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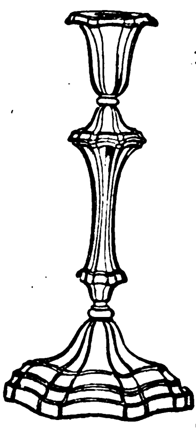

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PROFESSOR OF GEOLOGY IN KING'S COLLEGE, LONDON;
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A TREATISE ON GEOLOGY.

CHAPTER I.

INTRODUCTORY VIEW OF THE OBJECTS OF GEOLOGICAL SCIENCE, AND THE MEANS FOR INVESTIGATING AND INTERPRETING THE NATURAL HISTORY OF THE EARTH.

1. Objects of Geological Science.

The phenomena of geology are so various and complicated, that hardly any class of writers has left them wholly untouched; and the aspect of this science changes according to the peculiar object of different inquirers. Strabo, accustomed to enlarged views of physical geography, spoke of the existing forms of the surface of a part of Asia Minor, in reference to the ancient revolutions of nature which had occasioned them, and thus appeared to include geology among the tributaries to physical geography. Werner, habituated to minute discrimination of minerals and rocks, regarded the science, whose object it was to propose explanations of these differences, as a branch of mineralogy; while in Hutton's comprehensive mind geology applied itself to all the variable conditions of our planet, in all ascertainable or conceivable times, past, present, and to come.

Nor is there less diversity of object among the zealous students of geology. For some regard, as the principal object of their inquiries, the constitution of rocks and minerals,— the chemical effects which are traceable in the earth, and thus merely enlarge the limits of mineralogy; others turn their whole energy to the development of the history of fossil plants and animals, and thus constitute the interesting branch of organic geology *; while a third class watches the relation of the phenomena established by geologists to general statical and dynamical truths, and thus strives to found the new and attractive study of physical geology. Nor is there in this apparently imperfect apprehension of the extensive range of geological inquiry much to be reprehended. It is desirable that as many roads as possible should be opened toward the attainment of the varied truths which must be collected, by insulated observers, before it shall be found possible, for even the most comprehensive intellect, to frame a general and consistent view of the whole scope of this great branch of the study of nature.

The natural sciences are commonly understood to include all inquiries into the history of the inorganic and vital phenomena which take place on and about the surface of the globe, and the relation of these to general terrestrial, and cosmical conditions. The problems thus proposed for discussion are sufficiently ample and diversified to employ a very large number of observers and reasoners; they are, perhaps, inexhaustible; yet, were they all resolved, the study of nature would not be ended; for there would remain the inquiry, whether the present condition of nature is to be taken as a type of all her past and future states, or to be viewed as exhibiting one of many aspects, one of many gradations of change—a temporary adjustment, not a con-

* For this branch of Geology the term Palæontology is becoming usual.

tinual equilibrium — the last known term of a series whose law of variation is to be discovered.

Taking up this idea of the aspects of nature, at any particular epoch of the history of the earth (since the present laws of terrestrial and cosmical phenomena were appointed), being the last term of a long series — the complex effect of many anterior influences, we may proceed to inquire what monuments remain in nature of any previous aspects or conditions, and from these to infer the nature and amount of the agencies formerly concerned in producing and varying them. Having *ascertained* the series of *past* changes, we may venture to *speculate* on the *future* revolutions of the face of nature, to which the law of variation of the agencies concerned must necessarily lead.

Now, these are precisely the problems which it is the province of geology to consider. Gathering, from the labours of mineralogists, botanists, and zoologists, a knowledge of the existing species of inorganic and organic bodies; from geography, the account of the present configuration of the surface of the globe; from general physical researches, what is known of the constitution of the atmosphere, the ocean, and interior of the globe,—geology proceeds to inquire further, whether the mechanical, chemical, and vital phenomena, formerly exhibited on the earth, can be traced in their effects, so as to be put in comparison with those daily occurring; whether the mineral products of earlier eras of the world were identical in kind, and equal in rate of production, with the modern products of this description; whether the plants and animals of the ancient world were of the same structure as those which now adorn its surface; and whether the general physical conditions to which all these are correlated have always exerted the same kind and degree of influence as at present. In whatever way these questions are answered, they inevitably lead to speculation as to future revolutions which may vary the face of the globe; and thus geology, far from being the limited and narrow subject which was illustrated by Werner, after the model of the Saxon mountains, is found to include, perhaps, the largest class of inquiries which has ever been ranked under one head. For, in the attempt which it makes to decipher the history of the past, and to prognosticate the future changes of our planet, it requires the aid of all the gathered knowledge of nature, interpreted by the profoundest researches of abstract science. It is not even enough to know the actual state of the earth, we must further learn the measure of momentary changes in this state; and thus inquiries of a new order are suggested to naturalists, who are seldom aware, while investigating the problems before them, that these include dynamical as well as statical determinations, and that the former are necessary to the right understanding of the latter.

It has been made a reproach to geology, that, in its bold attempts to penetrate the dark veil which time has thrown over the mysteries of ancient nature, it has wandered far from its just mark, beyond the boundary of inductive philosophy and mathematical laws, into the unprofitable regions of cosmogony. Geologists have been equally blamed for stopping short of attainable truth, and declaring, upon inadequate grounds, that the earth shows no trace of a beginning, no prospect of an end. But geology is really distinct from cosmogony. Inquiries into the origin of the planetary bodies belong to one of the highest of human sciences, — astronomy. Geology, far from intruding within its precincts, supposes the globe to be constituted as a planet moving round the sun; takes for granted all the laws which this relation implies, and limits itself to the discovery of the strictly terrestrial phenomena which have happened upon this globe under these conditions. On the other hand, it was rash and presumptuous to assert the invariable uniformity of natural causes and effects, through all past time, upon data so insufficient as those known to Dr. Hutton; and, even if this were established, it would not be sound logic to infer that the earth showed "no traces of a beginning, no prospect of an end"; because, on that matter, other evidence might have been brought to bear.

But yet a candid reasoner need not greatly reprehend either the wandering of geology into cosmogony, or the too forcible acknowledgment of the incompleteness of all human research into the origin of the visible system of nature, which is contained in the much-censured language of Hutton. Neither of these errors is likely to be very injurious in science; nor can either be justly charged with the slightest tendency to make men forget that all the arrangements of nature are but the expression of the will of the Supreme Creator and Lawgiver of the universe. Let us not, therefore, be checked in our inquiries into the history of the globe, by anything but the good rules of philosophising, which are essential to the right use of the intellectual strength which God has conferred upon man, to be exercised on the mighty works of nature; and least of all let us be deterred from the pursuit of truth, by the vain and impious dread that we may go too far, and penetrate too deeply into those mysteries which, among their other uses, have this one, — that they continually excite to activity the soul of man; and, the more they are studied, lead to deeper delight and more awful contemplation of their glorious and beneficent Author.

Geology, or the natural history of the earth, as a planet revolving in space round a central orb of light and heat, surrounded by an atmosphere, and partially or wholly begirt by water, includes all the phenomena produced on the land, in the sea, and within the mass of the globe, by the operation of those mechanical, chemical, electrical, and vital forces, which are termed natural agencies, from the earliest epoch of which monuments remain, down to the present hour. All variations in the proportions of land and water; all variations of level; all changes in the combination and distribution of masses or molecules of matter, whether above, upon, or below the surface; all changes in the number, structure, forms, and relations of plants and animals, are to be ascertained as facts, and employed in reasoning, for tracing a general and continuous history of the physical revolutions which the earth has experienced since it became a planet.*

In this comprehensive definition of the objects of geological science, we include its real and legitimate field of research, without interfering in the least with the independent exercise of collateral sciences. To astronomy belongs the investigation of the history of the globe, as a part of the planetary system, and the results thus reached help to correct and limit geological inferences. Chemistry employs itself upon the inquiry into the laws and modes of mutual action among the particles of matter, and gives its results to aid in the general history of terrestrial phenomena. It is the province of zoology and botany to arrange and interpret the facts connected with life and organisation in plants and animals; and to these branches of knowledge geology owes immeasurable obligation. Thus the study of the ancient natural history of the earth draws help from every kind of inquiry which man can make into the actual constitution of nature, but robs none of its interest or glory; on the contrary, by the novelty of its discovered facts, fresh problems are presented to the cultivators of natural science, and a perpetual excitement is kept up, which has proved of infinite service to them all.

2. Means of Geological Investigation.

Thus ample and various are the problems clearly proposed in geology: in order to see how far they are de-

* "Geology is principally distinguished from Natural History, inasmuch as the latter is limited to the description and classification of the phenomena presented by our globe in the three kingdoms of nature, whilst it is the business of the former to connect these phenomena with their causes." "It consists in the knowledge of the causes which have acted, and still act, upon this earth, and thus embraces all the knowledge we can gain of nature, by an attentive study of terrestrial phenomena." — *De Luc, Lettre Premiere.*

terminate, and capable of solution, let us survey the means of investigation placed within our power, from what sources the data are to be collected, and in what manner the methods of interpretation are to be discovered.

In existing nature, we can examine and collate, for purposes of reasoning, three orders of data; viz. facts relating to organic beings; facts relating to inorganic bodies; facts concerning physical conditions, or modes of dependence of these two classes on each other, on the general laws of matter and motion, and the arrangements of the solar system. In this manner, it is seen that the radiation of light and heat from the sun; the alternation of day and night, caused by the rotation of the earth on its axis; the variations of seasons, depending on the position of its axis and on its revolution round the centre of the planetary system; the existence of an ambient atmosphere; the inequality of elevation of land; the distribution of land and sea, and other cosmical and terrestrial conditions, have a distinct influence on all the arrangements of organic life, and on some of the phenomena of inorganic bodies. Sometimes the law of this dependence is evident; generally the *nature* of it is discoverable, always the *fact* is capable of being satisfactorily ascertained: and thus existing nature is presented to our minds as a system of beautifully adjusted parts, which it is the highest province of the noblest intellect to contemplate in one point of view, and pourtray under the aspect of a general theory.

In geology, however, the physical conditions are *not known*, but are to be *inferred*, for any particular epoch in the history of the globe, from the facts collected concerning the organic and inorganic bodies which belonged to that era, and are indicative of the physical influences then operating: and hence arise both the difficulties and the charms of geological reasoning. The difficulties are unavoidably very great; for, even in the acquisition of the data concerning organic and inorganic bodies, geology is often forced to be satisfied with less exactness than is attainable in modern natural history. Certain shells, fishes, &c., are recognised by the geologist, but he may not find them of all ages; cannot know correctly what were the limits of variation, of their magnitude, forms, habits, &c. In some important cases, he can hardly know whether particular mollusca and fishes lived in lakes, rivers, or the sea; whether certain plants grew on land or in water. Now, as it is only on a correct knowledge of the affinities which the fossil remains of life bear to existing races, that any just inference can be founded concerning the contemporaneous physical conditions, we see how fertile are the sources of error, and with what justice men of philosophic minds have endeavoured to restrain that propensity to speculation which imperceptibly gets possession of the human mind, and has particularly luxuriated among the enthusiastic votaries of geology. There is less difficulty with respect to inorganic bodies, because the laws of their aggregation are such as, in many instances, can be tested by experiments which apply with equal exactness to the ancient and modern mineral kingdoms.

Scale of Geological Time.

It is further to be observed, that the very foundation of all history of geological phenomena is difficult to fix; for if it be embarrassing, even in civil history, to ascertain the relative dates of many most important occurrences, how careful should we be in marking even the order of succession of geological phenomena of the same kind; how diffident of our power of determining at all the lines of contemporaneity among occurrences of different nature, which happened in different regions of the globe, and under at least some difference of physical conditions! The very first inquiry to be answered, then, is, what are the limits within which it is possible to determine the relative dates of geological phenomena? For if no scale of geological time be known, the problem of the history of the successive conditions of the globe becomes almost desperate.

There is, however, at any place considered alone, a scale left us in the crust of the earth, by which to measure exactly the order of antiquity among the terms of the series of organic life, and to compare the relative antiquity of these terms at different and remote places, often with perfect satisfaction, and generally within moderate limits of error. This scale is the series of stratified rocks; and thus a great difficulty is overcome, and many of the inorganic and organic productions of older nature are capable of being arranged in the order of their successive appearance. We must, therefore, explain the nature of this fundamental scale, and illustrate its application; for we are, perhaps, not in a state to define the extent of its applicability.

Series of Stratified Rocks.

The crust of the earth is, for the most part, stratified — that is to say, the most abundant of the materials whereof it is composed, are in the form of widely extended and comparatively thin layers (called strata), laid one upon another, to a great numerical amount; these strata were, beyond all question, deposited in water, because many of them contain marine or fresh water shells, fishes, corals, and other marine exuviæ (and even were this not the case, the fact of the production of analogous or very similar strata beneath modern waters would justify the inference); therefore, *the lowest were formed first, the uppermost last.* To attempt proof of such a proposition would be to outrage common sense: he who cannot supply to himself the proof that the lowest layers of sediment produced by the waters of a pond, lake, river, or ocean, were deposited before the upper ones, is incapable of apprehending any natural truth. Yet, upon this simple and self-evident proposition rests the whole body of geological inferences which include relative time.

That the lower strata are the oldest, the uppermost the most recent, is a truth independent of all circumstances but the fact of the rocks being stratified and of aqueous origin: but what is the interval of time? Whether it was long or short — a day or a thousand years — how much older one rock is than another — if ascertainable at all, cannot be known without adding to the fact of the order of succession a number of other circumstances, characteristic not merely of succession, but of duration.

Lapse of Time inferred from the nature of the Series of Rocks.

The circumstances which help to define our notions of the time elapsed in the formation of the crust of the globe, — to translate, as it were, the symbolical notation of the geological scale of time into intelligible periods, having relation to the duration of the human race,—are various, and all concur in impressing the mind of a candid reasoner with evergrowing convictions of the immense antiquity of the globe; the many long periods of geological changes which it has experienced before arriving at the state when, in the magnificent language of holy writ, it was said to be expressly re-arranged for the creation of man, and the present system of terraqueous conditions.

The historic records of man's residence on the earth are, for most parts of the globe, utterly incomplete; so that, but for the Jewish Scriptures and other documents of eastern nations, we should be in danger of attributing to the human race an origin too recent by thousands of years. Now, as all historic records end, for each country, with the surface, — terminate at some point of man's history posterior to the preparation of that tract for his residence, we see how far more ancient than the historic date of the human race is the series of productions which lie below the surface. The limit of least antiquity of the scale of geological time is in every country beyond the date of the present surface. The series of strata is so ancient, that even its uppermost and newest term in every country is older than the race of man now existing there; though we are not entitled to say, without further examination, that it is older than the human species generally, for it is supposable that a former race of men might have existed over an older surface of the same part of the spherical area, under older physical conditions.

Antiquity of the Surface.

The records and traditions of mankind, which give a few thousand years to the existence of the human species on the globe under its present physical conditions, are in some respects corroborated by geological evidence of the comparatively recent date at which atmospheric agencies and drainage waters began to waste the surface of the earth, *under the present relations of the level of land and sea.* The notices of Herodotus concerning the formation of the alluvial land in Egypt from the inundations of the Nile, and similar facts connected with other great rivers, combine with the elaborate arguments of De Luc, concerning the formation of deltas in the upper ends of lakes, instances of which abound in every country, to show that the historic relations of the level of land and sea are, for the most part, not of so ancient a date as to be beyond comparison with the traditionary dates of the antiquity of the human race.

Having thus adopted as the limit of least antiquity of the scale of stratified rocks, the traditionary age of the human race, let us turn to consider the nature and meaning of the scale itself, so as to learn its value and range in the interpretation of the phenomena which happened in earlier physical conditions of the globe.

Nature of the Scale of Time.

The rocks composing the crust of the globe are for the most part stratified; but exceptions occur, especially in mountainous countries: the series of strata is commonly definite, or composed of a certain number of *simple terms, i. e.,* layers, each of a particular quality, in every small district; considered with reference to very large districts, it is found that, by grouping together the layers in natural assemblages, the series of these *compound terms* is also definite: finally, on comparing the series of even remote tracts, the compound terms themselves combine into groups, which are ranged in the same definite order whenever present together; for in some countries whole groups are absent, and others interpolated in the series. It is clear, therefore, that amidst all the causes of local diversity in the series of strata, some general influences have prevailed to give a determinate analogy of character to the resulting succession of stratified rocks in all parts of the globe If we can search out the causes of local diversity and general agreement, and thus ascertain the law of the geölogical scale of time, nothing will remain to be done but the comparison of this law with the analogous operations of modern nature, in order to attain the most precise account of geological time which the human mind can reach.

Terms of the Scale of Geological Time.

The different strata which are terms of the series or spaces on the scale of geological time are of various mineral qualities — arenaceous, argillaceous, calcareous, or composed of mixtures of these in unequal proportions. In the substance of many of them, peculiar minerals, as mica, red oxide of iron, silicate of iron, &c., are diffused; they differ in hardness, granulation, crystalline structure, and many other circumstances. Every one of these differences had its cause in some peculiar contemporaneous physical condition — these strata succeed one another in a settled order over the same area — were deposited beneath the water on the same part of the bed of the sea; it is certain, therefore, that in and about the same regions of the globe the physical conditions varied thousands of times during the formation of the series of strata. The mere inspection of one stratified rock composed of several *analogous* beds, gives a strong impression of elapsed time; but when we see thousands of beds of *different* qualities, the mind is opened to the further evidence which geologists bring on this important subject.*

Many, indeed most, of these strata contain the remains of animals which were living in the water at or before the time of the deposition of the rocks, and several are full of plants which were swept down from the dry land on which they grew into the ancient ocean. and then entombed in the strata at that epoch in progress of formation. By methods of undoubted accuracy, the length of life of some of these buried trees is ascertained to have been considerable — that they lived a hundred years for instance; the shells entombed often show the growth from young to old during the formation of one or a few thin layers of rock. Thus, in many instances, we are forced to suppose the lapse of a period of years during the accumulation of even one thin bed of stone. And even if this conclusion were not circumstantially exact, if the shells of all ages, living together in the sea, were buried in one bed by one action, or

* The entire mass of our continents is composed of strata, similar in this respect to the regular courses of stones in our buildings. A succession of strata indicates a succession of time for their formation; and the *change* from one species of stratum to another placed upon it, indicates a change of cause. Thus is the mass of our continents the product of successive operations, during which the producing causes have undergone successive changes. We see, moreover, that many of these strata contain the remains of animals; and that in some successive strata these organized bodies are of different species. By this we judge that some considerable length of time was necessary for the formation of these strata, both on account of the succession of individuals of the same species of animals in some of them, and also on account of the change of species in the same places where the former are buried. — *De Luc's Letters.*

even brought from small distances to be so buried, yet the inference is little altered by these admissions; for still, between the formation of certain beds, above and below those shells, their lifetime must have passed.

