancient ice.

The great glacial period of the northern hemisphere was in all probability an event so recent in a geological sense, that man, the crowning work of creation, had already been introduced on the earth It was, however, so distant, that there has been time since to produce in our own island partial elevation of the land to the extent of nearly 2,000 feet. At the period we speak of, a large part of England

13*

and Western Europe, including all the great plains now watered by the principal European rivers, many hills now several hundred feet above the sea, and one hill in Wales (Moel Tryfaen, on the south side of the Menai Straits), about 1,400 feet high, were beyond doubt beneath the sea-level to a sufficient depth to receive deposits, and in many cases to act as traps for the icebergs floating downwards from the icy sea.

The land now including the valley of the Thames, and reaching across the oolitic hills to the Bristol Channel, was then a strait some 600 feet deep; and no doubt at that time Western Europe existed only as an archipelago of small islands, between which the icebergs drifted, while the loftier of the islands were themselves ice-covered.

The period of cold thus indicated seems to have changed slowly, and was succeeded, after an interval, by a period of more moderate temperature. It is not unlikely that the volcanic energy now expended in occasional explosions and eruptions in Iceland, may at that time have elevated the polar land and produced the cold. We have already seen that partial volcanic activity is traceable in the north of Ireland and the Scottish islands during the latter part of the older Tertiary period, and it is probable that elevations of the mountains and depressions of the plains may have been carried on at the same time, being parts of the same system of disturbance affecting the whole of the northern extremity of the globe, and connected with these centres of activity. It is possible, and indeed probable, that after the polar land had sunk, and when the climate became moderate, there was a partial return to a cold and glacial period. After this relapse, however, the changes that took place were gradually more and more favourable to an equable climate; the ice receded first from the plains, then from the deep narrow valleys, and finally from all but the loftiest mountain summits; the plains were crossed and eaten away by rivers, leaving wide spaces occupied by river silt, called by geologists *loess*, and, at the contact of sea and land large areas of low land known as *deltas*. Rising from the banks of the rivers and along many coast lines, we now find in many places broken and steep faces of cliff, where the river, the sea wave, and the tide have made inroads, but could not remove the material so rapidly as the rate of rising required.

From the account thus given of the position of the land during and after the glacial period, and the fact that some portions of Western Europe have required to be lifted up as much as 2,000 feet in cases where there is no appearance whatever of violent upheaval or sudden disturbance, it is clear that the recent history of Europe—using the term *recent* in its geological sense—involves very large movements. It is, however, probable, if not certain, that although some of those of largest amount were local, many, reaching to the extent of an upheaval of six or eight hundred feet, were very general over wide regions. Thus there has been ample room within this period for great modifications of climate, such as indeed we have other reason for assuming. The union of the British islands with each other, and their connection with the continent, as well as their subsequent separation, effected by movements alternately of elevation and depression, is also easy to understand, for oscillations to even a smaller extent would be more than sufficient for these purposes.

At the close of the last glacial period, the student must, therefore, understand, land existed in many parts of Europe where it does now, but at a much lower level. The high plains, and some mountains, were low plains and hills. But the mountain chains were perhaps even higher. The low plains were the sea bottom—in some places under deep water. Much of the land of the pre-glacial period was buried, and became covered with gravel and stones, derived from icebergs, or drifted icebergs. Other lands of the same period, however, remained, and these were sufficient to retain and transmit many of the principal species of quadrupeds. Some species, however, disappeared entirely from the earth, and others were driven from the district. The rest adapted themselves; but other races were superseding them, unless, indeed, the adaptation consisted of, or resulted in, a modification of specific character.

It is not easy in this department of geology to determine with precision the exact relative dates of deposits in distant countries. We know, however, that during the period marked by the presence of the elephantine animals in Northern Europe, the plains of North America, the great plains of South America, the interior of Australia, and the island of New Zealand, were all inhabited by important, and in many cases gigantic representatives of the peculiar tribes of quadrupeds and birds that now dwell there. Thus in South America the present sloth, a small tree-climbing animal, was represented by the *Megatherium*, the *Mylodon*, and other quadrupeds of singularly massive proportions, fitted to pull down the trees on which they fed, but whose leaves they could not otherwise reach. The small armadilloes were in like manner represented by gigantic *Glyptodons*, and the feline animals by a tiger, whose tusks, shaped like scimiters, were nine inches long, and were therefore fitted to cope with these singular armour-plated brutes, all of which are long since extinct. So also in Australia the kangaroo, and other marsupial, or pouched quadrupeds, had their analogues in other pouched animals, both vegetable and animal feeders, but whose dimensions were extremely larger, and all their proportions more solid. It is not easy to give any reasonable suggestion as to the cause of this marked peculiarity in size of the representatives of the various natural groups. Something of the same kind has been already alluded to, in describing the quadrupeds and reptiles of the Sewalik Hills in India. In New Zealand there was, though at a later period, a genus of gigantic birds (*Dinornis*) closely resembling in structure the small wingless bird called Apteryx still found in those islands. In Europe the elephantine animals, spread generally over the land at this time, were probably not much larger than existing elephants and rhinoceroses, though much larger than the present pachyderms of the country. But these were accompanied by many species of other kinds, such as lions, bears, hyænas, and even camels and giraffes, all of large proportions, and all now locally extinct. Some at least of the deer were also gigantic.

