most favourable conditions, only a small proportion of the total flora and fauna of any period could be preserved in the fossil state, enormous gaps occur where no record has been preserved at all. It is as if whole chapters and books were missing from an historical work. Some of these lacunæ are sufficiently obvious. Thus, in some cases, powerful dislocations have thrown considerable portions of the rocks out of sight. Sometimes extensive metamorphism has so affected them that their original characters, including their organic contents, have been destroyed. Oftenest of all, denudation has come into play, and vast masses of fossiliferous rock have been entirely worn away. That this cause has operated frequently is shown by the abundant unconformabilities in the structure of the earth's crust.

While the mere fact that one series of rocks lies unconformably on another proves the lapse of a considerable interval between their respective dates, the relative length of this interval may sometimes be demonstrated by means of fossil evidence and by this alone. Let us suppose, for example, that a certain group of formations has been disturbed, upraised, denuded, and covered unconformably by a second group. In lithological characters the two may closely resemble each other, and there may be nothing to show that the gap represented by their unconformability is not of a trifling character. In many cases, indeed, it would be quite impossible to pronounce any well-grounded judgment as to the amount of interval, even measured by the vague relative standards of geological chronology. But if each group contains a well-preserved suite of organic remains, it may not only be possible, but easy, to say exactly how much of the geological record has been left out between the two sets of formations. By comparing the fossils with those obtained from regions where the geological record is more complete, it may be ascertained perhaps that the lower rocks belong to a certain platform or stage in geological history which for our present purpose we may call D, and that the upper rocks can in like manner be paralleled with stage H. It would be then apparent that at this locality the chronicles of three great geological periods E, F, and G were wanting, which are elsewhere found to be intercalated between D and H. The lapse of time represented by this unconformability would thus be equivalent to that required for the accumulation of the three missing formations in those regions where sedimentation went on undisturbed.

But fossil evidence may be made to prove the existence of gaps which are not otherwise apparent. As has been already remarked, changes in organic forms must, on the whole, have been extremely slow in the geological past. The whole species of a sea-floor could not pass entirely away, and be replaced by other forms, without the lapse of long periods of time. If then among the conformable stratified formations of former ages we encounter sudden and abrupt changes in the facies of the fossils, we may be certain that these must mark omissions in the record, which we may hope to fill in from a more perfect series elsewhere. The complete contrasts between unconformable strata are sufficiently explicable. It is not so easy to give a satisfactory account of those which occur where the beds are strictly conformable, and where no evidence can be observed of any considerable change of physical conditions at the time of deposit. A group of strata having the same general lithological characters throughout may be marked by a great discrepance between the fossils above and below a certain line. A few species may pass from the one into the other, or perhaps every species may be different. In cases of this kind, when proved to be not merely local but persistent over wide areas, we must admit, notwithstanding the apparently undisturbed and continuous character of the original deposition of the strata, that the abrupt transition from the one facies of fossils to the other must represent a long interval of time which has not been recorded by the deposit of strata. Professor Ramsay, who called attention to these gaps, termed them "breaks in the succession of organic remains." He showed that they occur abundantly among the Palæozoic and Secondary rocks of England. It is obvious, of course, that these breaks, even though traceable over wide regions, were not general over the whole globe. There have never been any universal interruptions in the continuity of the chain of being, so far as geological evidence can show. But the physical changes which caused the breaks may have been general over a zoological district or minor region. They no doubt often caused the complete extinction of genera and species which had a small geographical range.

From all these facts it is clear that the geological record, as it now exists, is at the best but an imperfect chronicle of geological history. In no country is it complete. The lacunæ of one region must be supplied from another. Yet in proportion to the geographical distance between the localities where the gaps occur and those whence the missing intervals are supplied, the element of uncertainty in our reading of the record is increased. The most desirable method of research is to exhaust the evidence for each area or province, and to compare the general order of its succession as a whole with that which can be established for other provinces. It is, therefore, only after long and patient observation and comparison that the geological history of different quarters of the globe can be correlated.