Series of Terms on the Scale of Geological Time.

But these conclusions become at once strengthened and more definite when we take into consideration the nature of the series of these terms; each of which indicates the lapse of time. For, first, it is found that the terms are recurrent, so that again and again *similar* or *analogous* strata are repeated, in different combinations, proving that the physical conditions which governed these depositions of strata were in some respects of periodical occurrence, or rather subject to interruption and fluctuation, so that different combinations prevailed at different periods. If we ask, in modern nature, so uniform in the local results of the same kind, the explanation of this, the reply will be immediately found: those periods of new combinations among the physical conditions of a given region are far beyond the range of human experience.

Moreover, an additional fact of great interest here comes to fortify all our inferences — the organic remains of plants and animals which abound in the earth are not those of the tribes that now live, but of many wholly extinct, and often quite different, races — different in form and structure, and, consequently, in function and habits of life, though certainly belonging to a general system of nature founded on analogous principal conditions. Further, it is not sufficient nor correct to say, there is one living and one extinct creation: the plants and animals buried in the earth belong to many distinct and successive creations, which differ among one another no less than they almost all differ from the actual forms of life. These distinct creations of former date are found buried in different parts of the series of strata; one series of organic forms belongs to the lower and older strata, another to those of middle, another to those of later date. The different groups of strata, deposited in successive periods, are thus filled with distinct races of plants and animals, which lived at successive periods, and thus it is proved that in every region the land and the sea were covered and filled at successive times with new creations suited to the new physical conditions of the altered planet.

This is not speculation, it is certainty. Each system or group of stratified rocks contains the remains of the plants and animals which existed at or previous to its production in or near the water in which it was formed: it is the museum of the period, the only repository of the monuments of that age of the world. By collecting these, and viewing them in the order of succession in which they occur in nature, we contemplate the forms of life which have successively occupied the globe, and by comparing them, on philosophical grounds, with the creatures that now exist, we can frame conjectures more or less satisfactory as to the state of the atmosphere, light, heat, and other circumstances, to which their life was adapted.

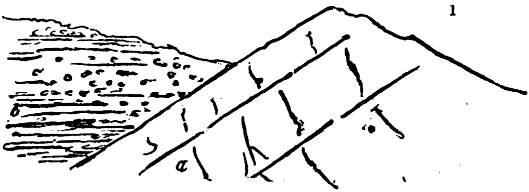
If we are to reason at all concerning the phenomena of nature, one of two conclusions must be adopted with reference to this subject; either the physical conditions whereto the existence of those plants and animals was related, changed gradually and equally in obedience to some continuous law — the forms of life being varied accordingly — or were liable to violent interruptions or revolutions, consequent upon new circumstances, or the accumulated tension of some feeble but continuous disturbing agency. Which of these views is true, will be the subject of inquiry hereafter: for the argument as to the lapse of geological time, it is immaterial which may be preferred; since in existing nature the rate of such physical changes, supposing them to be continual, is so small, as to have caused almost *no changes of organic life* in several thousand years; — witness the sculptured monuments of Egyptian grandeur; — and violent revolutions, capable of so influencing organic life (if probable at all), require, according to what is known of the earth and planetary system, periods or intervals too great for the mind to comprehend.

Interruptions of the Series of Time.

In certain rocks we find angular fragments, or rolled pebbles, derived by mechanical action from pre-existent and pre-consolidated rocks. The Righi, in Switzerland, is composed of such conglomerate masses; — the red sandstone of Cumberland and Westmorland is full of pieces of the subjacent slaty rocks; — the sands near London are stored with rolled flints from the subjacent chalk. The fragmentary masses, thus imbedded, are often the repositories of organic remains, sometimes of portions of mineral veins, both of anterior date to the rocks now including them. Thus we see proof of the occurrence of *different modes of action* over the same geographical areas, and our belief in the length of time requisite for all these occurrences becomes immoveable.

In general the stratified masses of the earth's crust are placed with their surfaces parallel to each other; from which we know that during their accumulation no violent disturbance of the external parts of our planet happened in those regions to confuse the regularity, and alter the horizontal plane of deposition. But in particular instances this conformity of the strata is departed from, and certain (older) rocks appear inclined at various, often steep, angles, or standing even vertical, while the more recent deposits lie level or nearly so, upon them. What renders this case of disturbed stratification more impressive, with respect to the lapse of time, is the occurrence of positive circumstantial proof of the intervention of mechanical, chemical, or vital agencies of considerable duration between the elevation of the older, and the deposition of the newer strata. Thus in diag. No. 1. the inclined beds *a* of limestone were exposed to watery action, and broken up in part, so that fragments and pebbles of

1



them are found collected into beds among the mass of later level sandy deposits *b* (Mendip Hills): and in

2

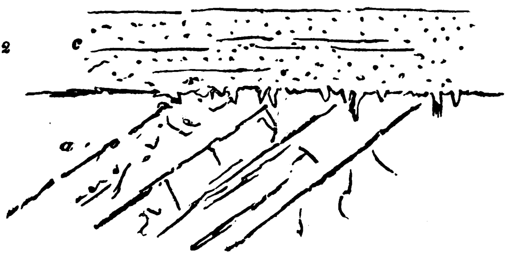


fig. 2. the same inclined limestone beds *a* are covered by horizontal oolitic strata *c*; and are worn and polished on the face of junction, and penetrated into holes by boring shells, which lived in the oolitiferous sea, long after the elevation of the older rocks.

Length of the Scale of Time.

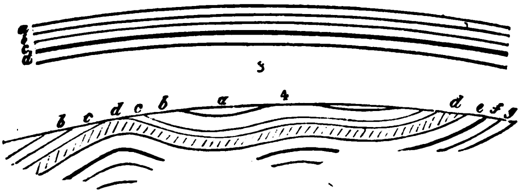
The scale of geological time given by the series of stratified rocks is one of unequal parts: for it is almost certain that the deposition of a given thickness of sandstone, was accomplished in a different time from that consumed in the production of an equal thickness of clay, limestone, coal, &c. Yet as many of the *groups* of strata contain both sandy, argillaceous, and calcareous members, there is less error in estimating the relative periods which elapsed in the production of such groups by their proportionate thickness, than in applying the method to the several strata and beds of the groups.

In a general sense, then, the total length of the scale of strata is of importance, as an element for direct computation of the total time elapsed in the formation of the crust of the globe. This length in some cases amounts to more than ten miles, and is seldom to be estimated at less than five.

Means of Investigation of Facts.

Having now sufficiently explained the nature and origin of that standard of time to which all geological phenomena are to be referred, it remains to be seen, 1st. What are the means in our power for collecting the facts concerning chemical, mechanical, and vital phenomena, effected in ancient periods, which are to be combined into a history of the physical changes of the globe? 2d. What are the methods of interpretation applicable to their phenomena?

Direct observations of the mineral composition of the globe are the groundwork of geology; but were our knowledge limited to the depth which is reached by actual penetration of the crust of the globe, by pits, wells, and other excavations, or seen in isolated mountain slopes, it would be of little value for the object proposed. — The deepest mine in the world (Kitzpuhl in the Tyrol) is only 2764 feet below the surface, the loftiest summits of the Himalaya only ascend 28,000 feet above it.—Yet in consequence of the manner in which the stratified materials are arranged in the crust of the earth, it is possible, by proper combination of direct observations, to know the structure of the globe to the depth of three, five, or ten miles, according to the situation and circumstances of the country. This will be understood by attention to the annexed diagrams where *fig.* 3 represents a false, and *fig.* 4 a true, representation of the arrangement of strata, in a part of the crust of the earth.



If the globe were conceived to be cut through, the section near the surface would show a number of layers variously inclined to the horizon as in *fig.* 4., so as to come up to the surface in succession *a*, *b*, *c*, *d*, &c.; not, as in *fig.* 3., parallel to the horizon, as many persons are apt to imagine. The thicknesses of *a*, *b*, *c*, *d*, &c. separately, may be easily known by pits and wells, or natural sections in ravines or precipices; their order of succession may be found by the same means, and thus the total thicknesses of all the stratified rocks visible in any one country, may be easily known by direct observation. By a judicious selection of examples, the upper part of the series of strata may be measured in one district, as *a*, *b*, *c*, *d*, *fig.* 4., the middle in another, which contains the lower portions of the former series, as *d*, *e*, *f*, *g*, in *fig.* 4.; and the inferior portions in a third, fourth, &c., so as to complete one general table or section of the whole series of strata visible in an island, or continent; and, finally, on the *face of the whole globe.*

This labour is actually accomplished for many large portions of the globe; and it is found that the stratification of the matter of the earth ceases at some depth which is not the same at different places, — three, five, ten, or more miles — below which are rocks of different structure, aspect, and origin, and not stratified.

Here, then, is the limit of our knowledge, from actual inspection and exact induction of facts concerning the constitution of the earth: geology, as such, can penetrate no farther than this small fraction of the radius of the earth. But the far-searching power of mathematical science is capable, by correct interpretation of astronomical observations, and refined experiments on the specific density of the globe, of giving us some further information as to the nature and arrangement of even the central masses of our planet.

Direct observation of organic remains is the only source of information concerning the ancient orders of living beings, which were in existence at or previous to the deposition of the several strata: no reasoning *à priori* can be, in this inquiry, of the smallest service; but may be exceedingly injurious by infusing error and prejudices. It would be a gross error, for instance, to assume that the earlier forms of life were less complex in visible structure than those which now exist—that the lower orders only of animals and plants had been called into being; for since the forms of life are most certainly made dependent on physical conditions, unless these latter can be known beforehand, there can be no *reasoning* on the matter, and there ought to be no *speculation* in inductive geology.

Means of Interpretation of Phenomena.

Admitting that by direct observation and the aid of higher science, geology has collected the evidence of the nature and arrangement of the mineral masses and organic reliquiæ, we may proceed to point out the method of interpretation which must be applied to the phenomena, in order to discover the physical conditions which prevailed in the several successive periods of the earth's structure in the situations observed. From the known to the unknown, through some common relations, has ever been the march of philosophical discovery: the skill of the general reasoner consists in the selection and use of these common relations for the determination of the principal conditions or agencies. It is through the knowledge of the conditions or agencies concerned in the phenomena of existing nature, that we must approach with caution to the solution of the similar problems offered by the phenomena of ancient times: the common relations are found by comparison of the analogous effects; but if the modern effects are merely known as laws of phenomena, and not reduced, to use Mr. Whewell's expressive language, to laws of causation, the corresponding phenomena of geology must remain equally unexplained.

The intelligent reader will easily see that it is not meant to convey the impression that nothing in older geology can be understood, unless there be known something exactly like it in modern nature; the laws of causation which regulate the phenomena now occurring on the globe, once correctly known, will certainly be recognised in a vast variety of older effects, in which the same agencies — however differently combined, — produced, or predominated so as to characterise, the result.

Thus the laws of chemical phenomena explain the production of the most ancient minerals, as well as of those daily produced before our eyes—the laws of physiology apply as well to the fossil flora, and the world of extinct animal life, as to the botanical and zoological enrichment of the actual land and sea: so also the laws of aggregation of sedimentary substances in water — of fused rocks and earthy matters — the laws of optical and calorific phenomena — these laws of action are limited in their application only by the circumctances of the case or of the experiment, independent of time, and exempt from change.

Geology thus presents itself in an aspect which may surprise those who have not studied the philosophy of the subject: though it gathers the most striking and beautiful facts, it depends for their interpretation entirely upon the progress of collateral science, and puts forth no speculation or hypothesis, except in conformity with the known laws of nature, and as a means of exciting and directing inquiry. In proportion as the philosophy of chemical, mechanical, and vital phenomena advances, so the interpretation of geological phenomena expands; and if at any time the leaders of geology have substituted conjecture for induction — a dogma for a dictum — they were then offending not so much geology as chemistry, physiology, and astronomy; and by these have they been justly condemned. Would that this warning might suffice to keep many hands to the sketch book and hammer, which they know well to use; and prevent them from attempting, without adequate knowledge, to aid in the progress of geological theory.

CHAP. II.

GENERAL REASONINGS CONCERNING THE SUBSTANCE OF THE GLOBE.

Chemical Data as to the Exterior Parts of the Earth.

WHAT is the nature of the mass of the globe is a question to which chemistry and natural philosophy furnish the only answers which our faculties can comprehend. The nature of matter, in the abstract sense, it is not given to man to know; but instead of this perhaps useless, and certainly unattainable, knowledge, we are able to discover differences among the sorts of matter when subjected to the same conditions — differences of weight, of hardness, of fusibility, solubility, crystalline arrangement, and many other important circumstances. These properties define the sort of matter to our senses; and thus it appears that many different compounds of matter exist in the earth. These compounds, resolved into their elements by the processes of chemistry, yield a certain number (fifty-four) of substances which, under the conditions yet applied to them, are found to be incapable of further analysis, and are therefore called simple or elementary substances. They are singularly diversified in weight, mode of existence when separate, and relation to temperature and electricity.

In a free state under ordinary pressure and temperature, some (five) exist as gas; viz., hydrogen, oxygen, chlorine, fluorine, azote. Seven are non-metallic solids and liquids; viz., sulphur, phosphorus, selenium, iodine, bromine, boron, carbon.

The remainder are metallic or metalloid, and, with the exception of mercury, which is both liquid and solid within the range of terrestrial temperature at the surface, all solid.

Thirteen of these are metallic or metalloid bodies, which unite with oxygen to form the earths and alkalies, viz., sodium, potassium, lithium, aluminum, silicium, yttrium, glucinum, thorinum, calcium, magnesium, titanium, strontium, barium.

Twenty-nine are what are commonly called metals; viz., manganese, zinc, iron, tin, cadmium, which decompose water at a red heat; and arsenic, antimony, copper, molybdenum, uranium, tellurium, chromium, cerium, nickel, vanadium, cobalt, lead, tungstenum, titanium, mercury, columbium, bismuth, osmium, silver, palladium, rhodium, platinum, gold, iridium, which do not decompose water.

"With the metallic and non-metallic bodies in the previous lists oxygen enters so generally into combinations, which yield solid compounds, and in such large proportions, especially with the earthy and alkaline metalloids, that we may venture even to say that one half of the ponderable matter of the globe is composed of oxygen gas. The speculations, to which this conducts as to the concentration from a gaseous condition of the matter of the planetary system, seem to be in agreement with the astronomical views of Herschel and Laplace, but are perhaps beyond the range of geology, which considers not the origin of the globe, but its successive changes of condition." *

Table of the Proportions per cent. of Oxygen in certain abundant Earths, Minerals, and Rocks,

100 Silica = 48·4 Silicium + 51·6 oxygen.
100 Alumina = 53·2 Aluminum + 46·8 Oxygen.
100 Magnesia = 61·4 Magnesium + 38·6 Oxygen.
100 Lime = 72 Calcium + 28 Oxgen.

* Guide to Geology.

100 Quartz = 48·4 Metallic base + 51·6 Oxygen.
100 Felspar = 54 Metallic bases + 46 Oxygen.
100 Mica = 56 Metallic bases + 44 Oxygen.
100 Granite = 52 Metallic bases + 48 Oxygen.
100 Basalt = 57 Metallic bases + 43 Oxygen.

100 Gneiss = 53 Metallic bases + 47 Oxygen.
100 Clay Slate = 54? Metallic bases + 46? Oxygen.
100 Sandstone = from 49 to 53 Metallic bases + 47 to 51 Oxygen.
100 Limestone = 52 Metallic base + 48 Oxygen.*

In studying the simple and various compound mineral masses occasioned by this union of oxygen with the metals and the metallic bases of earths and alkalies, the geologist labours on the same bodies as the mineralogist and the chemist, but not for the same end. To take a well known rock, granite, as an example —

"The geologist considers the circumstances under which this rock occurs in mass or in veins, with a view to determine the agencies which were concerned in its production, the period when it was produced, and other important characters. The composition of the stone is so far a matter of study for him as it helps to clear up these problems.

"To the mineralogist granite is an object of study, because it is composed of certain minerals which are characterised by certain constant properties. It is not granite that he studies, but its constituents, quartz, felspar, and mica. These minerals are investigated by their qualities of geometrical form, specific gravity, hardness, relation to light, electricity, &c. as separate objects.

"Finally, the chemist takes these separate minerals, resolves them into their several ingredients, examines the properties and proportions of them, and investigates the laws of their combination." †

* See on the Chemical Constitution of Rocks, De la Beche's Geological Manual, 2d edit.

† Guide to Geology, 3d edit.

Physical Data as to the interior Constitution of the Earth.

But these oxygenised substances are only such as are found among the bodies at or near the surface of the earth; and though some of these have been elevated from considerable depths by volcanic action, the information thus acquired may not be at all applicable to the interior parts of our planet. Observation is here entirely at fault, and we must be content to remain wholly ignorant of the analytical constitution of the interior masses of the globe. We may never know what chemical or optical properties belong to it; but instead of this kind of knowledge, which, however curious, would be of little value even in theory, we have received some very important instruction from astronomy and general physics, as to the circumstances under which matter, whatever be its chemical constitution, now exists and was formerly aggregated in the interior parts of our planet.