It is very important to bear in mind the great development of the larger forms of quadrupedal life at this particular period. There may have been other periods of similar kind, as during the deposit of the upper secondary rocks, when reptile life was in a corresponding degree very vigorous. So also during the carboniferous period vegetation must have been almost preternaturally rapid to account for the familiar appearances common in the coal measures. There may have been some reason for this in the position of the earth with regard to the sun, or the state of the sun itself, as has been already hinted; but hitherto the geologist has not succeeded in doing more than establish the fact, without in any satisfactory way accounting for it.

We may safely regard as the recent period that which introduces man as an inhabitant of the earth. Continental geologists have called it *quaternary*, to distinguish it from tertiary, and some English geologists speak and write of it as *pleistocene*. It is so far new that we can trace a continuous history from its commencement, everywhere having relation to existing climate and existing races. Many of its inhabitants have removed, some to warmer others to colder climates; but there is no longer any complete break, as is the case with some of the older rocks.

But if in some sense new, this first appearance of man on the earth is in point of years by no means modern. Estimating to the best of our ability, by such evidence as can be obtained, we cannot escape the conclusion that man has been long on the earth; has outlived vast changes of climate, and has seen race after race of animals disappear around him. The evidence is neither small in quantity nor weak and doubtful in quality. It comes not from one place or one country. It is supported not by a few, but by a large number of facts.

The introduction of man on the earth is an event of which we have no direct proof, but of his existence during a certain period we may be satisfied if we find his weapons, his implements, his pottery, his ornaments, and, above all, his skeleton. It is not too much to say, that all these are met with under circumstances which connect them with geological phenomena requiring much time for their completion. Let us consider a few cases, and estimate their value.

At New Orleans, in the delta of the Mississippi, charcoal and a human skeleton were found, at the depth of fifteen feet, under four layers of woody matter, successively deposited with mud and sand. In many caverns human remains of various kinds, and skeletons, have been found at the bottom, buried with the bones of extinct quadrupeds, coated with a thick shell of stalagmite. At certain stages in the deposit of stalacite are other human indications, and among them Roman remains of known date. By an estimate from this, it would appear that the lowest human remains must be of a date carrying us back a quarter of a million of years. A similar calculation made on the occasion of a railway cutting laying bare a highly instructive section in Switzerland, led to the same result.

All we can say then is, that after (perhaps at the close of) the Glacial Period, we find that men inhabited Europe. They constructed implements by chipping flints into flakes and knives (*see* fig. 45). They were probably cannibals. They lived in caverns —they fed on the animals they could kill by their superior intelligence. They split the bones of their prey to extract the marrow. We have no proof that they cooked their meat. At the same time, it must be remembered, that the lowest state of savage life in one part of the world is perfectly consistent with large groups of the most highly civilized races in another part. The deposits with human remains that might have been deposited a few years ago in Central Australia, would point to the least advanced and least intelligent races as the inhabitants. Not far off, however, existed a multitude of highly developed and intellectual men, whose intellectual powers had already enabled them to bring from the uttermost parts of the earth the luxuries and contrivances, whose invention had taxed the cleverest brains for centuries.

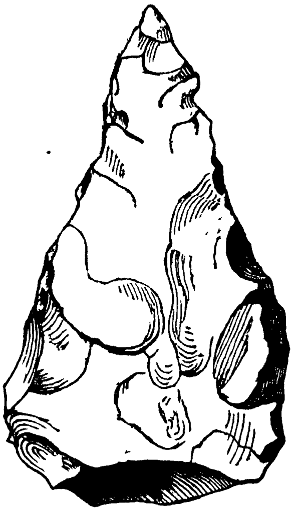


FIG. 45.—Sculptured flint implement of the Stone Period.

During the early part of the recent or human period, much work was going on upon the earth's surface, producing or greatly modifying the plains and valleys, and affecting even the lofty and snow-covered mountain tops. At this time there was a line of active volcanoes, reaching down from the Eifel in Rhenish Prussia into Spain, erupting occasionally, and accumulating volcanic ash, and pouring out lava or basalt in large quantity. The land in the Polar Sea was probably sinking, but the plains of Europe were rising, and, while rising, were subject to great and rapid denudation, wearing grooves in the rock, which in time became developed into the river valleys. Thus were produced those gravels, which owing to a continuance of upheaval, are now found on the plateaux far above the present bed of the river which formed them and then left them behind. These are now called *high level gravels*, and they are abundant in all those countries that have been subjected to glacial action. No torrent or deluge has passed over the ground to produce them. They are perhaps the result of the same, or nearly the same, volume of water and strength of current that still cuts out a channel in places where the land is being upheaved, and fills it up when there is rest or depression. In certain valleys the caverns now opening on the hill or cliff side far above the river were then at the level of the water, and have been filled by the river mud and silt, or by gravel transported by the ancient stream.