Subdivisions of the Geological Record by means of Fossils.—As fossil evidence furnishes a much more satisfactory and widely applicable means of subdividing the stratified rocks of the earth's crust than mere lithological characters, it is made the basis of the geological classification of these rocks. Thus we may find a particular stratum marked by the occurrence in it of various fossils, one or more of which may be distinctive, either from occurring in no other bed above and below, or from special abundance in that stratum. These species might therefore be used as a guide to the occurrence of the bed in question, which might be called by the name of the most abundant species. In this way a geological horizon or zone would be marked off, and geologists would thereafter recognize its exact position in the series of formations. But before such a generalization can be safely made, we must be sure that the species in question really never does appear on any other platform. This evidently demands wide experience over an extended field of observation. The assertion that a particular species occurs only on one horizon manifestly rests on negative evidence as much as on positive. The palæontologist who makes it cannot mean more than that he knows the fossil to lie on that horizon, and that, so far as his own experience and that of others goes, it has never been met with anywhere else. But a single example of the occurrence of the fossil on a different zone would greatly damage the value of his generalization, and a few such cases would demolish it altogether. Hence all such statements ought at first to be made tentatively. To establish a geological horizon on limited fossil evidence, and then to assume the identity of all strata containing the same fossils, is to reason in a circle and to introduce utter confusion into our interpretation of the geological record. The first and fundamental point is to determine accurately the order of superposition of the strata. Until this is done detailed palæontological classification may prove to be worthless. But when once the succession of the rocks has been fixed palæontological evidence may become paramount.

From what has been above advanced it must be evident that, even if the several groups in a formation or system of rocks in any district or country have been minutely subdivided by means of their characteristic fossils and if, after

the lapse of many years, no discovery has occurred to alter the established order of succession of these fossils, nevertheless the subdivisions can only be held good for the region in which they have been made. They must not be supposed to be strictly applicable everywhere. Advancing into another district or country where the petrographical characters of the same formation or system indicate that the original conditions of deposit must have been very different, we ought to be prepared to find a greater or less departure from the first observed or what might be regarded as the normal order of organic succession. There can be no doubt that the appearance of new organic forms in any locality has been in large measure connected with such physical changes as are indicated by diversities of sedimentary materials and arrangement. The Upper Silurian formations, for example, as studied by Murchison in Shropshire and the adjacent counties, present a clear sequence of strata well defined by characteristic fossils. But within a distance of 60 miles it becomes impossible to establish these subdivisions by fossil evidence. If we examine corresponding strata in Scotland, we find that they contain some fossils which never rise above the Lower Silurian formations in Wales and the west of England. Again, in Bohemia and in Russia we meet with still greater departures from the order of appearance in the original Silurian area, some of the most characteristic Upper Silurian organisms being there found far down beneath strata replete with records of Lower Silurian life. Nevertheless the general succession of life from Lower to Upper Silurian types remains distinctly traceable. Such facts warn us against the danger of being led astray by an artificial precision of palæontological detail. Even where the palæontological sequence is best established, it rests probably in most cases not merely upon the actual chronological succession of organic forms, but also, far more than is usually imagined, upon original accidental differences of local physical conditions. As these conditions have constantly varied from region to region, it must hardly ever happen that the same minute palæontological subdivisions, so important and instructive in themselves, can be identified and paralleled, except over comparatively limited geographical areas.

It cannot be too frequently stated, nor too prominently kept in view, that, although gaps occur in the succession of organic remains as recorded in the rocks, there have been no such blank intervals in the progress of plant and animal life upon the globe. The march of life has been unbroken, onward and upward. Geological history, therefore, if its records in the stratified formations were perfect, ought to show a blending and gradation of epoch with epoch, so that no sharp divisions of its events could be made. But the progress has been constantly interrupted; now by upheaval, now by volcanic outbursts, now by depression. These interruptions serve as natural divisions in the chronicle, and enable the geologist to arrange his history into periods. As the order of succession among stratified rocks was first made out in Europe, and as many of the gaps in that succession were found to be widespread over the European area, the divisions which experience established for that portion of the globe came to be regarded as typical, and the names adopted for them were applied to the rocks of other and far distant regions. This application has brought out the fact that some of the most marked breaks in the European series do not exist elsewhere, and, on the other hand, that some portions of that series are much more complete than in other regions. Hence, while the general similarity of succession may remain, different subdivisions and nomenclature are required as we pass from continent to continent.