1. Methods have been devised of measuring the attractive force of the whole globe, compared to that of some of its parts, certain mountains, for instance, and thus poising its mass against some known weight; and these methods, confirmed by astronomical inferences, leave no doubt that the density and specific gravity of the globe is nearly five times as great as that of water at common temperatures and pressures. The average specific gravity of the principal stony masses near the surface of the earth is about 2½ times that of water; consequently, the interior parts of the earth are occupied by material substances heavier than those near the surface.

2. But it does not follow that they would be heavier if brought to the surface; for the pressure of the whole mass of the globe toward the centre must necessarily occasion a condensation of the substances, whether solid, liquid, or gaseous, therein occurring. This condensation due to mere pressure would indeed, upon all

mineral compounds known to us, go so far as to augment their density much more than is requisite for the fulfilment of the condition required by the calculation. According to Leslie (as quoted by Mrs. Somerville) water would be as heavy as mercury at 362 miles below the surface of the earth, and air as heavy as water at 84 miles. Calculations of this kind, however, involve suppositions as to the continuity of the law of the density of elastic bodies being proportional to the pressure upon them; they are thus in strictness liable to objection; but the error which might arise from this cause is quite unimportant for the argument in the text. We must therefore admit that either the interior substances are naturally lighter; that they are of so different a nature as to yield but little even to the immense pressure upon them; or that their inherent elasticity is aided by some principle of expansion, which balances a part of the pressure to the centre.

3. To aid us in choosing between these cases we may call in the aid of mathematical science and astronomical observations, from which it results, 1. That the figure of the earth is an oblate spheroid, such as would be produced by revolution on its axis, provided the constituent matter of the globe were in such a state as to be allowed freely to arrange itself in obedience to the central and tangential forces concerned. 2. It is ascertained as a consequence of the theory of the moon's motions, that the interior parts of the earth are not only more dense than the exterior, but that the inner surfaces of equal density are symmetrical to the same centre and axis as the external elliptical figure.*

From these observations conjoined, there is no doubt that the matter of the globe, having free relative motion, was arranged under the double influence of central and tangential forces; and consequently, that the substances in the interior must be naturally at least as heavy as those near the surface under the same circumstances.

Free relative motion to the extent here required,

* See Conybeare in Reports of the British Association, vol. i. p. 408.

viz. to the central parts, implies a total incoherence or fluidity of the mass of the globe. Such fluidity appears perfectly intelligible, as the effect of a general and pervading high temperature; and, perhaps, this is the only supposition which will at all meet the case. But it derives a considerable accession of probability from the fact that the earth is even *now hot* within; a point on which all experiments on subterranean temperature, and, perhaps, the grander phenomena of volcanoes, appear to agree; and a variety of evidence will be hereafter adduced to show that it was formerly *hotter*, at small depths below the surface, than it is at present.

From all this we obtain, as the most probable solution of the problem of the constitution of the interior parts of the earth, that the substances therein occurring have such analogies to those now seen near the surface, that they would have been subjected to very much greater condensation than they have suffered,—the globe would have been denser than it is,—were it not for the expansive influence of heat in the interior of the planetary mass. Whether the inner or medial parts of the substance of the globe be fluid or solid, must remain for very refined researches in physical astronomy to decide, if, indeed, evidence can be collected, on points involving the consideration of fixity or motion of the interior masses, sufficiently precise to give authority to the rigorous results of calculations applied for the purpose of testing this great question. Mr. Hopkins is understood to have been engaged in the great labour of discussing the phenomena of precession and nutation with this view.

Mass of the Globe whence derived.

With this knowledge of the *nature of the mass* of the globe, the modes of *combination* of the several ingredients of the mass, and the properties under certain physical conditions of these ingredients *existing separately*, one of two conclusions must be adopted by the human mind. Either we must believe these combinations to have been original, that is to say, that the ingredients have had no separate existence and properties, till the art of chemistry found the means of disuniting and insulating them; or view the existing aggregations of matter, as results of combination of the separate elements, produced by some change of conditions. If the former view be adopted, there is no room for further discussion; if the latter, an inexhaustible source of intellectual exertion is opened, and all the mysteries of nature are subjected to the scrutiny of man.

There may be persons who view this as a matter of no importance, and would, perhaps, be content to save themselves the trouble of inquiring into the works of creation, by the indolent belief that the world was made as we see it, its complicated phenomena not produced by appropriate laws of causation, but the result of an immediate fiat of Deity. As far as regards the reverential thoughts due to the Divine Lawgiver of nature, it may appear, on a first view, unimportant whether we admit the creation of the complicated phenomena, visible in the structure of the globe, by an immediate act of Almighty Power, or produced from some former condition in the same elements by the agency of intermediate laws of causation; but, on careful examination, it will certainly be found otherwise.

If it be true and demonstrated, that in the existing economy of nature all phenomena (whether they appear to our imperfect conceptions simple or complicated) are the result of invariable appointed laws, acting under definite conditions; if it appear that, in our own time, the phenomena of mechanical, chemical, and vital action among the elements and masses of matter are analogous to those of which monuments remain in the crust of the earth; if the laws which are known to govern and to correspond accurately to the modern effects stand in the same relation to those of older date; who, that looks upon the laws of modern nature, as affording proof of the being and attributes of God, will take a different view of the similar phenomena of ancient date, and thus virtually derogate from the respect due to the Lawgiver, by limiting the duration, and questioning the application of the law?

For it cannot be denied, that the appearances in the rocks which compose the crust of the globe, are such as to indicate most clearly that all their ingredients have existed in some other and earlier condition. The pebbles and fragments of stone imbedded in rocks of different nature are such as might be produced by previous *mechanical action;* crystals such as those imbedded in others are known to be effects of *chemical* forces; shells, plants, &c. retaining all their delicate external forms, and even their internal structure, can they be supposed to be mere *lusus naturæ,* or created to deceive mankind? Which is the more reasonable, to receive as truth the obvious indication of the senses, to acknowledge these effects to have happened through proximate causes, or to attribute to the Divine Wisdom the instantaneous creation of effects which, by their very nature and the nature of man, must inevitably mislead right reasoning to a wrong conclusion? It must, therefore, be allowed that the causes which the effects indicate, when rightly interpreted, are to be admitted as true; if the effects are rightly noted, and correctly interpreted, *all the inferences of geology,* however remarkable they may be, whatever agencies, conditions, or durations they assign to the composition of the crust of the earth, *must be received as natural truths.*

We may now follow the inquiry into the prior conditions of the materials consolidated in the crust of the earth. It is quickly seen that many considerable rocks are composed of parts which were *suspended* in water, as clays, sands, &c. and deposited from it as sediment; others are such as may be formed from *solution in water;* others resemble the products of *igneous fusion;* some appear the result of *electrical combinations.* All these latter are but forms of chemical processes among the elements of matter; and the sedimentary rocks, where their parts are clearly distinguishable, are found to be composed of grains or fragments, originally produced by aqueous, igneous, or electrical combination. Thus all the mineral masses of the earth known to us appear to have existed previously in a different state, when the elements were separated, so as to allow of their combination according to the forces of affinity, existing in definite proportions among the small portions of all material substance.

Take, for example, the very common rock sandstone; its component grains of quartz, felspar, and mica are, more or less, rolled or fragmented crystals of these substances, derived from rocks like gneiss, mica schist, &c., which are also composed of grains of the same kind, less affected by mechanical processes; or from granite, porphyry, &c., which are purely crystalline rocks. Such derivative sandstones are formed at this day from such crystallised granite, and other rocks. But the analysis goes further. Quartz is a compound of a metallic basis, silicium, and the air or gas oxygen. Felspar is a compound of silicium, calcium, potassium, &c., each united with its own proportion of oxygen. Mica is a compound of silicium, potassium, magnesium, calcium, &c. similarly combined with oxygen.

Under present physical conditions oxygen, being liberated from combination with these bases, would expand into 2000 times the bulk it occupies in the compound, and become a gas: and thus, since oxygen forms half the ponderable mass near the surface, half the crust of the globe, perhaps half its whole mass, would become an expansion or atmosphere round the diminished nucleus. It is evident that the tendency of all this inquiry is to lend some confirmation to the *speculations* of Herschel and Laplace, as to the condensation of the planetary masses from gaseous expansions, like the nebulæ and comets; speculations which appear to be gradually changing into probable *inferences* by the progress of modern astronomy. For the examination of these obscure bodies, with powerful telescopes, has shown them to be of extremely various characters, so as to offer many points in illustration of the supposed process of condensation and arrangement.

The progress yet made in chemical philosophy is perhaps not such as to enable us to discover the single condition on which the elements, now so firmly united, could exist separately, in a free gaseous expansion; yet, since chemical combinations are known to be subject to temperature, liable to be altered and even reversed with a change of this condition, may we not suggest, as the least improbable view, that the nebulous condition of a planet may be due to intense heat existing among its particles; that, in fact, a great heat prevents their combination, and maintains them *all together* in a gaseous state, as it is known to be capable of doing, for most of them singly, and several of them together? In mixed or combined gases metallic matters are frequently present (as arseniuretted hydrogen), and the atmosphere of our planet is believed by several philosophers to contain so large a proportion of the substances existing in the superficial parts of the globe, as to give origin to the meteoric stones.

CHAP. III.

GENERAL TRUTHS CONCERNING THE STRUCTURE OF THE EXTERNAL PARTS OF THE GLOBE.

From these facts and reasonings concerning the nature and constitution of the materials of the globe, derived from chemical and physical science, we may turn to contemplate the general truths obtained by direct processes of observation and induction, concerning the mode of arrangement of these materials, in that limited portion of the earth's mass which it is possible for man to explore by artificial excavations, or to understand by skilful interpretation of the disclosures effected by nature.

Beginning at the surface, and passing gradually towards the deeper parts, we shall be able easily to gather clear ideas of this fundamental portion of positive geology, without a right knowledge of which the otherwise pleasing task of following and examining the common reasonings in the science would be useless, if not presumptuous.

Structure of the external Parts of the Globe.

Soil, the external investment of the land, though it somewhat veil from geologists the objects of their peculiar research, merits attention; for this thin covering varies in some real relation to the rocks beneath, and appears, in many instances, to be nothing else than the substance of those rocks decomposed by time, and altered by vegetable admixtures. The depth of soil is extremely irregular, — some feet thick over certain sandy rocks, a foot thick over clays, only a few inches thick over chalk. In valleys the soil is accumulated from the waste of the hill sides: the surface of many (especially primary) mountainous regions is devoid of soil. In particular districts the soil is not merely formed by decomposition of the rocks beneath; it contains sand, pebbles, &c., brought from a distance, either by actual streams or some extraordinary force of water. Thus, in many instances, a mixture of substances takes place very beneficial to the fertility of the soil.

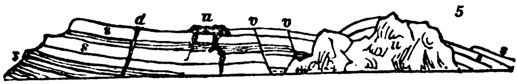
Beneath this thin and irregular layer, in some countries, the solid rock appears; but in others masses of loose sands, clays, gravel, &c., are found, which lie in hollows, or on the surfaces of the subjacent rocks, 10, 50, 100, or more feet in depth. These have evidently been *drifted by water*, and deposited from it, but yet they do not properly enter into the structure of the crust of the earth, but must be viewed as superficial and local accumulations, produced under circumstances considerably different from those which determined the formation of rocks. To these accumulations the names of alluvial and diluvial deposits have been applied: it appears desirable at present to use, for them and the soil collectively, the term *superficial accumulations.*

Rocks, and the substances which they enclose, lie beneath the superficial accumulations, and constitute the *crust of the earth* as known to geologists. The term "*rocks*" is apt to mislead beginners; for under this title geologists rank clay, sand, coal, and chalk, as well as limestone, granite, slate, and basalt, and other hard and solid masses, to which the use of the term is generally restricted: and they do so because they are all and equally constituent parts of the crust of the earth; and this crust is generally of a rocky consistence. The embarrassment which may be felt from this unusual employment of the term will diminish as we proceed, and find ourselves led to adopt various other modes of designating, in detail, the masses which it will yet often be convenient to speak of together under the vague term of Rocks.

Forms of Rock Masses.

On mountain sides, in ravines, and sea cliffs, the rocky masses of the earth are exhibited free from the obscurity of superficial accumulations: the industry of man, in mines, wells, roads, canals, has added to the facilities granted by nature, and from these opportunities the structure of the crust of the earth, the arrangement and relative position of the rocks, are known in the most essential points. The different sorts of rocks are by no means mixed together in confusion, but placed in a regular and ascertained method of occurrence, and often arranged in a certain determinate order of succession. Almost all rocks exhibit to the careful observer some interesting circumstances of interior structure, — particular divisions of their substance by joints, cleavage, &c.; but, neglecting for the present these subjects, we shall fix our attention on the *form of the rock masses* taken in their totality.

A very large proportion of rocks are formed so as to spread over areas of 10, 100, or 1000 square miles, with thicknesses of only as many or fewer feet or even inches: these are said to be *stratified* (*s*), or formed like a stratum or layer. Fissures, dividing particular rocks, are sometimes filled up with another sort of rock, which is then said to appear as a *dyke* (*d*); various spars, metallic matters filling fissures, or embodied in the rocks, are called *veins* (*v*); and many rocks, neither *stratified* nor in the form of *dykes* or *veins*, are in this sense amorphous, but are generally ranked with dykes, veins, &c., as *unstratified rocks* (*u*).

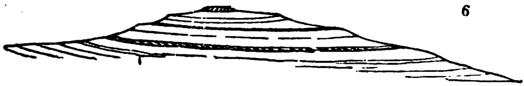


Dykes and veins form but a small part of the mass of the crust of the globe, which consists principally of stratified and unstratified rocks. In the plains, and comparatively low portions of the earth, the rocks are almost universally stratified,—the strata being often very thin, even to inches, but sometimes many yards or fathoms in thickness. The superficial area, over which a particular stratified rock expands, is sometimes enormous,—chalk, for instance, has a range of many hundred miles in length, by 5, 10, 20, or more in width, in England and France,—but sometimes very limited, as the magnesian limestone of the north of England, which ranges from Shields to Nottingham.

In more elevated districts, and on the flanks of mountainous regions, the rocks are also seen to be distinctly stratified. By patient attention it will be found that, even in the very midst of chains and groups of mountains, the marks of stratification may often be perceived; but it almost always happens that the axis of such chains or groups is formed by unstratified rocks, and these sometimes appear in lower situations.

Position of Rocks with respect to the Surface of the Earth. — Declination of Strata.

Stratified rocks have usually a nearly constant thickness, or else vary in this respect by insensible and regular gradation; their surfaces, or the *planes of stratification*, are therefore in general sensibly parallel, and their position may be known with respect to the surface of the earth, by observing the bearing of a level line (or *strike*) in the plane of stratification, and the angular amount of the descending slope (*dip*) or ascending slope (*rise*). The result of very numerous trials proves that the strata are over large surfaces often nearly but seldom quite horizontal; they dip, in fact, below the horizon, pass under the surface, and are covered up by other strata which also mostly dip in the same direction. Thus the surface of the earth in regions where stratified rocks occur is formed partly on their edges; and a *section* or vertical cut to some depth from the surface would present on its sides the appearance of the diagram, No. 6.



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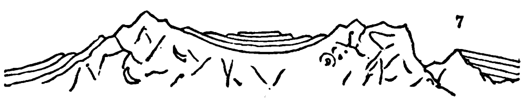
We may say that three fourths of the surface of the dry land of the globe is thus formed on the edges of moderately dipping strata: in all large districts the dip is found to be variable in amount and in direction, but, viewed on the great scale, always in harmony with one general law, which may be thus expressed:

The strata *dip from the chains and groups of mountains under the plains* which surround or divide them. Thus, from the group of Cumbrian mountains the stratified rocks dip W. at Whitehaven, N. at Hesket, E. at Shap, S. at Ulverston; from the chain of the Lammermuirs, they dip N. W. under the great valley of the Forth, and S. E. into Northumberland. The most general dip in England is easterly, the principal mountains being situated on the western border: from Brittany, the Ardennes, and Auvergne, the dips of the strata converge toward the low ground of the Basin of Paris; from the plains of Languedoc the strata rise toward the Pyrenees and the mountains of central France; the Pyrenees, the Apennines, the Alps, the Carpathians, the Grampians, are *axes* from which the stratified rocks decline, to pass under the lower ground on each side. Diag. No. 7.



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It is generally found that the dip of the strata, thus obviously related in direction to the axes and centres of mountain groups, is also related to them in amount, so that the angular value of the dip—or the number of feet in one hundred that the strata decline—decreases continually from the mountains toward the plains, and in the middle of these is sometimes evanescent. Near London, for example, and on the coast of England generally, strata, though not level, dip moderately (1° or 2°) toward the east; but on the line to North Wales the dip augments; on the border of the Principality it measures 5°, 10°, 15°, and in the range of the Berwyn mountains, 30° and 40°, or still higher angles.

The direction of mountain chains, and the position of mountain groups, being extremely diversified, the lines of strike and dip of the strata which depend upon them are also very various. Perhaps in the progress of the science some law of these directions may be established: in the progress of this essay we shall examine one such attempt by a distinguished foreign geologist. At present the most important things taught us by the phenomena of dipping strata are these:—1. The dip is related to the elevation of ground; and 2. The strata do not descend from one mountain chain below the surface of plain countries more than a very moderate depth (four to five miles) before they begin to rise again toward another axis of elevated ground.

The principal mountain chains and groups are thus seen to be the axes of declination of the stratified rocks; and it was not without reason that De Saussure explored with so much patience the giant elevations of Switzerland, Dr. Hutton and Werner studied the Scottish and Saxon chains, and Mitchell with a grand generalisation referred to the leading features of physical geography as a basis of laws of geological phenomena. The axes of mountain chains and groups being before shown to be generally occupied by unstratified rocks, we have arrived at the important inference, that the dip, or deviation of stratified rocks from the horizontal position, depends on the same axes or centres as the exhibition of unstratified rocks: the production of the latter is therefore in some way connected with the declination of the former.