We advance now to a second stage in the history of the human race in Europe. On the land, whether valley or plain, near the deepening streams, lived a race of men already advanced beyond the savage state. We find their implements consisting of neatly cut stone knives, axes, arrow-heads, saws, and hammers, all constructed of flint, shaped by other weapons of the same material, buried often in large number with the sand, silt, and gravel. They are frequently found in caverns, coated with thick masses of stalagmite, left behind by the evaporation of water charged with limestone, dropping continually on the floor of the cavern. With them we also find implements and ornaments made of the bones and horns of reindeer, teeth and bones of bear and hyæna, and (though rarely) fragments of the human skeleton. Pottery has only yet been discovered in one spot. The human remains differ from the modern skeleton, the bones being thicker and more massive. In this respect, they agree with the bones of Esquimaux, who, as a race, certainly exhibit intelligence, and are partly civilized.

Numerous caverns in England, in Belgium, in Central and Southern France, in Sicily and Malta and elsewhere, have yielded almost exactly the same kind of evidence with regard to the existence of men associated with remains of the reindeer, gigantic extinct bear (*Ursus spelæus*), a large hyena (*H. spelæa*), and other animals now called cavern animals. With them are remains of a large and, doubtless, heavy elephant, the *Mammoth* (*Elephas primigenius*), now extinct, a peculiar and extinct Rhinoceros (*R. tichorhinus*), a gigantic extinct deer, with widely-expanding horns, found perfect in the bogs of Ireland, and called the Irish Elk (*Cervus megaceros*); a large tiger (*Felis spelæa*), also extinct, together with the horse, the ass, the wild boar, the wolf, the fox, the otter, and some others, which have not been distinguished from the common species now living in Europe.

Among the most remarkable of the human remains in these caverns must certainly be ranked the curious and effective scratches of the animals of the period on fragments of ivory, or on the flat surface of the horn of the reindeer. These, in more than one instance, have represented animals before known only by their skeletons, and in two most interesting cases, marked peculiarities of form in the skeleton are represented in these drawings, made of course from the living animal. The mammoth (*see* fig. 47), the great cavern bear (*see* fig. 46), and a deer, are the animals thus represented. Human teeth were obtained from the cavern which yielded one of these.

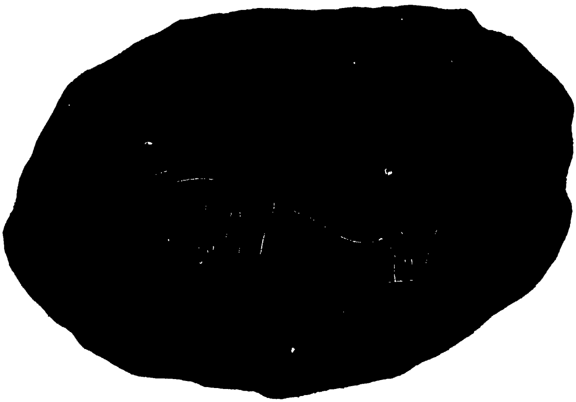


FIG. 46.—OUTLINE OF A CAVERN BEAR ON IVORY.
Scratched by men of the Reindeer Period.

It is certain that during this reindeer period the human inhabitants of Europe were by no means without cultivation. They constructed for themselves needles, from which we may conclude that they wore clothing whether of skins or of some woven material. They had combs of horn, bracelets and collars of shells, and teeth sometimes pierced for this purpose, and sometimes strung. Their weapons and implements indicate progress, when compared with those of the inhabitants of the preceding or late Glacial Period, being more carefully and effectually shaped. Their drawings on horn and ivory are in some cases admirable representations of species now extinct. It is, however, impossible to imagine anything more interesting than the identity of form of the elephant of Siberia with that of France after the Glacial Period. The former is known by the actual skull obtained from the gravel of the Polar Seas, and now in the museum of St. Petersburg, with portions of its hair and wool and some of the contents of its stomach when found in the ice. The outline of the latter is from a sketch on ivory found in a cavern in central France (*see* Fig. 47).

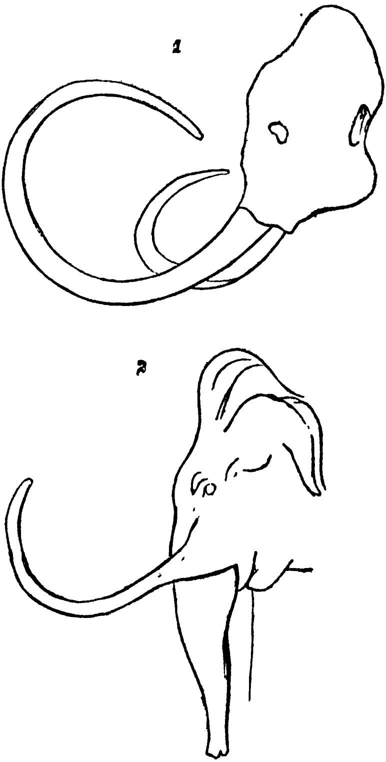


FIG. 47.—1. Skull of Siberian mammoth.—2. Drawing of head of elephant, scratched on ivory by the men of the Stone Period.