A bed, or limited number of beds, characterized by one or more distinctive fossils, is termed a *zone* or *horizon*, and, as already mentioned, is often known by the name of a typical fossil, as the different zones in the Lias are by their special species of ammonite. A series of such zones, united by the occurrence among them of a number of the same species or genera, is called a *group*. A series of groups similarly related constitute a *formation*, and a number of formations may be united into a *system*. The terminology employed in this classification will be discussed in the following part.

PART VI.—STRATIGRAPHICAL GEOLOGY.

This branch of the science arranges the rocks of the earth's crust in the order of their appearance, and interprets the sequence of events of which they form the records. Its province is to cull from all the other departments of geology the facts which may be needed to show what has been the progress of our planet, and of each continent and country, from the earliest times of which the rocks have preserved any memorial. Thus from mineralogy and petrography it obtains information regarding the origin and subsequent mutations of minerals and rocks. From dynamical geology it learns by what agencies the materials of the earth's crust have been formed, altered, broken, upheaved, and melted. From structural geology it understands how these materials were put together so as to build up the complicated crust of the earth. From palæontological geology it receives in well-determined fossil remains a clue by which to discriminate the different stratified formations, and to trace the grand onward march of organized existence upon this planet. Stratigraphical geology thus gathers up the sum of all that is made known by the other departments of the science, and makes it subservient to the interpretation of the geological history of the earth.

The leading principles of stratigraphy may be summed up as follows:—

1. In every stratigraphical research the fundamental requisite is to establish the order of superposition of the strata. Until this is accomplished it is impossible to arrange the dates and make out the sequence of geological history.

2. The stratified portion of the earth's crust, or geological record, as it has been termed, may be subdivided into natural groups or formations of strata, each marked throughout by some common genera or species, or by a general resemblance in the type or character of its organic remains.

3. Many living species of plants and animals can be traced downward through the more recent geological formations; but they grow fewer in number as they are followed into more ancient deposits. With their disappearance we encounter other species and genera which are no longer living. These in turn may be traced backward into earlier formations, till they too cease, and their places are taken by yet older forms. It is thus shown that the stratified rocks contain the records of a gradual progression of organic forms. A species which has once died out does not seem ever to have reappeared. But as has been already pointed out in reference to Barrande's doctrine of colonies, a species may within a limited area appear in a formation older than that of which it is characteristic, having temporarily migrated into the district from some neighbouring region where it had already established itself.

4. When the order of succession of organic remains among the stratified rocks has been determined, they become an invaluable guide in the investigation of the relative age of rocks and the structure of the land. Each zone and formation, being characterized by its own species or genera, may be recognized by their means, and the true succession of strata may thus be confidently established even in a country which has been shattered by dislocation, or where the rocks have been folded and inverted.

5. The relative chronological value of the divisions of the geological record is not to be measured by mere depth of strata. While it may be reasonably assumed that a great thickness of stratified rock must mark the passage of a long period of time, it cannot safely be affirmed that a much less thickness elsewhere represents a correspondingly diminished period. This may sometimes be made evident by an unconformability between two sets of rocks, as has already been explained. The total depth of both groups together may be, say 1000 feet. Elsewhere we may find a single unbroken formation reaching a depth of 10,000 feet; but it would be utterly erroneous to conclude that the latter represents ten times the length of time shown by the two former. So far from this being the case, it might not be difficult to show that the minor thickness of rock really denoted by far the longer geological interval. If, for instance, it could be proved that the upper part of both the sections lay on one and the same geological platform, but that the lower unconformable series in the one locality belonged to a far lower and older system of rocks than the base of the thick conformable series in the other, then it would be clear that the gap marked by the unconformability really indicated a longer period than the massive succession of deposits.