If we suppose the unstratified rocks to have been raised from below, the position of the strata, the relations of physical geography, and the relations of the two classes of rocks would be at once explained. In order to see what foundation may exist for such a speculation, let us inquire into further details and other cases of the position of stratified and unstratified rocks.

Local Declinations and unusual Positions of Strata, &c.

It is not only in mountainous regions that the strata are found dipping at high angles; the same phenomena are repeated on a smaller scale, and for smaller distances, at many points situated in the midst of the great basins of strata far from the principal axes of declination.

The appearances presented at these points of disturbed stratification are extremely various, but they admit of a simple and useful classification. Nothing is more common, in many large districts, than a slight elevation of the plane of stratification along a certain straight line, so that the rocks decline from it on both sides, as *a*, diag. No. 8. This is called an *anticlinal axis*, and the elevated ridge a *saddle*. Its converse (*b*), the line to which the strata decline, is called a *synclinal axis*, and the whole depression a *trough*.

It not unfrequently happens, on a small scale, as in the Craven district of Yorkshire, in the Abberley hills, Clee hills, the shores of Berwickshire, &c., and still more frequently and remarkably on a great scale, among the Alps (Vale of Chamouni, Lauterbrun, &c.), that the strata near an anticlinal axis, instead of being formed in evenly declining planes, are twisted and contorted in several directions, as if exceeding violence had been repeatedly exerted in lateral as well as vertical directions (*c*). In many instances (as on the line of the Penine fault near Crossfell, near Kirby Lonsdale, and near Lancaster), the strata are reared on end, so as to be nearly or actually vertical (*d*); in other rarer examples (Malvern hills) they are totally overthrown, or, after having been raised to a vertical position, the upper parts have been pushed outwards, so that the strata usually lying uppermost in the group are actually, for a short distance, undermost (*e*).

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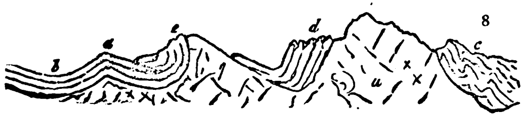

Faults.

Besides these, other forms of disturbed stratification demand attention; especially those in which the continuity of the strata is broken, and the divided parts placed at different levels. This interruption and dislocation of the strata commonly happens along a plane approaching to the vertical, which is usually marked by a rude and irregular fissure. This fissure, whether empty or in any manner filled (with fragments of the bordering rocks or other substances), is called "*a fault*," and locally "*a dyke*," "*a trouble*," "*a gall*," "*a slip*," &c.

The most simple and frequent case of faults is represented in the annexed vertical section (No. 9.) at the letter *a*, the strata lying nearly level, the fault vertical, the dislocation moderate in amount, and no particular bending of the rocks near it. In *b* the fault deviates

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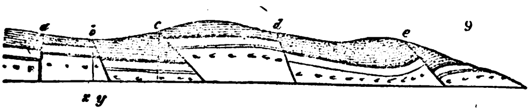
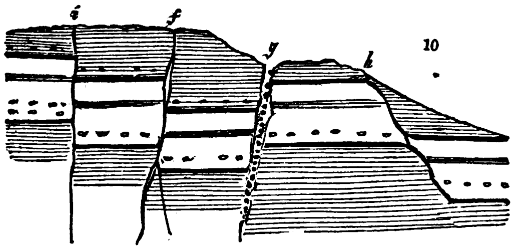
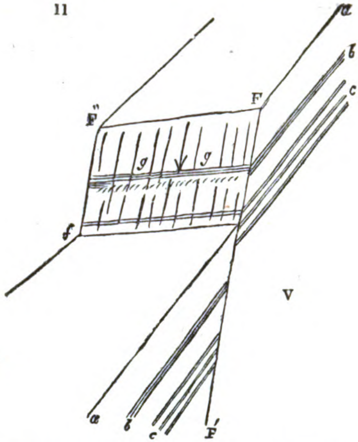


from the vertical by the angle *x b y*, and is said to have an underlay; the strata are considerably depressed, and in such a manner that a perpendicular dropped from *b* would fall clear of the edges of the depressed beds; not as in *c*, which represents a rare and exceptional case, so rare, indeed, that a clear example of it with a considerable depression of beds never occurred to the author, among very numerous instances studied in all classes of stratified rocks. In *d* the strata bend to the fault so as to coincide with its direction. In *e* the contrary effect is seen, the strata bending so as to meet the fault at right angles, as on the line of the great Tynedale fault, which disturbs the beds 1200 feet.

In some instances the fault fissures are open, as *f*, in others full of angular dispersed fragments from the adjoining rocks (*g*); sometimes a *leader* of one or more of the softer strata follows up the fissure for a considerable distance (*h*); but frequently, as *i*, the fissure is closed.—See the annexed vertical section.



The surfaces of the fissure accompanying a fault are often remarkable, and afford good evidence in favour of the dislocation of the masses having been accomplished by great mechanical violence, and perhaps a single continued effort. Let V *fig.* 11. be any vertical plane crossing *f* F F′ F″, the plane of a fault fissure, which is accompanied by a dislocation of strata through the extent *f* F″; *a b c*, being the corresponding beds on the two sides of the fault. The face *f* F F′ F″, one side of the fissure of the fault, is often scored by grooves (*g g*) parallel to the direction of the dislocation of the strata; that is to say, deep lines are ploughed on the broken ends of the rocks in the very direction in which they must have been produced, supposing, as the other phenomena indicate, the rocks to have slipped along the plane of the fault. A magnificent example of this is



seen at Cullercoats in the great Tynedale, or 90 fathom dyke, of the Newcastle Coalfield.

Extent and Frequency of Faults.

The extent of vertical displacement occasioned by faults varies from a few inches or feet to thousands of feet; examples of the former are common, of the latter rare. When carefully studied, however, the principal difference between them — the extent of the movement, is the only one which appears constant and essential. This is obviously related to the force employed in producing the fracture. That force may have been different in amount in the two cases contrasted, or different in the duration of its exertion; for the conformity of the circumstances of fracture seems to forbid a supposition of a different mode of action. Now, as an examination of the smaller and larger faults, when their planes can be clearly seen, appears to show that only one kind of action has been impressed upon the masses, as they appear to have slided in one direction, have been rubbed on their faces in one direction, and exhibit almost never any signs of repeated action along the same or neighbouring planes, we are forced to adopt, as a highly probable view of their origin, one continuous effort of a great force tending to extend, and, consequently inducing tension in, and fracture of, the crust of the globe. It appears no more necessary to suppose many interrupted efforts for a great fault like the Tynedale or Craven faults, of a thousand feet or yards, than for the numerous "hitches" in a colliery of one or a dozen feet.

It is commonly the case that such faults, when viewed on a horizontal plane, range nearly in straight lines, and for considerable, but very variable, lengths. When many faults occur, each producing only a moderate "throw," "shift," or displacement of the strata, their range is usually of only a few hundred yards, or a few miles, when they fall into and are stopped by some greater faults, or axes of movement.

On the contrary, when only a few faults occur in a district, and these have a great effect as to vertical movement, their course is usually of very considerable extent, even to many miles (the Tynedale and Craven faults range from 20 to 40 miles); but these also terminate in other faults or great centres or axes of movement. Faults which cross and appear to displace one another laterally, obey the same law of the angles as when their planes are compared to the surfaces of stratification, and the direction of vertical movements. (*Fig.* 9. *b.*) Faults are the most common of all the forms of disturbed stratification: but, except in particular cases, they are the least influential on the physical configuration of the country. All the rocks which are disturbed by any fault have experienced on one side the same movement, and to the same extent, excepting only those portions which have been subjected to violent pressure; and the bottom of the faults has never been reached, except when they terminate in another dislocation.

Relation of Faults, Mineral Veins, Dykes, &c., to the great Lines of disturbed Rocks.

It is noticed, as a circumstance of common occurrence, that mineral veins are no otherwise different from faults than by reason of the fissures which these have opened in the rocks being filled by sparry and metallic matters. This filling of a fissure constitutes a mineral vein; a similar fissure filled by basaltic or other rocks would be called a rock dyke; if occupied by clay and soft materials, a clay dyke. The point of importance in each of these cases is the mechanical formation of a fissure of the rocks along the plane of the fault; and it is to be determined by further inquiry, what was the cause of this particular line being followed by the disturbing force, and how the fissure, when made, came to be filled with its sparry, rocky, or soft argillaceous contents.

There appears to be some general relation observable between the lines of fault and the axes of great subterranean movement: that a "master fault" swallows up the smaller ones, or ramifies into them near the surface, has long been believed by the colliers of Somersetshire (as we learn from Dr. W. Smith). It appears, from our own and other researches, that the fissures accompanying mineral veins in the north of England, in the Penine Chain, and on the side of the Vale of Clwydd, terminate in such master faults; it also appears, by a careful analysis of phenomena, that mineral veins are so related to axes of disturbed strata, (like the Stiperstones, Greenhow hill, &c.), that they spring out from such, or tend to cross them at right angles, and scarcely appear anywhere abundant except in the vicinity of points or lines of great disruption of the rocks. Faults, dykes, and veins must, therefore, be referred, as to the origin of the fractures, to the same general cause which placed the strata of the mountains in their disturbed and inclined positions.

Before adopting, definitively, the conclusion obviously indicated by all the preceding facts, that the stratified rocks in the crust of the earth have been broken up, so that its disrupted masses have been placed in new positions, and that the unstratified rocks have been raised in consequence of such disruptions along the axes, and about the centres of mountain chains and groups, it will be proper to inquire further into the nature and origin of these two classes of rocks.

Origin of stratified and unstratified Rocks.

The great and leading distinction between these rocks, is the form of their whole, masses; but, besides this, we observe, in other respects, very important differences, which facilitate investigations into their origin, — differences of internal structure, chemical character, mineral aggregation, and imbedded substances.

Stratification is a form of matter seldom produced in perfection among the effects of modern nature, except by the agency of water. The sediment from rivers, the deposits in lakes, the sandy and pebbly accumulations from the sea, all possess the true characters of stratification, for they tend to be produced in considerable breadths, with comparatively small thicknesses. And as among the ancient rocks we frequently find contiguous deposits of different chemical nature, as limestone succeeding clay or sandstone, so in these more modern products, similar *successions of strata* occur: clays and sands, and marly limestones of different colour, consistence, and chemical quality. Many of the ancient sandy strata are laminated parallel to the surface, so are the modern sediments from a river or the tide; others are irregularly composed of oblique laminæ, or ripple-marked on the surface, as are the deposits from agitated rivers and tidal currents.

All the comparisons which can be made between ancient strata and analogous products of modern nature, appear clearly to evince their aqueous origin, no other essential differences being discoverable between them, except the great thickness and extent of the ancient rocks; and could we raise for examination the bed of the Atlantic or the Mediterranean, perhaps a part of this discrepancy might vanish; for Donati's researches on the bed of the Adriatic show the great extent of the modern deposits in that sea.

The unstratified rocks tried by the same test, the form of their masses, can in no manner be paralleled to the productions of water. The dykes and veins which belong to the same class as the huge amorphous masses, and are often of the same kind of rock, do resemble in their forms, to a considerable degree, the known products of modern volcanoes: particular ancient unstratified rocks, as basalt, exist in forms, and under circumstances, very similar to analogous rocks, the fruit of volcanic fires.

The chemical composition of the two classes of rocks resembles in some points, and differs in others: they are in some points similar, for they contain some identical minerals, and many identical elementary substances; but numerous minerals are found in the unstratified rocks which are not known among the others. Limestone, sandstone, and clay, which constitute so many of the stratified masses, are forms of mineral aggregations such as never occur among granites, basalts, porphyries, &c., which make up a large portion of the unstratified rocks.

But the difference in their mineral aggregation is yet more remarkable. The ingredients of the stratified rocks appear almost always in such a state, as to suggest to the observer their aggregation from a state of solution, suspension, or drifting in water: limestone rocks, for instance, appear to have been collected, as smaller quantities are at this day, from the decomposition of water by chemical and vital agencies; clays were clearly collected from matter finely divided and diffused or suspended in water. Sandstones are as clearly the accumulation of grains of quartz, or other minerals worn and rounded in water, while conglomerates leave no more doubt of the former action of agitated water, than the pebbles of a river bed, or the sea shore.

On the contrary, the unstratified rocks are mostly crystallised; that is to say, their constituent ingredients are symmetrically arranged and bounded by regular surfaces, meeting at definite angles: they are not such as in general to be separately soluble in water at any temperature; they never show any marks of arrangement such as might arise from suspension or drifting, nor any such proofs of mechanical action, as worn grains of sand, or pebbles of rock. But their composition is in the great mass, and in the nature of the constituent crystals, always analogous, and frequently identical with, the known effects of heat in the furnace of the chemist, or the subterranean laboratory of nature.

Finally, these two classes of rocks differ essentially in another most important respect, which, taken in conjunction with the preceding facts, is quite decisive of their difference of origin: the stratified rocks are generally stored with the reliquiæ of plants and animals, even to a greater degree than modern marls, clays, and sands deposited from water; while the unstratified rocks contain none of these things, or if, by chance, a solitary shell has been found *amongst* such rocks, its inclusion is easily explained, just as by some accident volcanic scoriæ have been found to cover bones in Auvergne.

The animal remains found in the stratified rocks are chiefly marine, and nearly all aquatic; they occur, in many instances, under circumstances of position and relation which *prove* that they were often quietly buried or drifted by water from small distances, but sometimes worn to pebbles; just as from the deep and quiet sea we now dredge shells in complete preservation, their spines and ornaments perfect; while nearer the shore, worn shells, and under the cliffs, among the pebbles, are rolled and fragmented particles.

It is, therefore, impossible to doubt that the stratified rocks, holding remains of aquatic animals or water-drifted portions of land plants, were formed in water: this applies to the far greater number of the strata. But it is equally clear, that those strata which alternate with these, and do not yield organic remains, but are of the same general characters, and were, by marks of structure and aggregation, evidently produced in the same way, are also of watery origin. All the really stratified rocks, then, are the product of water; but the unstratified rocks are generally the fruit of the action of heat.

We must, therefore, here divide the subjects for consideration in the structure of the globe according to the aqueous or igneous agency concerned, and shall commence with the history of the deposits from water.

The most general view to which we are thus conducted, gives to all the stratified rocks an aqueous, and to the unstratified an igneous, origin: the former were deposited from above, in calm or agitated water, along the shores, in the depths of the sea, or in lakes; the latter were raised from below, by the excitement of internal heat. Subterranean movements affected the stratified rocks, and elevated them from their level position into mountain chains and ranges of hills, and the same influence, or an action consequent upon it, raised the fluid or solid unstratified rocks along the axes, or at the centres, of the elevatory movements. Thus, it is a certain and general truth, that in the composition of the crust of the globe, in the arrangement of rocks in their present position, in the production of the physical features of our planet, both internal heat and the agency of external water have had their share; and by studying, carefully, the effects now produced, though apparently on a smaller scale, by the same natural agencies, under varied circumstances, we may hope to arrive at correct general inferences as to the manner in which even the grandest and most surprising of the old revolutions of nature were occasioned.

Relative Periods of disturbed Stratification.

One of the most remarkable of all the results yet arrived at, by combining the study of the two classes of rocks just distinguished, is the certainty that the subterranean movements of the solid crust of the globe, to which the deranged positions of the strata are owing, were not all of the same date; but that some mountain ridges, and some lines and points of unstratified rocks, had been uplifted before others, — some strata disturbed, before others were formed. The mode by which this has been ascertained is extremely simple. When, as in the section (*fig.*12.), certain old strata (*a b c*, &c.) are found displaced

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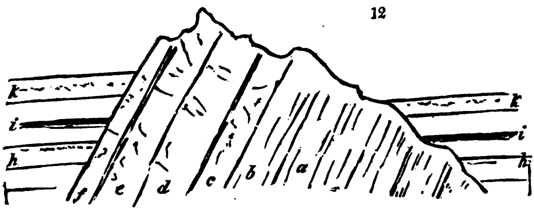
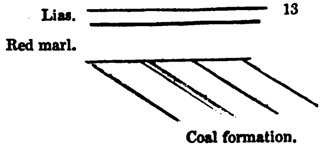


from their original nearly level position, and thrown to high angles of elevation, and other more recent strata (*h i k*) are placed level against the slopes, or even covering the ends of the former, it is plain that the dislocation of *a b c* happened in the interval of geological time which occurred between the completion of the newest bed (*f*) of the dislocated, and the oldest bed (*h*) of the undisturbed deposits. On different chains of mountains, along different lines of faults, &c., the period when the disturbances happened, judged of by this test, is found to be often very different. One of the most singular examples of this dislocation of some strata, in districts where others of more recent deposition remain undisturbed, was noticed by Dr. William Smith, in 1791, at Pucklechurch in Gloucestershire, and in Somersetshire. The coal formation is here found dipping at a high angle below, and covered up by horizontal strata of red marl and lias, thus:



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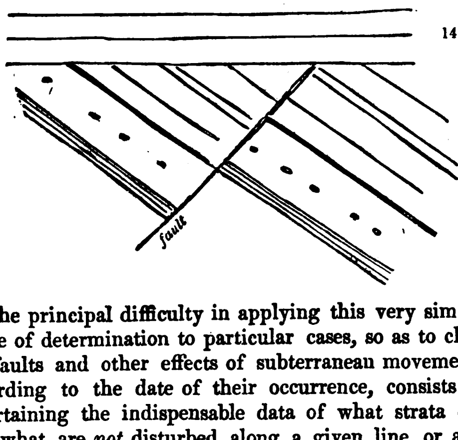
In Yorkshire and Durham the same thing is observed with respect to the magnesian limestone and the coal, with the addition that the coal strata are broken by faults, which do not affect the limestone above; thus:



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The principal difficulty in applying this very simple mode of determination to particular cases, so as to class all faults and other effects of subterranean movements according to the date of their occurrence, consists in ascertaining the indispensable data of what strata *are* and what are *not* disturbed along a given line, or at a certain point. When the undisturbed strata lie *upon*, or abut clearly *against*, or plainly *surround* the disturbed rocks, the evidence is satisfactory, and easily verified; but, in most cases, this clear testimony is wanting, and it is by considering the *relative directions* and *relative dips* of the two sets of strata (the disturbed and undisturbed), that we are to arrive at a determination of the question. The following notices and sketches will illustrate this point.