The fact that a large and complete group of important quadrupeds characterized the Post-Glacial Period in Europe, and that man was a contemporary of these animals, is placed beyond doubt by the multitude of examples, the mode of occurrence of the remains, and the complete harmony that exists among the different branches of the evidence. In process of time, changes took place in the distribution of the animals, and it is evident that these had reference to changes of climate. The extreme cold of the glacial time was modified, and the land was acquiring the form and outline that now belong to it.

There exist in Denmark, Scotland, and other places in Northern Europe, hillocks made up of the shells of oysters, mussels, whelks, and other shell-fish, mixed with bones of quadrupeds, birds, and fishes, and various human remains. More than a hundred of such hillocks, some of them more than 300 yards long, 50 yards wide, and 10 feet high, have been counted on the shores of the Baltic. Some are oblong and others round. The shells and fish bones generally are such as show that they belonged to kinds of animals not now living in the Baltic, but inhabiting a deeper and apparently a salter sea. These heaps (called sometimes *kitchen-middens* or kitchen-heaps) mark the sites of ancient villages inhabited by men of an early period, although apparently subsequent to that of the Reindeer, and when the savages were beginning to smooth and polish the hard stones they used for knives, lance-heads, &c. In Switzerland are remains of other kinds left by the people of this period. Whilst, however, an advance in intelligence and civilization is evident in some respects, and the dwellers on these coasts appear to have known nothing of some of the large quadrupeds already alluded to as belonging to the Reindeer Period, the kitchen-middens yield no mark of the cultivation of the food plants, or of domesticated animals. The animals found in Northern Europe at this time included the Urus or wild ox, several deer, the reindeer (rare), the dog, the fox, the lynx, the wild cat, the goat, the wild boar, the wolf, the seal, the otter, the beaver, the wild swan, the goose, the duck, the cock of the woods, and the penguin. The people seem to have fed chiefly on the urus and dog, and there seems proof that they were, to some extent, cannibals. Their weapons and implements were of smooth and polished flint. In France the horse and sheep were added to the list, and among the shells there are innumerable shells of snails, animals still eaten not only in France but in many parts of Europe.

This age of polished flint has left its mark in most parts of Europe. Nowhere have works in metal been found belonging to it; although extreme ingenuity is shown in the contrivances by which hard stone has been made to do the work of metal. But like the earlier, or chipped flint period, this also passed away by degrees, and some ingenious inventor arose, who discovered the mode of reducing and working metals, and who soon was the means of displacing the old stone weapons and implements by others of bronze.

The year 1853 is worthy of note in the history of geological discovery, in reference to the habits of these ancient workers of metal. In that year, owing to the unusual dryness of the summer, the lakes were so much lowered as to lay bare for the first time within record, the remains of ancient cities, built on piles in the lakes. These ancient cities, having lasted for a time, and served their purpose, had been destroyed by fire, though not without leaving behind materials for the complete history of the peoples who dwelt in Central Europe during and after the time of the polished flints, and when metals were first beginning to be employed for many purposes. Since the discovery of these villages, details have been obtained concerning about 150 stations on the borders of the Swiss lakes, while similar results have also been arrived at from examining lakes in Ireland and other countries.

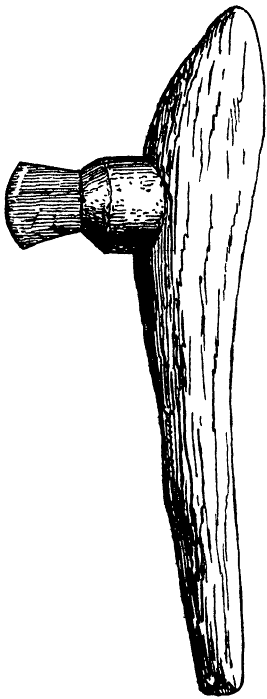


FIG. 48.—Polished stone axe in horn handle.

Of all the stations or lake dwellings discovered in Switzerland, about one-third appear to belong to the age of polished stone; rather more than a third contain remains of bronze utensils; and the rest contain objects made of iron. They thus represent three distinct but continuous periods. Bronze was manufactured before iron, as it is much easier to reduce by fire, and more manageable under the hammer. Before bronze was introduced, the handles of weapons were chiefly of wood or horn, the hafts and working parts being constructed of stone. (See the axe, fig. 48, drawn from a specimen of the later polished Stone Period.)

The lake cities were built on piles parallel to the banks of the lakes, and one or two hundred yards distant from the banks. They were connected with the land by causeways, and were generally founded where the water now varies from three to sixteen feet in depth. The number of piles on which each village was built amounts in some cases to upwards of 100,000. Where the bottom was rocky, other contrivances were resorted to. Precisely such habitations are now to be found in the island of New Guinea.