6. Fossil evidence furnishes the chief means of comparing the relative value of formations and groups of rock. A break in the succession of organic remains marks an interval of time often unrepresented by strata at the place where the break is found. The relative importance of these breaks, and therefore, probably, the comparative intervals of time which they mark, may be estimated by the difference of the facies of the fossils on each side. If, for example, in one case we find every species to be dissimilar above and below a certain horizon, while in another locality only half of the species on each side are peculiar, we naturally infer, if the total number of species seems large enough to warrant the inference, that the interval marked by the former break was very much longer than that marked by the second. But we may go further and compare by means of fossil evidence the relation between breaks in the succession of organic remains and the depth of strata between them.

Three formations of fossiliferous strata, A, C, and H, may occur conformably above each other. By a comparison of the fossil contents of all parts of A, it may be ascertained that, while some species are peculiar to its lower, others to its higher portions, yet the majority extend throughout the formation. If now it is found that of the total number of species in the upper portion of A only one-third passes up into C, it may be inferred with some probability that the time represented by the break between A and C was really longer than that required for the accumulation of the whole of the formation A. It might even be possible to discover elsewhere a thick intermediate formation B filling up the gap between A and C. In like manner were it to be discovered that, while the whole of the formation C is characterized by a common suite of fossils, not one of the species and only one half of the genera pass up into H, the inference could hardly be resisted that the gap between the two formations marks the passage of a far longer interval than was needed for the deposition of the whole of C. And thus we reach the remarkable conclusion that, thick though the stratified formations of a country may be, in some cases they may not represent so long a total period of time as do the gaps in their succession,—in other words, that non-deposition was more frequent and prolonged than deposition, or that the intervals of time which have been recorded by strata have not been so long as those which have not been so recorded.

In all speculations of this nature, however, it is necessary to reason from as wide a basis of observation as possible, seeing that so much of the evidence is negative. Especially needful is it to bear in mind that the cessation of one or more species at a certain line among the rocks of a particular district may mean nothing more than that, owing to some change in the conditions of life or of deposition, these species were compelled to migrate or became locally extinct at the time marked by that line. They may have continued to flourish abundantly in neighbouring districts for a long period afterward. Many examples of this obvious truth might be cited. Thus in a great succession of mingled marine, brackish-water, and terrestrial strata, like that of the Carboniferous Limestone series of Scotland, corals, crinoids, and brachiopods abound in the limestones and accompanying shales, but disappear as the sandstones, ironstones, clays, coals, and bituminous shales supervene. An observer meeting for the first time with an instance of the disappearance, and remembering what he had read about "breaks in succession," might be tempted to speculate about the extinction of these organisms, and their replacement by other and later forms of life, such as the ferns, lycopods, ganoid fishes, and other fossils so abundant in the overlying strata. But further research would show him that high above the plant-bearing sandstones and coals other limestones and shales might be observed, once more charged with the same marine fossils as before, and still farther overlying groups of sandstones, coals, and carbonaceous beds followed by yet higher marine limestones. He would thus learn that the same organisms, after being locally exterminated, returned again and again to the same area. After such a lesson he would probably pause before too confidently asserting that the highest bed in which we can detect certain fossils marked really their final appearance in the history of life. A break in the succession may thus be extremely local, one set of organisms having been driven to a different part of the same region, while another set occupied their place until the first was enabled to return.

7. The geological record is at the best but an imperfect chronicle of the geological history of the earth. It abounds in gaps, some of which have been caused by the destruction of strata owing to metamorphism, denudation, or otherwise, some by original non-deposition, as above explained. Nevertheless from this record alone can the progress of the earth be traced. It contains the registers of the births and deaths of tribes of plants and animals which have from time to time lived on the earth. But a small proportion of the total number of species which have appeared in past time have been thus chronicled, yet by collecting the broken fragments of the record an outline at least of the history of life upon the earth can be deciphered.