Whenever, in any district, the stratified rocks, instead of *all* lying parallel to one another, suffering the same deviations from horizontality, bending in the same flexures, dropping or rising by the same faults, and respecting in their declinations the same axis or centre of dips, divide themselves, in these respects, into two or more sets, which differ from one another in all or any of these respects, there is said to be ***unconformity of the strata.*** The place of this unconformity is the interval between the two sets thus disagreeing; it is said to occur between the oldest of one and the newest of the other set; it affects the geographical distribution of the strata, as shown on a map, and their relative inclination and exposures, as shown in a section. Thus in the map diagram (*fig.* 15.),

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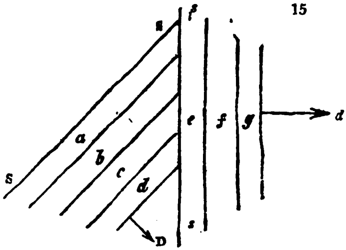

the series of strata marked *a b c d* are parallel in one set, and *e f g* in another; but their directions, or strikes, (S, S and *s s*) on the surface differ, and the lowest of the upper set (*e*) rests in one place on *a*, in another on *b*, in another on *c* or *d*.; the dips, D and *d*, are in different directions.

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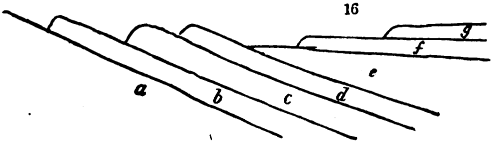

In a section (as *fig.* 16.), some difference of inclination commonly occurs. But when the strikes and dips of either the upper or lower set vary, which is a very common case, the same district, as Yorkshire or Derbyshire, may exhibit in the same region both conformity and unconformity between the same two sets of beds, as in the

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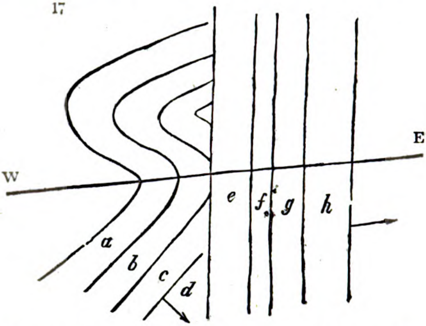

map diagram (*fig.* 17.); where *a b c d* are coal strata, with variable dips and strikes, generally unconformed, but on the line W E, for a short distance, conformed to the saliferous strata lying upon them (*e f g h*). Yet, in this case, the section on the line W E would exhibit a want of conformity in the dip (as in *fig.* 16.), the beds *a b c d* being more inclined than *e f g h*. When the strata are not in contact, or, for any reason the junction cannot be clearly seen, many observations of dip and strike in each set of beds will in general determine the existence of unconformity: but it would be folly to rest so important a decision upon *testimony less demonstrative* than the country will yield; and, in some cases, sufficient evidence is unattainable by any exertion of industry and skill.

CHAP. IV.

SERIES OF STRATIFIED ROCKS.

By following the methods previously described (pages 18, 19.) the whole series of strata existing in any country can be known; by comparing the results thus obtained in different countries, the extent of the strata, and the degree of generality of the causes concerned in producing them, can also be known. The investigations, in both respects, have now proceeded so far as to fully justify a geologist in asserting, that the principal features of the stratified rocks in the crust of the globe are very similar over large regions; the aggregate thickness of their mass is everywhere limited to a few miles; the order of succession among the principal groups is the same, or analogous; even the minute variations of their composition, aggregation, and structure are observable in remote situations; their organic contents are reducible to the same schemes of classification, and everywhere indicate several great physical changes on the surface of the globe, since it became the theatre of vegetable and animal life.

The foundations of all sound generalisations in geological science are accurate and mutually explanatory sections and maps of the whole series of stratified and igneous rocks existing in each natural geological district; a term by which we wish to express a part of the earth's crust, whether large or small, in which the formation of aqueous deposits has followed, amidst many local irregularities, one general law of succession. Such sections and maps express, by one common type or formula, the general result of many separate and local investigations; the principal local deviations from the general type must be on no account omitted, for these limited differences are often more important in theory (as well as in practical applications) than all the general resemblances. Assuming that the British islands form such a natural district, we shall be able to present a satisfactory general table or section of the series of strata which here compose the crust of the globe, *placed* in the order of their succession downwards, from the surface of the most recent aqueous deposits.

Table of British Deposits.

Superficial Accumulations.

Soil. Alluvial depositions.	From the ordinary action of springs, rivers, lakes, the sea.
Diluvial depositions.	From unusual and violent operations of water.

Stratified Rocks.

Tertiary Strata.

Names of formations.	Thickness in yards.	Subdivisions or groups.	Nature of the deposits.
Crag.	16	Upper or red crag.	Marine shells, pebbles, sand, &c
		Lower or coralline crag.	Marine shells and corals in sand, or coarse limestone.
Freshwater marls.	33	Upper freshwater.	Marly limestone and clays.
		Estuary beds.	Marine or estuary clays, marls, &c.
		Lower freshwater.	Marly limestone and clays.
London clay.	200 to 600	London clay.	Clay with septaria, &c.
		Plastic clay.	Variegated sands, clays, lignite, &c.

Secondary Strata.

Cretaceous System.

Chalk.	200	Upper chalk.	Soft chalk, with flints in layers.
		Lower chalk.	Harder chalk.
		Chalk marl.	Soft argillaceous chalk.
Green sand.	160	Upper green sand.	Green sands.
		Gault.	Blue marl or clay.
		Lower green sand.	Ferruginous, brown, or green sand, with local deposits of limestone.

Oolitic System.

Names of formations.	Thickness in yards.	Subdivisions or groups.	Nature of the deposits.
Wealden.	300	Weald clay.	Clays and calcareous layers.
		Hastings sands.	Variously coloured sands and clays.
		Purbeck beds.	Clays and limestones.
Upper oolite.	130	Portland oolite.	Limestone, often cherty, with sand.
		Kimmeridge clay.	Blue clay, with septaria.
Middle oolite.	150	Upper calcareous grit.	Sandstone (calcareous).
		Coralline oolite.	Oolitic limestone.
		Lower calcareous grit.	Sandstone (calcareous).
		Oxford clay.	Blue clay, with septaria.
		Kelloway rock.	Sandstone (calcareous).
Lower oolite.*	130	Cornbrash.	Coarse limestone.
		Forest marble.	Coarse limestone, sands, and clays.
		Great oolite.	Limestone, oolitic, compact, or sandy.
		Fullers' earth.	Limestones, clays, &c.
		Inferior oolite.	Limestone, oolitic, ferruginous.
		Sand.	Calcareous or ferruginous sand and sandstone.
Lias.	350	Upper lias shale.	Blue laminated clay.
		Marlstone.	Sandy, calcareous, and irony beds.
		Middle lias shale.	Blue laminated clay.
		Lias limestone.	Blue and white compact limestones.
		Lower lias marls.	Clays of different colours.

Saliferous or Red Sandstone System.

New red sandstone.	300	Variegated clays.	Red, greenish, &c. clays.
		Red and white sandstone.	Red and white sandstone and conglomerate.
Magnesian limestone (North of England).	100	Knottingley limestone.	Grey laminated limestone.
		Gypseous marls.	Red and white clays, &c.
		Magnesian limestone.	Yellow, granular, &c., limestone.
		Marl slate.	Laminated calcareous beds.
		Rothetodteliegende.	Red sandstones and clays.

* As seen near Bath. In other parts of England it offers important differences, as will appear hereafter.

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Carboniferous System.

Names of formations.	Thickness in yards.	Subdivisions or groups.	Nature of the deposits.
Coal.	1000	The subdivisions are only locally ascertained.	Strata of sandstone, shale, ironstone, with rare deposits of marine or freshwater limestone.
		Millstone grit.	Sandstones, often coarse-grained, or pebbly; shales, ironstones, thin limestones.
Carboniferous limestone (N. of England).	900	Yoredale rocks.	Limestones, sandstones, shales, coal.
		Scar limestones.	Limestones.
		Alternating sandstones and limestones.	Limestones, sandstones, &c., often red.
Old red sandstone (Herefordshire).	100 to 3300	Conglomerate group.	Conglomerates and sandstones.
		Cornstone group.	Coloured clays and concretionary limestones.
		Tilestone group.	Flagstones and clays.

Silurian System.

Ludlow rocks.	660	Upper Ludlow rock.	Laminated sandstone.
		Aymestry limestone.	Subcrystalline limestone.
		Lower Ludlow rock.	Sand shale, with concretionary limestone.
Wenlock rocks.	600	Wenlock limestone.	Grey and blue subcrystalline limestone.
		Wenlock shale.	Shale and earthy limestone.
Caradoc rocks.	830	Limestones and sandstones.	Laminated limestones and sandstones.
		Conglomerates, &c.	Gritstones, conglomerates, limestones.
Llandeilo rocks.	400	- -	Dark calcareous flags, sandstones, &c.

Cambrian or Grauwacké System.

Plynlymmon rocks.	Unknown.	- -	Argillaceous indurated rocks, sandy or slaty.
Bala Limestone.		- -	Dark laminated limestone and slate.
Snowdon rocks.		- -	Fine and coarse-grained slaty rocks.

Skiddaw or Clay Slate System.

Clay slate.	Unknown.	- -	Uniform dark slate.
Chiastolite slate.		- -	The same, with chiastolite.
Hornblende slate.		- -	The same, with hornblende.

Mica Schist System.

The subdivisions are only locally ascertained. Chloritic schists lie in the upper parts; quartz rock and primary limestones are interposed among the beds of mica schist.

Gneiss System.

Mica schist alternates with gneiss, which is diversified by beds of limestone and quartz rocks.

Beneath all these systems of stratified rocks, the production of water, we find, in all places where the base is clearly seen, a mass of granite and other unstratified rocks, the effect of great and pervading heat. Basalt, porphyry, and other igneous rocks, are frequently found protruding through the strata along anticlinal axes, and penetrating them in dykes along the course of faults and fissures.

In possession of this complete section of all the principal masses of stratified rocks in the British isles, and guided by a map of the ranges of each of these on the surface*,—aware, also, that within the narrow compass of these islands some of the groups of strata vary extremely (as the lower oolites, which are principally calcareous near Bath, but principally arenaceous near Whitby), and others have only a limited range (as the magnesian limestones), we may proceed to inquire how far the sections of other natural districts agree with that given above.

Throughout the great basins of Europe, and parts of Asia and Africa, including the countries bordering on the German Ocean, the Baltic, the Black Sea, and the Mediterranean, within the mountain boundaries of the Ural, Caucasus, Greece, Calabria, the Atlas, Western Spain, Brittany, Cornwall, the west of Ireland, Scotland, and Scandinavia, the same *general divisions*, viz., primary, secondary, tertiary, and superficial deposits occur, and the

* A geological map of the British Islands has been constructed by the author of this treatise, at a moderate price.

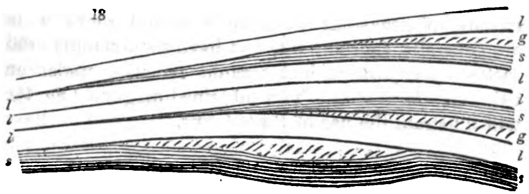
general features and succession of these great classes are the same: most of the *systems* of strata are also to be recognised, either in the mountains or the lower ground; and fresh additions to these analogies are continually added by geological travellers. But when we come to consider the constituent *formations*, discordance is manifested of the same kind as that which, as before observed, appears between different parts of England with respect to certain oolitic and carboniferous formations.

Among primary strata, for example, the clay slate, grauwacké and silurian rocks, are little known in the Alps; while mica schist and gneiss are rare in the Harz, Cornwall, and Wales. There is more carboniferous limestone in England and Ireland than in all Europe besides. The oolites of Germany and France sometimes perfectly resemble, in composition and succession, that group in England; but on the Italian side of the Alps, and in Greece, they have different characters. The chalk formation is little seen about or beyond the Alps; and, in the Carpathians greensand appears in plenty, but little or no chalk. Turning to more distant localities, we find, in North America, primary, secondary, tertiary, and superficial deposits, much allied to those of Europe, grouped, for the most part, in similar systems; but the series between the cretaceous and carboniferous rocks is much less developed than in Europe. On the contrary, in the Himalaya mountains, and the basin of the Indus, these formations are greatly developed, and rocks of the lias and oolitic formations are perfectly identified. As a general result, it appears already ascertained that the same great divisions of strata may be applied to nearly all parts of the globe; that, even in very distant localities, the same systems of strata were produced, though sometimes in isolated patches; but that the particular formations, though often very extensively spread, are yet somewhat irregular in their expansion, some extending in one direction, and others in a different one, so as clearly to evince their dependence on local and variable conditions.

Varieties of Stratification.

Stratified rocks are either of *equal* thickness over a large extent of country, or *attenuated* to a wedge shape in some one direction, or decreasing in thickness every way from a certain point or district, so as to constitute a *lenticular* formation. Strata of one certain kind of rock, which are, in some places, accumulated into a uniform mass, become divided in other districts, and separated into distinct members by the interposition of wedge-shaped deposits. All these circumstances are represented in the annexed diagram (*fig.* 18.), where

18



limestone strata are marked *l*, slate beds *s*, gritstone *g*; the gritstone and slate being in lenticular or wedge-shaped, and limestone in parallel, beds, divided in one direction, but conjoined in the other.

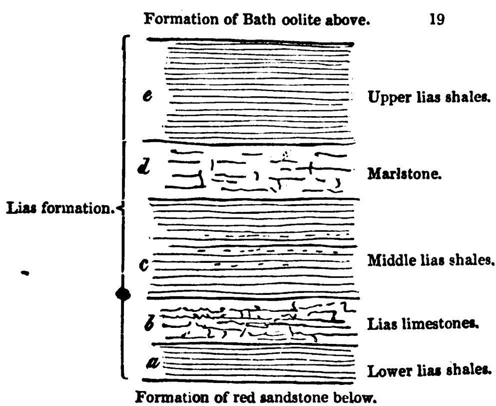
By observations of this kind in certain districts (*e. g.*, in the north of England, along the Penine chain, and on the Yorkshire coast), it has been inferred, that the different strata of limestone, shale, and grit, have originated under different circumstances; the former being an oceanic deposit, but the two latter substances derived from the waste of ancient lands bordering on the sea in which the limestone was formed. This conclusion is strongly corroborated by the fact, that it is chiefly or wholly in gritstones and shales that land plants occur, while the marine exuviæ of shells, corals, &c. abound almost exclusively in the limestones.

The term stratum or layer is of general signification, and independent of the absolute thickness of the mass:

by some writers (Dr. Smith and others) it has been used to express the whole of one mass of layers or beds of the same or nearly the same quality (as the Bath oolite), or one similar series of alternations (as the Weald clay). By others (Playfair, &c.) it is applied to the thinner layers of rocks, which Smith denominates beds. Neither mode is perhaps inaccurate, yet it is convenient now to settle the nomenclature we must employ in the following descriptions.

Many rocks, as limestones, are divided by parallel, or nearly parallel, seams, into what are by the quarrymen called *beds* or *posts*; in some cases these are further divisible into *laminæ*. Moreover, it is the custom of geologists to include several rocks which are generally concomitant, and have some common characters of deposition and organic remains, under one title, viz. *formation*. The subjoined diagram (*fig.* 19.) will illustrate the use of these terms.

19



The shales in this diagram (*a c e*) are from 20 to 300 feet thick, and are composed of *laminæ* parallel to the planes of stratification; the limestones (*b*) are *thin* *bedded,* the beds being separated by thin clays: the marlstone series (*d*) consists of sandstone beds, calcareous beds, and ironstone bands, separated by thin clays or shales.

The lias *formation* is included between the Bath oolite formation above, and the red sandstone formation below.

According to this mode of description, the word *stratum* need never be used as a special term of definition, but reserved for general reasoning. The word *series* is found to be extremely serviceable in designating a number of similar or similarly associated rocks: the arbitrary word *group* is also convenient in geological description.

The lamination of rocks offers some interesting facts. Some beds of gritstone (as *a*) are composed of laminæ parallel to the plane of the beds; such lamination is generally produced by the alternation of mica, whose broad plates cause a partial disunion of the parallel laminæ of quartzose grains. Other beds (as *b*) are composed of oblique or curved laminæ, a circumstance generally dependent on the irregular admixture of pebbles shells, or particles of unequal magnitude. The former may be supposed to be tranquil, the latter disturbed, deposits.

20

In shales and other argillaceous rocks, nodules of ironstone or limestone, aggregated round some solid

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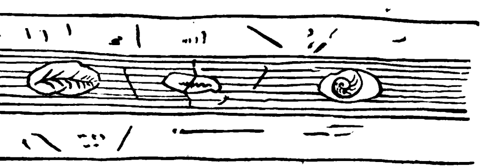
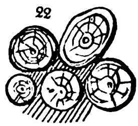


bodies (as a leaf or shell), are frequently included, and sometimes these interrupt the lamination of the shale, as in *fig*. 21. Such nodules are frequently traversed by plates of calcareous spar, and these receive the name of septaria.