It is not desirable here to describe in detail the history, as determined from the remains found among the piles of the lake cities, of the inhabitants of Europe during the age of bronze and iron. Approaching so nearly our own times, it belongs to human history, rather than to the history of the earth; but as, when man had once been introduced on the earth, the history of the earth could not be written without, in some measure, following his progress, it has been thought well to bring the student thus far on his journey. It appears, from the plants and animals preserved, that Europe had now gradually undergone changes, bringing back the climate, which had been extreme, to something more like its present moderate condition; that many of the larger animals had disappeared altogether; many others had retired far from their former haunts; while others again, newly introduced, had taken their place. During all this time, however, man has been a permanent resident in Europe, his condition apparently improving, and admitting of so much civilization as is indicated by ornamental, as well as neat and useful, manufactures in metal, textile manufactures, the use of fire in cooking, and many other appliances. About the same time in Western Europe as in Egypt, Greece, and Asia Minor, the habit of working in stone had become so far advanced as to admit of the construction of vast monuments, and the removal of blocks of the most gigantic magnitude, involving not only infinite labour and patience, but a real knowledge of the principles of mechanics.

We have already had occasion to allude to the extensive deposits of the Later Tertiary Period in America. Nothing, indeed, amongst formations of any older date can compare with the vastness of the tract over which ranged the extinct quadrupeds whose remains are embedded in the mud of the Pampas. It extends from the tropics into the temperate regions of America on both sides—westwards to the Cordillera, and southwards to Tierra del Fuego. They are so abundant that Mr. Darwin believes it would be impossible to cut a trench in any direction without finding marks of their existence. But they were living at a very recent period, although most of the quadrupeds whose bones are so common are now altogether extinct. But it must not be supposed that the extinction of tribes involves any great disturbance or any accident. Species die out by degrees, and are sometimes lost even when there seems little reason, so far as we can discover, for such a result. There is reason to suppose that the *Dinornis*, a gigantic bird of New Zealand, the *Moa* of the natives, was living not very long before the islands were first visited in modern times, and it is evident that the creature was known, at least by tradition, to the natives. Its eggs have been found as well as its bones.

But coming even to more recent times, we have, in the islands in the Indian Ocean, lying east of Madagascar, a land where there were birds of large size and singular appearance, of which pictures were painted, and which were removed alive to foreign countries less than three centuries ago, but of which now there would be no record or recollection, except a few stray bones, were it not for the drawings, pictures, and prints of the early voyagers. Of such animals the *Dodo* of the island of Mauritius is the best known. A copy from an early Dutch drawing is given in the annexed cut. The animal was a kind of pigeon,

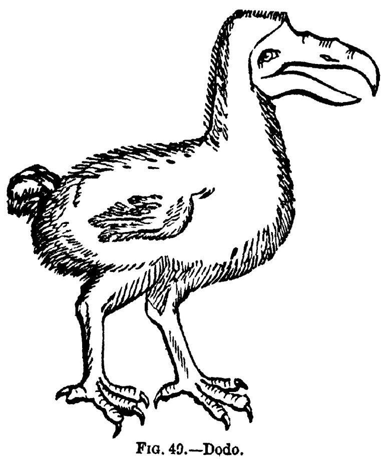


FIG. 49.—Dodo.

almost wingless, much larger than a swan, weighing in some cases perhaps 50 pounds, and fit for food. It has entirely disappeared. Other birds more resembling the cassowary, from the adjacent islands, are equally extinct, and all other record than the drawings and old descriptions is lost.

It thus appears that even far within the historic period the great work of the destruction of races has been going on almost under the very eyes of man. The dodo and his fellows have disappeared; the dinornis has disappeared; and in each case, as far as we can judge, without the operation of other than ordinary and natural causes. The many gigantic quadrupeds of South America are now represented by a few of the same class, but of much smaller proportions. The Australian extinct kangaroos, and other marsupials, of which there is an almost equal list, are now also limited to fewer as well as smaller species. In Europe, therefore, where we find that many large quadrupeds have disappeared within the human period, and where there has been a replacement by other races, there is no need to assume that any other than a slow change, though doubtless a very great change, has taken place in the climate and conditions of existence.