The nomenclature adopted for the subdivisions of the geological record bears witness to the rapid growth of geology. It is a patch-work in which no system nor language has been adhered to, but where the influences by which the progress of the science has been moulded may be distinctly traced. Some of the earliest names are lithological, and remind us of the fact that mineralogy and petrography preceded geology in the order of birth—Chalk, Oolite, Greensand, Millstone Grit. Others are topographical, and often recall the labours of the early geologists of England—London Clay, Oxford Clay, Purbeck, Portland, Kimeridge beds. Others are taken from local English provincial names, and remind us of the debt we owe to William Smith, by whom so many of them were first used—Lias, Gault, Crag, Cornbrash. Others of later date recognize an order of superposition as already established among formations—Old Red Sandstone, New Red Sandstone. By common consent it is admitted that names taken from the region where a formation or group of rocks is typically developed, are best adapted for general use. Cambrian, Silurian, Devonian, Permian, Jurassic, are of this class, and have been adopted all over the globe.

But whatever be the name chosen to designate a particular group of strata, it soon comes to be used as a chronological or homotaxial term, apart altogether from the stratigraphical character of the strata to which it is applied. Thus we speak of the Chalk or Cretaceous system, and embrace under that term formations which may contain no chalk; and we may describe as Silurian a series of strata utterly unlike in lithological characters to the formations in the typical Silurian country. In using these terms we unconsciously allow the idea of relative date to arise prominently before us. Hence such a word as chalk or cretaceous does not suggest so much to us the group of strata so called, as the interval of geological history which these strata represent. We speak of the Cretaceous, Jurassic, and Cambrian periods, and of the Cretaceous fauna, the Jurassic flora, the Cambrian trilobites, as if these adjectives denoted simply epochs of geological time.

The geological record is classified into five main divisions:—(1) the Archæan, Azoic (lifeless), or Eozoic (dawn of life) Periods; (2) the Primary or Palæozoic (ancient life) Periods; (3) the Secondary or Mesozoic (middle life) Periods; (4) the Tertiary or Cainozoic (recent life); and (5) the Quaternary or Post-Tertiary Periods. These divisions are further ranged into systems, each system into formations, each formation into groups, and each group or series into single zones or horizons. The subjoined generalized table exhibits the order in which the chief subdivisions appear.

Order of Succession of the Stratified Formation of the Earth's Crust.

	Britain.	Continental Europe.	North America.
Post-Tertiary or Quaternary	Recent—Alluvium, peat, &c.	Alluvium.	Recent or Terrace.
	Pleistocene—*Cave deposits, Glacial drift.*	Diluvium.	Champlain.
			Glacial.
Tertiary or Cainozoic.	Pliocene—*Crag deposits of Norfolk and Suffolk.*	Pliocene—*Tegel, Dinotherium-Sand.*	Sumter.
	Miocene—*Lignite of Bovey Tracey, Mull, &c.*	Miocene—*Leithakalk, Upper Molasse.*	Yorktown.
		Oligocene—*Lower Molasse, Grès de Fontainebleau, &c.*	
	Eocene—*Tertiaries of Hampshire Basin, and Isle of Wight.*	Eocene—*Nummulite-limestone, Flysch.*	Alabama. Lignitic.
Secondary or Mesozoic.	Cretaceous. Upper.	Senonian—*Craie blanche et tuffeau, Upper Quadersandstein.*	Fox-Hills group. (Upper Missouri Region.)
	Cretaceous. Lower.	Turonian—*Pläner-kalk.* Cenomanian—*Grès vert.* Gault. Neocomian.	Pierre group. Niobrara group. Benton group. Dakotah group.
	Jurassic. Oolitic. Upper.	Upper or White Jura (Malm).	Jurassic rocks appear to be but poorly developed in N. America.
	Jurassic. Oolitic. Lower.	Middle or Brown Jura (Dogger).	
	Jurassic. Liassic.	Lower or Black Jura (Lias).	
	Triassic. Upper.	Rhætic beds, Keuper. Muschelkalk.	Triassic.
	Triassic. Lower.	Bunter.	
Primary or Palæozoic.	Permian.	Dyas or *Zechstein*, Permian, *Rothliegendes.*	Permian.
	Carboniferous. Coal-measures.	Terrain houiller, Steinkohlen.	Carboniferous.
	Carboniferous. Millstone Grit.	Flötzleerer Sandstein	
	Carboniferous. Carboniferous Limestone.	Calcaire Carbonifère, Kohlenkalk, Kulm.	Sub-Carboniferous.
	Devonian and Old Red Sandstone.	Devonian	Devonian.
	Silurian.	Silurian (Transition or Grauwacke system).	Silurian.
	Cambrian.	Primordial Silurian, older grauwacke and slate. Primitive schists.	Primordial Silurian and Cambrian. Huronian.
Archæan or Azoic (Eozoic).	Fundamental gneiss.	Ur-gneiss.	Laurentian.