In limestone beds the nodules of chert, in chalk the nodules of flint, often appear to have been aggregated round some previously solidified sponge, coral, or shell, This process of accretion round a nucleus is beautifully exemplified in certain "oolitic" limestones, so called from their being composed of spherical grains. Each of these consist of several concentric coats, collected round a previously solidified body, as a minute grain of sand, fragment of shell, or other centre of attraction. Radiating fibres frequently cross the spherical shells.

22



Something of this concretionary structure appears in particular unstratified rocks (as pitchstone); but in general all the appearances previously described belong to the stratified formations exclusively.

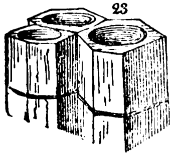
Divisional Structures.

All rocks are traversed by divisional planes of less or greater width and frequency, and thus divided into masses of definable shapes and proportions. These "joints," as they are often called, present themselves under a great variety of appearances, but almost always such as to be intelligible on the supposition of the mass of the rock having been *contracted*, so as to separate into prismatic and other forms, as clay, starch, &c. contract and split by drying.

The joints vary in their combination, so as to produce masses of different forms in rocks of different nature: they also vary in rocks of the same nature which are of different antiquity: their frequency and regularity also depend upon the mineral aggregation of the rock: it is further probable that they are somewhat complicated with additional fissures, near axes and centres of elevation or depression of rocks.

Among unstratified rocks the most remarkable and best known form is that of the divided prisms of basalt, as seen in Staffa and the Giant's Causeway. This appearance arises from the intersection of planes rectangulated to the surface of the rock, and meeting one another in several directions, so as to insulate polygonal prisms. These prisms are divided across, by concavo-convex surfaces, as *fig.* 23.

23



Much more common in these rocks is the form of an irregular polygonal prism not divided across, as in the greenstone and pitchstone of Corygills, Arran. It is interesting to observe, in vertical dykes of these rocks (as in Cleveland, Yorkshire), the prisms lying horizontally, and in other cases curved (as in Staffa), in obedience to the general law of the planes of the prismatic faces being at right angles to the bounding surface of the mass.

Many rocks of igneous origin (as greenstone, claystone, porphyry, sienite,) show this prismatic structure more or less distinctly, but none so perfectly as basalt.

A prismatic form of the masses is found also among stratified rocks, when these are very thick and of uniform composition, as in the rock-salt mines of Northwich (observed 1827), in the gypsum quarries of Montmartre, and in the thick scar limestone of Wharfdale (observed 1834).

A great variety of other appearances are presented in the stratified rocks by the various directions and intersections of the different sorts of joints.

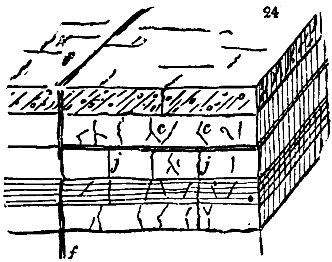
Under particular circumstances, and especially in the vicinity of faults, anticlinal axes, and other forms of displacement, the beds of rock are frequently *cracked* in their substance; sometimes these cracks are filled with sparry substances (carbonate of lime frequently, metallic matters rarely); sometimes they are very minute chinks lined on the sides with dendritical oxide of iron or manganese, in which case they are called dry cracks.

Their direction is very irregular, and there is no doubt that in many cases they are the effect of mechanical strain or tension in the mass of rocks which accompanied the displacement of the rocks. Near the anticlinal axes of Ribblesdale, sparry cracks are wonderfully numerous; but away from these axes the level beds are little marked by such accidents.

Besides these irregular cracks (*c*), which often do not pass through the whole mass of a bed, are *joints* (*j*) which divide at least one bed, and often several, and which exhibit some regularity of direction; these are so situated in the different beds, have such diversity of slopes, irregularity of number, openness, and other characters, and are so abundant in situations far from lines and points of displacement, as to leave no doubt that they are due to a very general cause.

Amongst these joints, some more open and extended, than others, passing through a greater number of beds, dividing a whole rock, or even a considerable portion of a formation, may be distinguished as fissures (*f*) or *master joints*. The diagram, *fig*. 24., is intended to convey a correct notion of these several divisional planes.

24



Viewed on a horizontal plan, joints frequently end in fissures; and these latter commonly exhibit a great degree of local symmetry. In the mountain limestone districts of the north of England, the arrangement of the fissures has been ascertained to be correctly represented by the following diagram, in which the breadth of shade in any direction corresponds to the number of fissures observed. Thus, in the direction N. N. W. and S. S. E., and E. N. E. and W. S. W., and about these lines, a greater number of fissures occur, thus producing two principal systems of divisions in the rocks at right angles to each other; while in the lines N. E. by N. and N. W. by W., and about these lines, few or no fissures have been noticed. Thus there are positive and negative axes of frequency and rarity of the fissures situated at right angles to each other respectively. The same result of predominance of fissures in N. N. W. directions is found to obtain in Derbyshire (Hopkins), in Cornwall (De la Beche), and in some districts of Ireland (Griffith).

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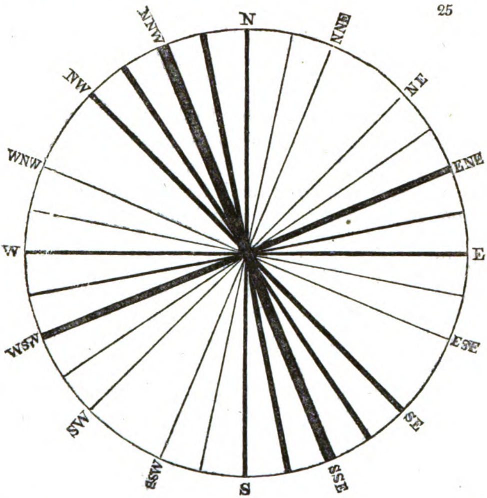


The effect of these fissures in causing lines of weakness of the rocks may be understood from the diagram: the breadth occupied in each radius being proportioned to the number of long joints, or fissures, observed in that direction.

The following is the table of observations referred to.*

General Table of Results for the Secondary Rocks of Yorkshire.

Names of Formations.	No. of Observations in Yorkshire.	W. by N.	W. N. W.	N. W. by W.	N. W.	N. W. by N.	N. N. W.	N. by W.	N.	N. by E.	N. N. E.	N. E. by N.	N. E.	N. E. by E.	E. N. E.	E. by N.	E.
Magnesian limestone	4				1		1		1		1						
Coal -	3						1	1	1								
Millstone grit -	13					1	5	2							4	1	
Chert group -	17				1	4	6						1		4	1	
Yordale series -	35		2		1	1	8	5½	5½				2	1	3	2	4
Lower limestone	15	1			4	1	2	1	2					1	1		2
Red sandstone -	1									1							
Whin sill	1																1
	89	1	2	0	7	7	23	9½	9½	1	1	0	3	2	12	4	7

It appears that some remarkable differences of characters belong to the joints and fissures in rocks of different chemical and mineral quality. In limestone the joints are usually rectangled to the planes of stratification, and frequently open and regular; in gritstone they are very irregular, but often widely open; while in argillaceous rocks they are usually much more numerous, but far less open, and often oblique to the planes of stratification. In conglomerate rocks there are few regular joints, but the rude fissures are sometimes remarkably large.

On considering the occurrence of joints with reference to the age of the rocks, it appears quite certain that it is among the older rocks that joints are most numerous and symmetrical. If we compare in this respect the old argillaceous slate, to the shale of a coal tract, and then with the clays of an oolitic district, or make a similar comparison of the ancient primary

* Geology of Yorkshire, vol. ii. p. 97.

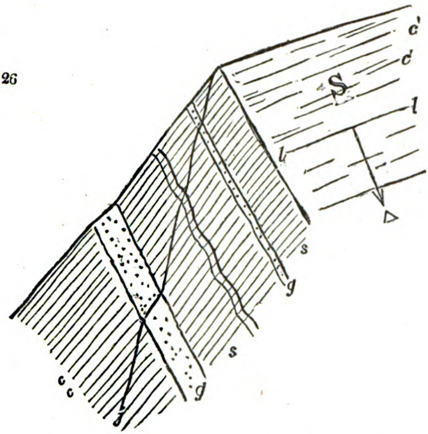
limestone of the highlands, with the calcareous rocks of later production, this dependence of the frequency and regularity of joints, on the age of the rocks, will clearly appear.

Cleavage.

Among the argillaceous slate rocks, a further peculiarity of internal structure takes place, which is deserving of special attention, since it appears to be the case of divisional planes carried to extreme in number and symmetry.

This structure, commonly called cleavage, is really distinct from joints and stratification, and may be, perhaps, understood in its relation to these by the accompanying sketch.

26



In this drawing, S is a plane of stratification dipping in the direction △; *c c* are the edges of planes of cleavage, which in the plane S continue in lines *c′ c′*. These planes are continuous, and very numerous in the fine grained beds *s*, which alternate with the coarse beds *g g*, but in these latter the laminæ of cleavage are often totally absent. *j* is a joint which varies its angle of dip in the different beds of rock. The line *l l*, at right angles to the dip of the strata Δ, is called the strike of the bed, and is of course level; and it is frequently observed that the horizontal line, or strike, of the cleavage, coincides with the strike of the strata. The planes of cleavage generally approach toward the perpendicular, whatever may be the amount of the dip of the strata: their course is almost exactly the same over immense spaces of country (in North Wales, in Cumberland, Charnwood Forest, &c.), and it is to them that the valuable substance called slate is owing. It is quite certain, in some instances, that this beautiful structure of the slate rocks was caused since the strata of these rocks were placed in their disturbed directions, and that it is the fruit of a peculiar degree of crystalline action in the mass; for in some cases at Aberystwith and elsewhere, the nearly vertical laminæ of cleavage cross highly contorted beds of slate dipping in various directions.

There are good reasons for thinking that this cleavage of the argillaceous primary strata is an effect due to the pervading agency of heat; amongst others we may mention the fact that near igneous rocks (as at Coley Hill near Newcastle) something of the same kind is produced in shales of later date; and that among the Alps of Savoy, the lias clays are so altered near the axis of elevation, as to assume much of the aspect of an old slate country.*

* For suggestions to observers on the subject of cleavage and joints, and a method of calculation to be applied to cases of inclined strata, see Guide to Geology, 3d edition. The Geological Intersector, a small and cheap instrument, which has been constructed by the author, and engraved by Mr. Lowry, may be used to represent the phenomena, and save the trouble of calculation.

CHAP. V.

ORGANIC REMAINS OF PLANTS AND ANIMALS.

PERHAPS geology might never have escaped from the domain of empiricism and conjecture but for the innumerable testimonies of elapsed periods and perished creations, which the stratified rocks of the globe present in the remains of ancient plants and animals. So many important questions concerning their nature, circumstances of existence, and mode of inhumation in the rocks, have been suggested by the examination of these interesting reliquiæ, and the natural sciences have in consequence received so powerful an impulse, and been directed with such great success to the solution of problems concerning the past history of the earth, that we scarcely feel disposed to dissent from the opinion of Cuvier, "that without (fossil) zoology, there was no true geology."

The stratified crust of the globe may, without exaggeration, be said to be full of these monuments of the vanished forms of life: they are of extremely various kinds; lie in many different states of preservation; occur very unequally in rocks of different kinds and ages; and thus present a large field of contemplation to the philosophic geologist.

Fossil Plants.

The organic remains both of plants and animals occur abundantly in the earth; the latter are most numerous. Of fossil plants, many are terrestrial, a few are fluviatile, others are marine. In the present system of nature terrestrial plants are, probably, ten times as numerous as the marine tribes, and it does not appear that the ratio of the fossil tribes is very different.

But the total number, as far as yet known, is wonderfully disproportionate. For, if we estimate the recent species of plants at only 60,000, and the fossil races, yet clearly distinguished, at 600, numbers which are, perhaps, equally below the truth, the proportion is 100 to 1. To infer, from this fact, that the ancient globe nourished few species of plants compared to the present rich flora of different latitudes, would be unauthorised by the data, though from other phenomena such a conclusion might appear probable. We must recollect that the stratified rocks were formed chiefly on the bed of the sea, and therefore could not be expected to contain, except rarely, the remains of terrestrial plants; just as at this day, it is only under particular conditions of the surface drainage that vegetables are carried abundantly to the deep. And, since most of the marine plants are natant or confined to rocky shores, there would be little reason in expecting these to be common among the oceanic sediments.

We must further observe, that the cellular substance of the marine tribes of plants might cause many of them to perish under the slow accumulation of the strata: nothing is less common than to find the *substance* of marine vegetables preserved in the same manner as the ligneous parts of land plants; and, indeed, among land plants, the experiments of Dr. Lindley show that many of them perish by maceration in water, while ferns, cycadeæ, and other tribes, resist decomposition for a long time. Hence, it is no wonder that such races of plants are the most frequently met with in a fossil state.

The ligneous parts of plants are sometimes (in the blue clays of the oolitic formation especially) converted to jet: sometimes, only the external layers of coniferous wood are so converted, while the internal parts are changed to carbonate of lime. In the latter case, the structure of every cell and vessel is distinctly seen in thin slices. When woody plants lie in limestone rock which contains silica, or in calcareous sandstone (as in the coralline oolite and calcareous grit), they are often silicified: very frequently in clays pyrites aids the beauty, but diminishes the duration of the specimens. In the shales of a coal tract plants of all kinds are converted to coal of different qualities: the same effect happens in the fine grained sandstones of the coal tracts; but in millstone grit, and other coarse sandstones, the only reliques of the plants are the external impressions of them, and a brown carbonaceous or ochraceous powder. In the upper coal measures of Lancashire, and in the shales of the peculiar oolitic strata of Yorkshire, we have found thin leaves yet retaining their elasticity, and changed to a brown translucent pellicle, in which the impressions of the superficial respiratory pores might be clearly seen. In other cases the nervures and seed vessels of fern leaves are perfectly retained in shale, fine sandstone, and ironstone.

The distribution of fossil plants in the earth is remarkable on many accounts. Being for the most part of terrestrial races, it is not surprising that they should be found principally in the sedimentary strata of sandstone and clay, for it is always associated with such sediments that they pass at this day with the Mississippi and other rivers to the ocean. So strict, however, is this connection, that in a series of alternating limestones, sandstones, and shales, the two latter may be richly stored with land plants, and the former filled with marine shells; neither partaking in the treasures of the other. It must be considered much in favour of this view of the dispersion of fossil plants by rivers entering the sea, that the trees are usually in fragments, the branches and leaves scattered, and roots generally wanting altogether. One case, indeed, has been apparently established, of the trees being buried in the very spot where they grew, by submergence of the land, "the Dirt Bed" of the Isle of Portland: but this is certainly an exceptional case; the rule is undoubtedly contrary.

Those who expect, consistently with general probability, that the earliest indications of life on the globe should be of the vegetable kingdom, may be somewhat astonished to learn, that traces of plants are really not known in a distinct form in strata so ancient as those which contain the shells of Snowdon and Tintagel (Snowdonian rocks), and that they are almost unknown even in the silurian system. What is calculated to add to this feeling of surprise is the circumstance that in the next system of strata which lies upon the silurian, two of the formations are the repository of most enormous accumulations of fossil plants; for in these rocks principally lie the coal beds of Europe and America, which are nothing else than a mass of chemically altered vegetables. How vast must have been the luxuriance of the vegetable world at that era in particular parts, appears from the thickness and continuity of the coal beds; for, it is probable, that the most dense forest of tropical America would, if buried under sediments, and subjected to the changes which yield coal, produce but a very thin bed of that substance. Yet, in the coal formation beds of three, four, six, ten, and more feet are not uncommon, and the different layers yield as much as sixty feet of solid coal.

Whatever were the causes which permitted that prodigious growth and aggregation of trees and other plants during the era of the production of coal, it appears they were never repeated, for the few unimportant deposits of coal in the oolitic system of Sutherland, Yorkshire, Bornholm, and Westphalia, which are chiefly formed of cycadeæ and equiseta, hardly deserve mention in comparison.

The races of plants entombed in the earth at different periods of its formation, are by no means the same. M. Adolphe Brongniart, to whom we are indebted for almost the first philosophical view of the affinities of fossil plants, presents the following comparative table of the extinct and living classes of plants: —

	First Period.	Second Period.	Third Period.	Fourth Period.	Living.
Agamia - - -	4	5	18	13	7000
Cryptogamia cellulosa -				2	1500
———— vasculosa -	222	8	31	6	1700
Phanerogamia gymnospermia		5	35	90	150
———— monocotyledonia	16	5	3	25	8000
———— dicotyledonia				100	32,000
Indeterminate - -	22				
	264	23	87	166	50,350
	540 (total of the four periods)				

The first period ends with the carboniferous system; the second includes the saliferous or new red sandstone system; the third comprises the oolitic and chalk systems; the fourth is the tertiary period.

The numbers of species are now considerably augmented since the table was drawn up (1829), but the proportions are not materially affected. It is still true, that vascular cryptogamia abound in an extraordinary degree among the earlier rocks, where ferns, calamites, and what seem like gigantic lycopodiaceæ are very prevalent; that in the second and third periods cycadiform and coniferous plants (phanerogamia gymnospermia) become remarkable and frequent, though ferns and lycopodiaceæ still prevail; while it is principally in the fourth period that the usual forms of dicotyledonous plants, now so plentiful on the earth, appear at all common. Moreover, on a close examination, it appears that nearly every fossil plant is of an extinct species, and that the several periods distinguished by M. Brongniart had each its own peculiar vegetable creation, distinct from every other that preceded and succeeded it.

Fossil Zoophyta.

Zoophyta being in the present system of nature all aquatic, and mostly marine, they may be expected to occur abundantly in the marine strata of the earth. They are, indeed, very plentiful, and it is interesting to observe that all, or nearly all, the species are marine. It is further remarkable, that few traces occur of any other zoophyta than such as, like the lithophyta, secreted stony supports; or like spongiadæ, had an internal horny or spicular skeleton; or like echinida, were covered with a crustaceous skin: the soft medusidæ, holothuridæ, &c., are, perhaps, sometimes recognisable by faint impressions in the rocks, but their substance has wholly vanished. The soft parts of nearly all the zoophyta are absent from the fossil state.