CHARACTERISTIC AND REMARKABLE FOSSILS.—These are chiefly from the lower beds. The boulder clay is not rich in fossils, and the remains found in the caverns and gravel are principally those of mammalia. (1) Amorphozoa—Sponges. (2) Foraminifera. (3) Corals—*Balanophyllea calyculus, Flabellum Woodii.* (4) Echinodermata—*Bryssus Scillæ, Echinocyamus, Temnechinus Woodwardii.* (5) Cirripedes—*Balanus tintinnabulum, Coronula, Scalpellum.* (6) Polyzoa—*Cellepora, Eschara, Fascicularia, Flustra, Heteropora, Hornera, Lepralia, Tubulipora.* (7) Bivalve shells—*Terebratula grandis, Terebratulina caput-serpentis; Admete viridula, Anomia, Arca lactæa, Astarte, Cardita analis,* *Cardium edule*, *C. Grœnlandicum*, *Chemnitzia*, *Corbula gibba*, *Cyprina Islandica*, *Cytherea rudis*, *Glycymeris*, *Leda lanceolata*, *Lima*, *Limopsis aurita*, *Lucina borealis*, *Mactræa*, *Modiola*, *Mya truncata*, *Ostræa*, *Panopæa Faujasii*, *P. Norvegica*, *Pecten percularis*, *Pectunculus*, *Pinna rudis*, *Tapes*, *Tellina obliqua*, *Venus casina*. (8) Univalves—*Buccinum Dalei*, *B. undatum*, *Bulla concinna*, *Calyptræa Chinensis*, *Capulus Hungaricus*, *Conovulus*, *Cypræa avellana*, *C.* (*Trivia*) *Europæa*, *Emarginula*, *Fusus contrarius*, *Murex erinaceus*, *Nassa* (10 species), *Natica occlusa* (and many species), *Nucula Cobboldiæ*, *Patella* (several species), *Pyrula reticulata*, *Rissoa* (15 species), *Scalaria* (12 species), *Terebra inversa*, *Trochus* (20 species), *Turritella communis*, *T. bicincta*, *Voluta Lamberti*. (9) Fishes—*Carcharodon*, *Megalodon*, *Otodus*, *Platax Woodwardii*, *Raia antiqua*, *Zygobatis*. (10) Mammalia—Ear bones of whales, *Ursus arvernensis*, *U. spelæus* (?) †, *Sorex* †, *Mygale moschata*, *Talpa Europæa*†, *Cervus megaceros* †, *C. capreolus* †, *C. claphus* †, *C. Sedgwickii*, *C. ardens*, *Bos primigenius*†, *Hippopotamus major*†, *Equus fossilis*†, *Rhinoceros megarhinus* †, *R. Etruscus*†, *Elephas antiquus*†, *E. meridionalis*†, *Arvicola amphibia*†, *Castor fiber* †, *Trogontherium Cuvieri*. Of these, all marked with a dagger (†), were continued into the newer part of the period (Post Glacial). The following are stated to be the characteristic Post-Glacial mammals—*Palæolithic man*, *Gulo luscus* (Glutton), *Ursus spelæus* (Cave bear), *U. ferox* (Grizzly bear), *Felis leo* (Cave lion), *F. pardus* (Panther), *Hyæna spelæa* (Cave hyæna), *Ovibos moschata* (Musk deer), *Rhinoceros tichorhinus*, *Elephas primigenius* (Mammoth), *Lemmus* (Lemming), *Spermophilus citillus*, *S. erythrogenoides*.

CHAPTER XI.

IGNEOUS AND METAMORPHIC ROCKS.

THE story of Geology is not told without some account of the results of the action of heat in the interior of the earth, and of changes thence produced. These are connected with the appearance of an important class of rocks, sometimes forming a definite and even large proportion of all the rocks visible at or near the surface of a large tract of country, and elsewhere only exhibited in small patches apparently thrust out from below or left behind when softer material, accumulated over or around them, has been washed away. In any case they are very different from the stratified rocks we have hitherto been considering, and in point of geological age they are altogether independent of them. They thus require to be described apart as belonging to all periods, and having been formed during all time. They differ also from stratified rocks in having been elaborated beneath and not upon the surface, and they are for this reason sometimes called *Hypogene.* (Greek: *hypo,* beneath; *ginomai,* to form).

Rocks of this kind arrange themselves naturally into three groups. First of all, the *basaltic series.* Basalt is the name given to the lavas of geological time. The word "lava" is applied to rock poured out from volcanoes in modern times and within human experience. Similar rocks not modern are called basalt. Their origin must be looked for in the deposits of clay and other material at some depth beneath the surface molten by local heat, and issuing out in a slow current under the influence of pressure from below. Though without water steam is connected with their history. They are full of cavities, especially at the surface, and these, filled at first with gases, are afterwards occupied by crystals of various minerals whose component parts were once present in the molten rock itself. Basaltic rocks being poured out in jets sometimes over a large area, and repeated many times, are often in beds or strata forming successive steps. From the Swedish word *trappa*, a stair, the name *trap-rocks* was given to these rocks by the early German geologists. Trap-rocks include not only the unaltered ancient lavas, but many crystalline rocks of the same general composition known by different names. Thus, *greenstone*, *clinkstone*, *hornstone*, *claystone*, and many others of feldspathic nature form parts of the great series. Those have been already noticed in the explanatory list (see page 21). The ancient basalts are generally more completely altered from the lava condition than those poured out in more recent geological periods, and are thus less easily identified, but they are often to be recognized by the other volcanic products, such as ashes and volcanic dust, worked up into strata and sometimes of great thickness, found at no great distance. Examples of this kind have been already noticed in speaking of some of the stratified rocks in former chapters.

There is no doubt whatever as to the fact that lavas issued from the interior of the earth through cracks formed in the solid crust during the deposit of the oldest strata. There is nothing in the material thus poured out or the circumstances under which it seems to have flowed to distinguish it from the lavas of more recent times and those of to-day. There is even a certainty that the outburst of lava was frequently accompanied by ashes and dust, and there is no evidence of the extent of the outflow having been greater in the early periods than more recently.