I. ARCHÆAN.

Underneath the oldest unaltered stratified and fossiliferous formations in Europe there occur masses of gneiss and other crystalline schistose rocks belonging perhaps to widely different geological periods, but, from want of satisfactory means of discrimination, necessarily united provisionally in one common series. That they are separated by a vast interval of time from the rocks which lie upon them is shown by the strong unconformability with which they are related to every formation of younger date than themselves. Everywhere thoroughly crystalline, they are disposed in rude, crumpled, often vertical beds, out of the ruins of which the overlying formations have been partly built.

BRITAIN.—In no part of the European area are these ancient rocks better seen than in the north-west of Scotland. Their position there, previously indicated by MacCulloch and Hay Cunningham, was first definitely established by Murchison, who showed that they possess a dominant strike to N.N.W., and are unconformably overlaid by all the other rocks of the Scottish Highlands. They consist of a tough massive gneiss usually hornblendic, with bands of hornblende-rock, hornblende-schist, quartz-felsite, granite, and other crystalline rocks. In two or three places they enclose bands of limestone, but neither in these nor in any other parts of their mass has the least trace of any organic structure been detected. It is impossible at present to offer any conjecture as to their probable thickness. It must be many thousand feet; but its approximate amount, if ever ascertainable, will only be made out after the region where they occur has been mapped in detail. These gneisses and schists possess a massiveness and rudeness of bedding which strongly distinguishes them from all the other and younger metamorphic rocks of Britain. They form nearly the whole of the Outer Hebrides, and occupy a variable belt of the western parts of the counties of Sutherland and Ross. Murchison proposed to term them the Fundamental or Lewisian Gneiss from the isle of Lewis—the chief of the Hebrides. Afterwards he called them Laurentian, regarding them as the equivalent of some part of the great Laurentian system of Canada.

In recent years Mr Hicks and others have endeavoured to show that in Wales there exist here and there protrusions of an old crystalline group of rocks from beneath the Cambrian system, and they have described these "pre-Cambrian" masses as overlaid unconformably by younger formations, as in the north-west of Scotland. Professor Ramsay, however, who with his colleagues in the Geological Survey mapped the Welsh areas in detail, contends that the supposed older gneiss is merely a metamorphosed portion of the Cambrian rocks.

CONTINENTAL EUROPE.—On the continent of Europe numerous areas of ancient gneiss rise from under the oldest fossiliferous formations. In Scandinavia the structure of part of the country resembles that of the north-west of Scotland: the fundamental-gneiss (*Urgneiss*), covering a large area, is overlaid unconformably by red sandstones which underlie the most ancient strata containing organic remains. The gneiss and its accompanying rocks range through Finland into the north-west of Russia, reappearing in the north-east of that vast empire in Petchora Land down to the White Sea, and rising in the nucleus of the chain of the Ural Mountains, and still further south in Podolia. In Central Europe they appear as islands in the midst of more recent formations. In the midst of the Carpathian Mountains they protrude at a number of points, but westwards in the Alpine chain they rise in a more continuous belt in the central portion of these crests, and show numerous mineralogical varieties, including protogine, mica-schist, and many other schists, as well as limestone