The recent zoophyta are either free in the sea, or attached for life after a very early period of growth: instances of both divisions occur in the earth. The fossil corals do not, perhaps, in general appear in the very place where they grew, but rather seem to have suffered some displacement before being buried in the oceanic sediments. But exceptions occur; and some of the fossil radiaria which were attached by a pedicle (crinoidea) are found in several places (near Bradford in Wiltshire), yet rooted to the limestone rock. In such cases, how vain is the supposition that the deposition of the substance of the rocks was either rapid, confused, or violent. The limestones of the silurian and grauwacke systems are so very rich in corals as to suggest to good observers the notion that these concretionary and rather irregular rocks were ancient coral reefs.

Calcareous matter composes the greater part of the hard parts of zoophyta; in a few instances besides the family of spongiadæ, siliceous spiculæ and fibres enter into the skeleton of the animal. In a fossil state corals, echinida, crinoidea, &c., are generally calcareous; rarely particular tribes of corals (as millepera, syringopora) are converted to siliceous matter: sponges are commonly siliceous, but sometimes calcareous. Occasionally nothing remains of the original body; its place in the rock is vacant, and there is left only the external impression or mould. These circumstances depend partly on the nature of the rock in which they are imbedded, and partly on the composition and texture of the original body. In limestone rocks the substance of coral is usually little changed, except by the introduction of calcareous or siliceous matter into the minutest interstices; but, in the same circumstances, the crusts of echinida and stellerida are converted to crystallised calcareous spar. Even in arenaceous and argillaceous strata, and amidst flint nodules where every sponge is silicified, the stems of crinoidea and spines of echinida are thus represented. A curious circumstance was noticed some time ago by the Rev. H. Jelly of Bath, concerning some lamelliferous corals of the oolite: the great mass of the coral was decomposed, and the cavity it once filled was partially occupied by pyramidal crystals of carbonate of lime, in whose transparent substance *the radiating plates of the coral* were clearly discernible; a fact in harmony with many other phenomena indicative of the power of crystalline attractions to overcome and involve arrangements of matter depending on other causes.

The laws of the distribution of fossil zoophyta so far agree with what has been already inferred concerning plants, as to prove that in this class of beings likewise, many distinct systems or assemblages of forms have existed at different ancient periods, which are all now extinct. Yet it is certain that the differences are mostly only such as belong to species, genera, and families, those minor groups of orders and classes which most distinctly reveal differences of physical condition, while agreements of a very general kind permit nearly all fossil zoophyta to be ranked as analogous to known living tribes. Even for the crinoidea, the most considerable exception, at least one living type is known. There is, undoubtedly, to be noticed a great difference as to the groups of zoophyta which belong to the different periods of the formation of the stratified crust of the globe; and a considerable discordance between the forms of the oldest fossil races, and those now actually existing. Zoophyta were collected by the author (1836) among bivalve shells, in one of the oldest fossiliferous slaty rocks of Britain, on the summit of Snowdon; they occur in the Bala limestone; abound to admiration in the calcareous parts of the silurian system, and in the limestones of the carboniferous rocks. The magnesian limestone has a small number; certain oolites are full of them; the green sand and chalk yield great plenty of sponges; the calcareous and arenaceous tertiaries of France furnish many beautiful forms of genera, often the same as those now found in the sea. Undoubtedly, as a general rule, zoophyta occur more plentifully in calcareous rocks than in any others; they are probably more numerous in the older strata; and there are probably more fossil than recent species, if we exclude from the latter, those whose bodies are unconnected to stony or horny external or internal supports.

It was once imagined that the higher orders of zoophyta, those ranked by Lamarck in his group of echinodermata, were absent from the older formations; and certainly they are, at least, not common among any of the primary strata. Crinoidea, however, occur in the silurian rocks, and they are more plentiful in the carboniferous limestone, than in any older or more recent deposits. Echinida first appear in the carboniferous limestone, but become far more numerous in the oolitic and chalk systems. Stellerida are, we believe, unknown below the oolitic system. Sponges are by far most numerous in the cretaceous rocks.

Systems.	Spongiæ.	Lamelliferæ.	Crinoidea.	Echinida.	Stellerida.
Tertiary	*	*	*	*	*
Cretaceous	✱	*	*	✱	✱
Oolitic	*	✱	*	✱	✱
Red sandstone			*		
Carboniferous	?	✱	✱	*	
Silurian	*	*	*		
Lower systems	?	*			

In the above table, the small stars indicate that some species of the groups of zoophyta whose names occur above are found in the system of strata on the line of which they are situated; the large stars are placed on the line of that system of strata in which the group of zoophyta is specially numerous.

Mollusca.

Recent mollusca are principally found at moderate depths in the sea, and respire the air contained in water; some particular tribes live in fresh water, and either breathe the air in water by branchiæ, or come to the surface to respire by lungs; others live on the land. In a very few cases certain stratified masses appear to have been accumulated either in limited areas of fresh water, or in estuaries so much under the influence of rivers and inundations as to contain land and fresh-water shells alone or mixed with the exuviæ of marine animals. But these few and exceptional cases yield, perhaps, altogether in England not one twentieth part of the number of fossil testaceous remains; on the continent of Europe the proportion is not very different. In the existing economy of nature, however, the land shells are so extremely numerous that, with the fresh-water tribes, they probably constitute one fourth of the total number of known species. We must not, however, conclude, from the comparative rarity of land and fresh-water shells in a fossil state, that the ancient land and fresh waters were but scantily supplied with mollusca; for, in the first place, their remains would seldom be transported to the ocean; and further, the presumed fresh-water shells are extremely plentiful in the coal tracts, weald of Sussex, and fresh water beds of the Isle of Wight. The total number of fossil marine mollusca already collected is about equal to that of the living races: what may be the proportions hereafter is difficult to estimate, for it is certain that great additions will be made to both the catalogues.

It is not entirely without reason that geologists have been long accustomed to look on the study of fossil shells as more instructive with regard to the physical conditions of the globe in ancient times than most other reliquiæ of animal life. They are of all fossils the most numerous, the most generally diffused through rocks of all ages, most perfectly preserved, and of such definable forms as to be easily described, figured, and recognised. The state of perfection in which many delicately ornamented shells occur, is such as to leave little doubt of their having been quietly entombed on or near the spots where they lived in the deep sea; while in other cases the disunion of valves and the fragmentary state, even of the most solid shells, recall to our memory the agitation of waves over the sands and pebbles of the shore.

The hard calcareous coverings of mollusca are perfectly preserved in a fossil state, but it is a rare thing to find a trace of the perishable parts; even the semi-calcareous hinge ligament of bivalves is rarely observed in cardia and veneridæ.

Among recent shells the most contrasted appearances of structure are those presented by the oyster, which is lamellar, and the venus, which is, apparently, compact, and the internal plate of the cuttle, which is of a fibrous nature. All are full of carbonate of lime, as a hardening earth, and all mixed with membranous gelatine, which, by its different arrangements, determines the above and other interior structures.* It is remarkable that oysters, and shells which like them are composed of distinct broad lamellæ of alternating membrane and carbonate of lime, have resisted in almost all rocks, argillaceous, calcareous, arenaceous, the chemical changes to which veneridæ, trigoniæ, and others of an apparently compact texture, have completely yielded. While the former retain their lamellæ and pearly surfaces, the latter have often been wholly dissolved in limestone rocks, and their places left vacant; while a cast of the inside of the shell, and an impression of the outside, disclose completely the history of the change. A further process is frequently superadded, by which the cavity is again partially or wholly filled with crystals of carbonate of lime, which has been introduced by filtration through the surrounding rock. In other cases siliceous matter, pyrites, and other substances, have passed by a similar process. The common fossil called belemnites, of the same group as the cuttle,

* See Mr. Gray on the Structure of Shells in Phil. Trans.

is a remarkable instance of the force of original structure in controlling the effects of chemical agencies; for in clay, sands, chalk, flint, limestone, pyrites, this singular fossil generally retains its fibrous structure, colour, translucency, and chemical properties; while in the same masses echini are changed to calcareous spar, and sponges to flint, and many shells have totally vanished.

The conclusion which so strongly forces itself on the mind of an observer who considers the shelly treasures of the stratified rocks, that each of these was successively the bed of the sea, becomes of undoubted certainty, when the minuter circumstances of the distribution of molluscous exuviæ are known. In the present seas, some shells, like the oyster, are gregareous, and cover large surfaces, so as to constitute shelly banks in which but a few species live together; others are dredged promiscuously from a common feeding ground. There are fossil as well as recent beds of oysters, and they are in each case argillaceous beds; perhaps cardia are more plentiful in old sandy strata, as well as in modern sandy bays; terebratulæ and lingulæ are usually associated in nests or families; and it is certain that much curious information, as to the circumstances of their existence, may be gathered from studying the details of the distribution of fossil mollusca.

But on a great scale they present very important truths. From the ancient slates of Snowdon to the most modern deposits in Norfolk and Sicily, the stratified rocks abound with shells; and though it is certain that calcareous rocks, and the strata near to them, contain the greatest number, enough are found in the sandstones and clays to furnish the means of establishing some very important conclusions. The first which arrests our attention is the continual augmentation of the amount of marine life from the primary to the tertiary period. In the following table *, drawn up by the author, the number of species known, and also the proportionate number to every 100 feet thickness of strata, are given for the successive systems: —

* Guide to Geology, 3d edit. p. 68.

	No. of Species.	Thickness of Strata.	No. of Species to 100 feet thickness.
Living - -	5000		
Tertiary - -	2728	2000	137
Cretaceous -	500	1100	45·5
Oolitic - -	771	2500	31
Saliferous - -	118	2000	6
Carboniferous -	366	5100 to 10,000	3·6
Silurian and Grauwacke -	349	20,000 or more	1·7

The most predominant of the recent forms of mollusca are the classes of Conchifera, Gasteropoda, and Cephalopoda; these are also the most numerous in a fossil state, for of pteropodous mollusca, a few traces only occur in the tertiary strata. If the recent species of shelly mollusca be supposed to amount to 5000 species, the numbers belonging to each of these great classes may be stated thus, —

Conchifera - -	1800
Gasteropoda - -	3100
Cephalopoda -	100

As far as yet is known, the same classes, in a fossil state, contain, —

Conchifera - -	2130
Gasteropoda - -	2276
Cephalopoda -	698

If we analyse the classes, greater discordances appear. Thus the existing conchifera ranked in three groups, present the following numbers, —

Conchifera plagimyona (*Latreille*) -	1400
——— Mesomyona (*Latr.*) -	350
——— Brachiopoda - -	50

but in a fossil state the numbers are about,

Conchifera plagimyona - -	1030
——— Mesomyona - -	720
——— Brachiopoda - -	380

In the same way it appears, that while in existing nature the shelly gasteropoda ranked in two great divisions, according to their principal food, give the following proportions: —

Herbivorous gasteropoda	-	1400
Zoophagous ———	-	1700

these divisions, in the fossil state, yield, —

Herbivorous gasteropoda	-	1160
Zoophagous ———	-	1110

It appears then, that the fossil world of mollusca differs remarkably from the actual creation in the greater proportionate abundance of cephalopoda, herbivorous gasteropoda and brachiopodous and mesomyonous conchifera. If the whole number of species of shelly mollusca of the three classes named, were supposed 1000 in the fossil and recent states, the proportions of the several groups would be nearly as under: —

	Fossil.	Recent.
Conchifera plagimyona - -	205	280
——— mesomyona - -	142	70
——— brachiopoda - -	75	10
Gasteropoda phytophaga -	225	280
——— zoophaga -	215	340
Cephalopoda - - - -	138	20

These differences, however, are by no means equal in all the several systems of strata: they are least in the tertiary, and greatest in the older classes of rocks. If the total number of shelly mollusca in any one system be called 1000, the proportionate number of the several classes may be seen in the following table, and compared with the recent creation.

	Primary.	Carboniferous.	Saliferous.	Oolitic.	Cretaceous.	Tertiary.	Living
Conchifera plagimyona	157	93	271	246	198	268	280
——— mesomyona	66	74	271	174	246	70	70
——— brachiopoda	365	306	237	79	144	8	10
Gasteropoda phytophaga	166	250	144	135	114	172	280
——— zoophaga	17	30?	25	12	32	388	340
Cephalopoda	229	242	52	354	266	94	20

The analogy of the tertiary to the actual system of organic nature is very apparent in these numerical proportions, and the distinctness of both from the older types in the lower strata is one of the most remarkable and important generalisations in geology.

Nearly all the fossil mollusca, even in the tertiary system, belong to extinct species, a large proportion to extinct genera, particularly among the cephalopoda, brachiopoda, and mesomyona.

The following tables*, will exhibit the numerical proportion of species of particular genera in the living and ancient systems of nature, and illustrate other important truths.

Table I.—GENERA CONTAINING MANY LIVING SPECIES. (GASTEROPODA.)

	Cypræa.	Conus.	Voluta.	Strombus.	Murex.	Fusus.	Cerithium.	Mitra.	Pleuroto-ma.
Living species - -	135	181	66	45	75	67	87	112	71
In tertiary strata -	19	49	32	9	89	111	220	66	156
In cretaceous system -			2	1	2		1		
In oolitic system -					1				
In saliferous system									
In carboniferous system									
In primary strata -									

In this table the strong analogy of the tertiary and living forms of animals, and their distinctness from those of earlier date, are very decided.

* Taken from the Guide to Geology, 3d edition.

Table II.—Genera containing many Fossil Species. (Conchifera.)

	Producta.	Spirifera.	Terebratula	Trigonia.	Pholadomya.	Plagiostoma.	Inoceramus.	Gryphæa.
Living species - -			15	1	1			1
In tertiary strata -			18		1			3
In cretaceous system -			57	12	1	13	19	7
In oolitic system -		6	49	14	16	17	1	17
In saliferous system -	7	5	14	7		8		1?
In carboniferous system	36	48	21		1		1	
In primary strata -	21	37	30	3	1			

The unequal periods of existence of different genera are here very apparent. Producta, after existing in primary and carboniferous ages, perishes in the saliferous period. Spirifera passes through all these periods and ends in the oolitic; but terebratula occurs through all the strata, and still lives.

Table III.—Genera of Cephalopoda.

	Bellerophon.	Orthoceras.	Belemnites.	Nautilus.	Ammonites.	Hamites.	Scaphites.	Baculites.	Nummulites.
Living species - -				2					
In tertiary strata -				4	?				
In cretaceous system -			8	9	57	28	4	5	3
In oolitic system - -			75	13	164	2	1		
In saliferous system -				2	3				
In carboniferous system -	13	28		26	33				
In primary strata - -	11	29		3	17				

Most of the fossil cephalopoda belong to extinct genera: of these, bellerophon and orthoceras are confined to the primary and carboniferous strata: hamites, scaphites, &c. are almost peculiar to the cretaceous system (a few only in the oolites). Belemnites belong to the oolitic and chalk rocks exclusively.

Table IV. — Subgenera of Ammonites according to Von Buch and Munster.

	Clymenia.	Goniatites.	Ceratites.	Arietes.	Falciferi.	Amalthei.	Capricorni.	Planulati.	Dorsati.	Coronati.	Macrocephali.	Armati.	Dentati.	Ornati.	Flexuosi.
Living species - -															
In tertiary strata - -															
In cretaceous system -					2	4					9	14	13	2	3
In oolitic system - -				12	22	27	12	26	5	11	11	11	4	5	3
In saliferous system -			3												
In carboniferous system -		33													
In primary strata - -	14	26													

These are all extinct forms, and while the greater number of species and subgenera abound in oolitic, and many in cretaceous rocks, none occur in tertiary rocks; one group occurs in saliferous, and different types in carboniferous and primary strata.

Thus general and particular results all agree in demonstrating that the physical conditions of the ancient ocean must have been very different in some respects from what obtain at present; and that these conditions were subject to great variation during the long periods which elapsed in the formation of the crust of the earth. In the course of these changes whole groups of animals perished; others were created, to perish in their turn; and these operations were many times repeated, not only before the present races of animals were formed, but even before the relative numbers in the leading groups approximated to the proportions which appear in the actual sea.

Articulated Animals.

The annulose animals form two great series; those without jointed feet, viz., vermes, annulosa, cirripeda; and those with jointed feet, viz., insecta, myriapoda, arachnida, crustacea. Many of the vermes being wholly soft, and living as parasites; many of the true annulosa being also soft; their remains are rarely recognisable in the earth; while serpula, spirorbis, and other shelly annulosa, are very numerous. Cirripeda are not plentiful, and only found in the upper secondary and in tertiary deposits. If we might venture to refer to the articulated animals some portions of the marvellous infusoria, whose true structure has lately been developed by Ehrenberg, the fossil Tripoli of Bilin and Franzenbad (Bohemia), full of gaillonella, navicula and other microscopic animalcula, should be mentioned, as almost wholly composed of the skeletons of articulated animals with jointed feet. Insects which, though not wholly terrestrial, are not found in the sea, numerous as they are in the air, the soil, and fresh water, are very rarely met with in a fossil state. Arachnida and myriapoda, equally unknown in the sea, are as little common as fossil insects; but crustacea, mostly a marine race, are not unfrequent in all the series of the strata, though generally unlike existing tribes. The following table of some of the fossil genera of crustacea may give a correct notion of their distribution in the earth.

	Agnostus.	Calymene.	Asaphus.	Palinurus.	Astacus.	Pagurus.	Cancer.
Living				*	*	*	*
Tertiary				*	*	*	*
Cretaceous				*	*	* ?	
Oolitic				*	*		
Saliferous				*			
Carboniferous			*				
Primary	*	*	*				

The whole great family of trilobites, including many other genera besides calymene and asaphus, is confined to the primary and carboniferous strata.