Of the Cambrian and Silurian greenstones or basalts and other volcanic products in England, we have already spoken. They may be examined and studied at this day among the rocks they once burst through, but along with which they have since lain little changed from their original state while exposed to frequent upheaval and subsidence to an enormous extent. There can be no doubt, therefore, as to the age of these rocks, since we find their exact position between recognized subdivisions of known series. So also in the rocks of the Carboniferous series the *toadstone* of Derbyshire, which is a true basalt, has penetrated as lava through crevices and fissures in certain gritstones and limestones, has spread itself out there on the surface, and has afterwards been covered by other gritstones and limestones also of the Carboniferous Period. Most of the greenstones that form characteristic features in English scenery are thus distinctly referred to certain well marked geological positions. In Scotland the volcanic eruptions are traceable in the newer part of the Old Red Sandstone Period, and extend into the Carboniferous, where columnar greenstone on a grand scale is frequently exhibited. It would seem certain that lava and volcanic products continued to be poured out until after the close of the Palæozoic period, for in Devonshire there are found unmistakeable traces of their presence in the new red sandstone. In these rocks near Tiverton are some gritstones apparently formed of volcanic ash, and numerous fragments of lava buried in the sandstones, some angular and others rolled into pebbles.

In the British islands there are, with the exception of the Devonshire Trias and some oolitic rocks in the Hebrides, few indications of volcanic disturbance belonging to the Secondary Period. The north-east coast of Ireland and the opposite islands of Scotland, however, exhibit all the ordinary phenomena of volcanoes in a degree unexampled in the earlier rocks. The Giant's Causeway and Fingal's Cave are good illustrations. The volcanic rocks continued to erupt in the north of Ireland and the Isle of Mull during the Older Tertiary Period, and other and much more important eruptions were then taking place in Central and Southern France, Spain, and many parts of Germany, where the craters still exist with every indication of activity, and have only recently been extinguished.

But these had been long preceded by lava-flows in Italy and Greece which have not ceased at the present day. In Asia Minor and India there are vast plateaux of basalt capping the hills and proving that there has been no apparent diminution in recent times of the extent of these accumulations. They have always formed part of the earth's history. They have been advancing with the growth of other deposits, and they form an important section of each successive period of the earth's history.

Next to the basaltic series so universally to be found throughout the earth, and of all periods, we have other rocks generally regarded as igneous, though there is little proof of their having at any time approached the surface in a molten state. These are the granites, or, as they are sometimes called, the porphyritic rocks. Though like basalts and greenstones in some respects, they cannot be mixed up with them as one group. They are crystalline in a more complete sense, consisting of crystals embedded in a kind of glassy paste. These rocks, when carefully examined under the microscope, are found to contain cavities occupied partly with fluid. Everything tends to prove that they have been formed deep in the earth under the great pressure of all the mass of matter lying over them, increased, it may be, by the force of steam at a very high temperature. There is no reason to doubt that the granites have been formed of precisely the same materials as those which now make up our stratified rocks. There is equally little reason to doubt that the manufacture of granite has proceeded parallel with the accumulation of stratified rocks at the surface, and the issue of lava from fissures. But it is probable that the granite is formed more slowly, cooled more slowly, and has been produced and brought into its present state at greater depth. It is probable also that it has been upheaved and brought to the surface only when already cooled, and completely solid, though perhaps much fissured. As there are lavas of all pèriods so are there granites of all periods. There are old granites older than the Laurentian schists and serpentines. There are granites of the Silurian Period and others perhaps of the Carboniferous Period. There are, however, beyond a doubt many granitic rocks in the great mountain chains of the earth that were not formed or lifted till the Secondary Period, and others that distinctly belong to the last elevations of the Alps, the Himalayan chain and the Andes that reach far into the Tertiary Period. It is evident that we can rarely do more than determine at what part of the earth's history the granitic rocks came first into their present position, and that to say when they were converted from deposited strata into this altered form of crystalline rock must in most cases be impossible. The exceptions are when a whole mass of granitic rock is entangled among altered stratified rocks, retaining proofs of their age in included fossils. Thus in the Isle of Arran, where the granite forms mountain masses, it penetrates also fissures in schists and other rocks which have been upheaved with it, and the whole is partially covered with rocks which appear to be of Silurian or Cambrian age. In this case the granites themselves, with all the overlying rocks, have been penetrated by volcanic rocks that have passed through them in a molten state.

With granites we may rank another rock partially or completely stratified, known as *gneiss*. Granite passes into gneiss. Both are of similar composition, and perhaps the former is only a somewhat more advanced stage of metamorphosis. There is thus a third group of rocks due to chemical action assisted by heat, and continually tending to obliterate all mark of the mechanical origin of rocks. The metamorphosed rocks are very varied, and gradually pass into those which are regularly stratified and clearly of mechanical origin. But they have also a structure and apparent stratification (*lamination* or *cleavage*) of their own, and are often broken up into distinct portions by joints. These, as well as the granites, are, however, of all ages. They are chiefly seen in mountain districts on the flanks of the granite, but they occur also elsewhere where they have not been subjected to newer accumulations of material, or where the deposits once placed on them have been washed away.

We thus see the whole history of the earth's crust, and, so far as observation goes, it would seem to exhibit a constant repetition of the same general system. A rock is deposited to-day with remains of such life as belongs to the period, and comes naturally in the way of being mixed up with the sands or mud of the place where the work goes on. On the shores of the European or American continent we might find an almost endless variety of all forms of life, marine, fresh-water and terrestrial, while around the vast and imperfectly drained land of Australia, there could be little if any indication of other than marine forms of very limited variety of structure. Deposits from such different localities buried at the same time might in the one case be submerged and preserved—in the other, elevated and partly denuded. After a certain interval strata might be formed in both places, differing, however, so entirely in all indications that they might well seem to belong to different periods of the earth's history. In course of time some of these strata buried deep below the surface and there exposed to the influence of heat and chemical action, might be converted into rocks more or less altered, more or less crystalline, until at length parts of them became schists, gneiss, or granite, while other parts might remain scarcely altered, and others again be altogether removed and carried to a distance by denudation. It is just such a fragment of history that the existing rocks give us. As we have already had frequent occasion to observe, the account is imperfect, broken, and often confused; but the facts are clear, and their study cannot but lead to valuable conclusions.

Looking back now at the history of the earth that has been gradually unfolded to the student, and regarding it as a succession of outlines, each partial, but in the main correct, let us endeavour in a few words to state what appears to be the general impression that the whole is calculated to make. The picture—for so we may regard these outlines—contains a foreground, in which all is comparatively definite, and in which we recognize familiar groups; a middle distance, peopled by forms not very distinct, but of which the general meaning is not very difficult to understand; and a background, dying away into gloom and obscurity, not without indication of life, but with too little completeness in the groups to justify us in supposing that we can recognize their precise meaning. Every part of the picture teems with life; everything we can distinctly make out is explicable; but as the colours are less bright, and the lights less prominent, there is not enough seen to enable us to speak positively as to the meaning. A half light is at present all we can throw on our picture; for ignorance of the working of many important laws of nature casts a shade, preventing a clear examination of what really exists. We thus miss a great deal that we may hope by degrees to discover, but there can be no hope of ever seeing the details of the early past—the dark ages of the world—as we can recognize those of the present or those which have only lately become the past.

What is most important to recognize in this general view of events in the world's history is, that it is, on the whole, a record of progress and of the gradual working out of one system. If we consider any one part and trace the history from that part onwards, there is little difficulty in discovering that the more recent is evolved from the more ancient, retaining the same character but occupying a wider space. It needs, indeed, more knowledge of natural history than can be expected from the student or the general reader to discover this for himself, or even, perhaps, to comprehend it thoroughly, but it is strictly true. The law, such as it can be learnt, is of this nature, and the facts certainly point in this way, if in this way only, to a beginning and an end. The beginning, however, is lost in the obscurity of the oldest stratified and metamorphic rocks as completely as the end is concealed in the constantly widening range of life developed upon, beneath, and above the general surface of the earth.

Printed by Woodfall and Kinder, Milford Lane, Strand, London, W.C.

INDEX.

Printed by Woodfall and Kinder, Milford Lane, Strand, London, W.C.

A COURSE OF MATHEMATICS,

PURE AND MIXED.

BY J. R. YOUNG,

LATE PROFESSOR OF MATHEMATICS, BELFAST COLLEGE.

The object of this work is to furnish Candidates for the Military and Civil Service Examinations with such a practical knowledge of Pure and Mixed Mathematics as may prove most serviceable to them in the course of the ordeal to which they are about to be subjected. On such occasions a mere theoretical acquaintance with principles is by no means sufficient. It is also necessary that the young aspirant should have been trained by actual experiments, as it were, to the application of the abstract rules, the enunciation of which he has, otherwise, mastered only by an effort of memory. To assist him in thus gathering the fruits of his intellectual industry, Mr. J. R. Young has devised a multitude of problems, of greater or less difficulty, in Algebra, Trigonometry, Mensuration, Analytical Geometry (Conic Sections), Statics, Dynamics, Hydrostatics, the Differential and Integral Calculus, with their applications to the Higher Geometry, Mechanics, &c. The chief peculiarity of this work, however, is one that will recommend it to a very large class of students. The most difficult questions are rendered comparatively easy, by the practical simplifications that are introduced in their mode of solution. Instead of a pompous and puzzling display of technical phraseology, the utmost care has been taken to explain the most knotty points in a plain unaffected manner, intelligible to every ordinary capacity. In this respect, Mr. Young's "Course of Mathematics" will be found to possess a decided superiority over all preceding works on the same subject.

"In the work before us he has digested a complete Elementary Course by aid of his long experience as a teacher and a writer; and he has produced a very useful book. . . . Mr. Young has not allowed his own taste to rule the distribution, but has adjusted his parts with the skill of a veteran."—*Athenæum*, March 9, 1861.

"Mr. Young is well known as the author of undoubtedly the best treatise on the 'Theory of Equations' which is to be found in our language—a treatise distinguished by originality of thought, great learning, and admirable perspicuity. Nor are these qualities wanting in the work which we are reviewing. . . . Considering the difficulty of the task which Mr. Young has undertaken to discharge, and the extent of useful knowledge he has succeeded in imparting accurately and lucidly in so small a compass, we can without hesitation commend this work to the public as by far the best elementary Course of Mathematics in our language."—*The London Review*, April 6, 1861.