Fishes.

The finny races of the sea and fresh waters amount to many thousand (perhaps 8000 or more) species; those yet recognised in a fossil state are about 800, or one tenth; but, since a few years ago the number known was very inconsiderable, and new forms are continually presented to M. Agassiz, the master of this department of fossil zoology, there is reason to suppose that the proportion of recent and fossil numbers will speedily change. One reason of the comparative paucity of fossil fishes may be their enormous destruction for food; thus they perish in greater proportion than the other inhabitants of the sea. In the present state of nature, we find very few fishes, or parts of fishes, in the mud of a drained pond, canal, or river; and it is only in particular parts of the sea that the sounding line brings up from the bottom sharks' teeth, hakes' teeth, &c. It is probable, therefore, that only a small proportion of the number of species of fishes, anciently existing, is now to be obtained from the rocks.

It is further to be observed, that the fleshy and ligamental substance of fishes decomposes more readily than the soft parts of many animals; their bones, teeth, scales, &c., are, for this reason, much scattered in certain rocks, which, like the sandstones of Sussex, and the forest marble of Wilts, appear to have undergone the littoral action of the sea. The circumstances under which the remains of fishes have been imbedded appear to have been various. In the upper part of the silurian system, a thin bed of fragmented fish bones occurs; a thicker bed of ichthyoid and sauroid bones has been long known in the lias of the Severn cliffs: considerable agitation accompanied the deposition of fish teeth in most of the oolites, wealden beds, greensand layers, &c. But in the tilestone of the old red sandstone, fishes lie in great perfection in Herefordshire and Brecon, as well as at Arbroath in Scotland; the amblypteri, holoptychi, &c. are very perfect in the coal measures of Newhaven, and Burdiehouse near Edinburgh, Bradford, Yorkshire, the Hundrück, &c. The marl slates of the magnesian limestone, the slaty lias clays of Lyme Regis, certain clays and limestones of the oolitic system, and the chalk of Lewes, have yielded abundance of beautiful marine and fluviatile fishes in an extraordinary state of perfection. Besides these, the deposits of Monte Bolca and many fresh water strata of later (tertiary) date, are stored with fishes, every part of whose structure remains uninjured.

Struck with the contrast offered by these layers of fishes in ancient marine sediments, with the few and scattered fragments which occur in modern deposits, M. Agassiz has conjectured that the rate of deposition of these ancient strata must have been almost inconceivably rapid. An examination of the lamination, frequent changes of composition, alternation of organic remains, and other marks indicating tranquil and slow deposition, which occur in nearly all the localities where the fossil fishes are found in this state of perfection, does not appear to countenance these views; but we must evidently ascribe the destruction of whole races of fishes at a certain exact date (as in the copper state of Thuringia) to some remarkable change of physical condition in the liquids.

The bones of fishes and other vertebrated animals differ from the internal and external shelly appendages of the lower tribes by the admixture of phosphate of lime. The state of conservation of bones differs much, therefore, from that of shells and corals; their substance, in almost every case, remains; the peculiar polish of the teeth and scales of many fishes causes their immediate detection; they are generally heavy, often dark in colour, very compact and brittle; the cells in bones are often filled with crystallised carbonate of lime, but sometimes remain open. It was therefore possible for naturalists profoundly versed in recent ichthyology, to determine the real analogies between the ancient and modern finny races of lakes, rivers, and the sea, and many attempts were made to ascertain these analogies. But until modern times, the knowledge of the structure and functions of fishes, their comparative osteology and lepidology (to coin a useful word) was of small value, and it was reserved to Cuvier and Agassiz to introduce precision and certainty where all before had been error and confusion.

To the latter of these eminent men M. Cuvier bequeathed his labours; and M. Agassiz, with a happy boldness, deviated from the ordinary modes of classification, and entered on a totally new contemplation of the subject. The dermal system, as a natural index of important structural and functional differences, has not, in general, been much attended to among vertebrated animals; though the *hair* of mammalia, the *feathers* of birds, the *naked* or *plated skin* of reptiles, the *scales* of fishes, might have allured inquiry into the variations which they undergo, and the uses they might furnish to systematists. M. Agassiz has seized this neglected thread of system, proved the importance of the indications afforded by the nature of the dermal covering, and applied it to the classification of fishes with peculiar success.

Instead of the divisions usually adopted from the nature of the skeleton,—cartilaginous and osseous fishes, he distinguishes four great orders of fishes from the nature of their scales, and finds that with these differences of scales other great and important distinctions harmonize; but that the possession of a bony or cartilaginous skeleton is a question of comparative unimportance. The abundance and perfection of scales of fishes in a fossil state render this view, valuable as it is in recent zoology, absolutely essential to a study of the fossil kingdom; for thus a few scales remaining may lead to a knowledge of the species or genera belonging to each epoch; and as portions of fishes are found in every one system of strata, from the ancient silurian to the most recent of lacustrine deposits, we are presented with a *second scale of organisation* nearly as complete, and as distinctly related to *time*, higher in the ranks of creation, and therefore *more sensibly dependent on physical conditions* than the well known and justly valued series of remains of mollusca.

The orders of fishes, according to their scaly coverings, are four; viz.

1st. SCALES ENAMELLED.

Placoid fishes, whose skin is *irregularly* covered with large or small plates, or points of enamel, as the rays and sharks, (Etym. πλαξ, a broad plate), occur recent and numerous in the fossil state, being found in nearly all the systems of strata, though the genera are mostly peculiar in each system.

Ganoid fishes are *regularly* covered with angular thick scales, composed internally of bone, and externally of enamel, generally smooth and bright. (Etym. γανος, splendour). Occur recent, but more abundantly in the fossil kingdom, in which fifty extinct genera have been recognised.*

M. Agassiz appears to have ascertained that the strata below the cretaceous rocks contain very few, *if any*, other fishes than such as are included in these orders.

2d. SCALES NOT ENAMELLED.

Ctenoid fishes have their scales of a horny or bony substance, without enamel; serrated or pectinated on the free posterior margin, (whence their name, from κτεις, a comb).

Cycloid fishes have smooth horny or bony unenamelled scales, entire at the posterior margin, with concentric or other lines on the outer surface. (Etym. κυκλος, a circle.)

To the last two orders with unenamelled scales belongs by far the greater proportion of existing species

* Buckland's Bridgewater Treatise, p. 270.

of fishes, which, according to Cuvier, exceeded 5000; but are stated by M. Agassiz to amount to 8000. On the contrary, the greater number of fossil fishes belong to the two orders with enamelled scales. In the following table the geological distribution of these orders is sketched.

	Placoid.	Ganoid.	Ctenoid.	Cycloid.
Living	*	*	*	*
Tertiary	*	*	*	*
Cretaceous	*	*	*	*
Oolitic	*	*		
Saliferous	*	*		
Carboniferous	*	*		
Silurian	*	*		

Among existing fishes it is frequently found that the caudal tail fin divides into two equal branches; sometimes it is single and rounded, but in the case of some placoid and ganoid fishes (*e.g.* squalus and lepidosteus) the tail fin is double, the dorsal portion being prolonged to a considerable length, and the ventral portion much shorter. These three forms are seen in *figs.* 27, 28, 29., which represent the trout, the

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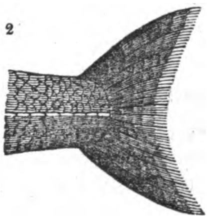
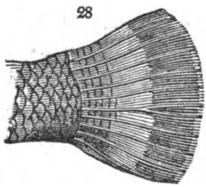
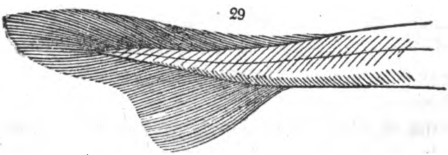


28



29



wrasse, and the shark. Now it is a remarkable circumstance observed by M. Agassiz, that all, or nearly all, the fossil fishes found in strata in and below the magnesian limestone, are heterocercal, or have their tails unequally bilobate, like the shark, sturgeon, lepidosteus, &c. (*fig.* 29.); but this form of tail is rarely found in the oolitic and superior systems of strata.

What is the general determining cause or function of this remarkable heterocercal structure in fishes is at present matter of conjecture. In the shark and sturgeon it is accompanied with a remarkable position of the mouth; but as this is not the case in the recent lepidosteus, or the fossil palæoniscus, it is an unsafe basis of reasoning. Perhaps the true solution may be found in the analogy which placoid fishes in general, and certain ganoid fishes, present to the class of reptiles; an analogy perceived by Linnæus, and strongly corroborated by the recent researches of Agassiz, as to the structure of the teeth, cranial sutures, air-bladder, &c. That the upper lobe of the heterocercal tail may really be viewed as the analogue of the real tail of reptiles, appears from this, that the *vertebral column is continued into it.* We, therefore, view this remarkable structure as a *character of the organisation of certain ancient geological periods,* and refer to the scaly surface of the upper caudal lobe of tetragonolepis, and other oolitic genera, as indications of its gradual change to the truly double or homocercous tail fin (*figs.* 27, 28.), which is one of the *characteristics of the existing period.*

All the fishes of the silurian, carboniferous, saliferous, and oolitic systems, and two thirds of those in the cretaceous system, are stated by Agassiz to belong to extinct genera.

Reptiles.

Of the existing four orders of reptiles, — batrachida, chelonida, ophidia, saurida,—the two former are partly aquatic, partly terrestrial; the two latter principally tenants of the land. Agreeably to the general rule, the terrestrial families of reptiles, and especially ophidia, are scarcely known in a fossil state: the fresh water batrachida and chelonida occur only in particular deposits, which seem to be wholly or partially of fresh water origin (as the wealden formation, the fresh water formations of the Isle of Wight, the brown coal deposits of the Rhine). Marine chelonida are not unfrequent in the secondary and tertiary strata. The saurian order presents us with some singular facts.

The existing crocodiles offer in the saurian group a particular and distinct type, which seems to unite, in some degree, the characters of the chelonida and true lizards: their life is spent, principally, in the waters of rivers which communicate with the sea (Nile, Ganges, Senegal, Mississippi); and they sometimes pass from the shore to prey in the salt waters. Three great divisions of crocodiles correspond to three distinct physical regions:—the alligators are wholly American; the true crocodiles belong entirely to Africa and the West Indian islands; the gavials are found only in India. All the fossil races of crocodiles which occur in the saliferous and oolitic systems are very similar to the long-snouted Indian gavials; these above the chalk approach the broader beaked Nilotic crocodiles.*

There is but little difference of magnitude between the fossil and the living races of crocodiles, for the great gavial of the Ganges measures twenty-five feet long; and we are not aware that any fossil crocodile has been found of larger dimensions.

Analogous to crocodiles, true lizards, and turtles, occur a great variety of fossil saurians, some of which were terrestrial, and more aquatic; many of them quite monstrous in dimensions, and extraordinary in organisation. The following table is taken from Von Meyer's Palæologica.

* Cuvier, Ossemens Fossiles. The investigation here referred to is extremely important and interesting.

SYSTEM OF FOSSIL SAURIANS ACCORDING TO THE DEVELOPMENT OF THEIR ORGANS OF MOVEMENT.

A. Saurians with Toes analogous to those of living Saurians.		B. Saurians with Limbs analogous to those of large Land Mammalia.	C. Saurians adapted for swimming.	D. Saurians adapted for flying.
1. Four toed.	2. Five toed.			
1. Aclodon, *H. v. M.* 2. Rhacheosaurus, *H. v. M.* 3. Pleurosaurus, *H. v. M.* * Geosaurus, *Cuv.* * Macrospondylus, *H. v. M.* * Mastodonsaurus, *Jacq.* (These are analogous to living crocodiles, caimans, and gavials.)	1. Protorosaurus, *H. v. M.* 2. Lacerta neptunia, *Goldf.* These are analogous to living Lacertidæ.	1. Megalosaurus, *Buckl.* 2. Iguanodon, *Mantell.*	1. Ichthyosaurus, *König.* 2. Plesiosaurus, *Conyb.* 3. Mososaurus, *Conyb.* * Phytosaurus, *Jag.* * Saurocephalus, *Harlan.* * Saurodon, *Hays.* * Teleosaurus, *Geoff.* * Streptospondylus, or steneosaurus, *H. v. M.* * Metriorhynchus, *H. v. M.*	Pterodactylus, *Cuvier.*

* In the genera thus marked, the organisation of the limbs is incompletely known (*H. v. M.*). (Teleosaurus is probably to be removed to section A., if we may judge from the limbs of the fine specimen in the museum at Whitby. Saurocephalus and Saurodon are ranked among fishes by M. Agassiz. — (*Author.*)

All the saurians of sect. A. div. 1., with the exception of mastodonsaurus (which occurs in the saliferous system) belong to the oolitic and lias rocks. In section A. div. 2., one, the protorosaurus, or monitor of Thuringia, is found in the saliferous, the other in the oolitic system.

The saurians of sect. B. are found only in the oolitic system. Those of sect. C. are-chiefly confined to the oolitic rocks; mososaurus belongs to the chalk, phytosaurus to the saliferous rocks. Pterodactylus belongs to the lias and oolites. Thus, upon the whole, it is in the oolitic period, between the eras of the red sandstones and the greensands, that the large saurians existed in greatest abundance about the shores, in the rivers, and on the land, in these now cold regions of the globe: this was, in Mr. Mantell's language, the "age of reptiles;" though recently two new genera (thecodontosaurus and palæosaurus) have been added to the catalogue from the magnesian limestone of Bristol (by Dr. Riley and Mr. Stutchbury), and one other species is supposed to occur in the limestone associated with coal at Ardwick near Manchester.

The discoveries among fossil reptiles of the saurian races by Cuvier, Sömmering, St. Hilaire, Von Meyer, Conybeare, and the naturalists of Bristol, have equally awakened the attention of zoologists and geologists. Among the singularities revealed by these investigations, we may notice in the ichthyosaurus, the curious and beautiful combination of the swimming form and retral nostrils of the dolphin; the teeth of the gavial, or crocodile; paddles somewhat like those of the turtle; vertebræ like those of a fish; and eyes furnished with solerotic bones like those of birds and certain lizards. Pterodactylus, an almost fabulous creation, unites the wings of a bat with the skeleton of a lizard; its long neck being formed of only seven vertebræ, while the snake-like neck of plesiosaurus includes from thirty to forty! M. St. Hilaire, contemplating the many analogies between some crocodilian fossils and the recent gavials, has been led to propose the speculation that the recent crocodiles are really the offspring of the older forms; the differences between them being merely the effect of different physical conditions operating during long geological periods upon one original race.

If instead of this somewhat poetical conjecture which cannot be proved, we substitute what is really known of the successive stages of reptile organisation from the era of magnesian conglomerates to the present time, the results are very remarkable.

The vertebræ of palæosaurus and thecodontosaurus agree with those of ichthyosaurus and common fishes, in being deeply concave at each end—a structure evidently adapted for free motion in water. In plesiosaurus, the vertebræ are slightly concave on each face; but in teleosaurus, steneosaurus, and the recent crocodiles, they are anteriorly convex. The former are really of ichthyoid, as distinguished from the latter, or truly crocodilian type; and, in a paper read to the Bristol meeting of the British Association, the discoverers of palæosaurus and thecodontosaurus, proposed the speculation that the system of doubly concave vertebræ (*fig.* 30.) is more ancient than that of the concavo-convex (*fig.* 31.), and

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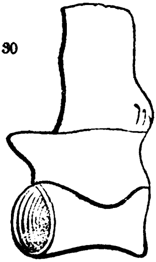

Thecodontosaurus.

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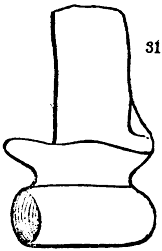

Crocodile.

that the change from one to the other may be found related to geological time. In the monitor of Thuringia, which, according to this view, should have doubly concave vertebræ, their front and hind faces are rectangled to the axis.*

* Von Meyer, Palæologica, p. 209.

Birds.

The remains of birds are extremely uncommon, even among the comparatively recent alluvial lacustrine and cavern deposits, still less frequent among the tertiary strata, and almost unknown among the older strata. This is one of many instances which agree in proving that the occurrence of the exuviæ of land animals and land plants in the stratified rocks, which were formed chiefly in the sea, is the result of causes so local, limited, and rare, as to be, in fact, *accidental,* and therefore no sufficient basis of reasoning as to what was the state of the ancient land at particular geological periods. At the present day we could learn little concerning the vegetables and animals of the land, from the few traces which remain of them in the beds of lakes, rivers, and the sea.

Mammalia.

The argument just used may be applied with equal justice to the paucity of remains of land mammalia in the marine strata of all ages; for even in the tertiary rocks such remains are rare. But it is, perhaps, necessary to find other causes for the scarcity of marine mammalia in all except certain of the tertiary strata and superficial sediments. The opinion formerly favoured was, that during the whole of the primary and secondary periods, at least, the class of mammalia had no existence, and only came into being during the tertiary period. But this conclusion, founded upon the mere want of such remains, was easily seen to be insecure, and at length proved to be erroneous by the decision of Cuvier, that certain small jaw bones, with teeth, found in the oolitic system at Stonesfield near Oxford, belonged to *viviparous quadrupeds,* and approximated to the genus DIDELPHYS.

Five specimens of these remarkable jaw bones are known, two of which are in the hands of Dr. Buckland, one belongs to Mr. Broderip *, one to M. Prevost, and the fifth (*fig.* 32.) was selected by the author of this Volume, from an ancient collection of fossils, the property of the Rev. C. Sykes, of Rooss, in Yorkshire, by whom it was presented to the museum of the Yorkshire Philosophical Society. These specimens are of inestimable value, for were they unknown, the whole of the positive testimony that the earth, during the secondary periods of geology, nourished land mammalia, would vanish, and the course of inferences as to the succession of organic life on the globe be greatly modified.

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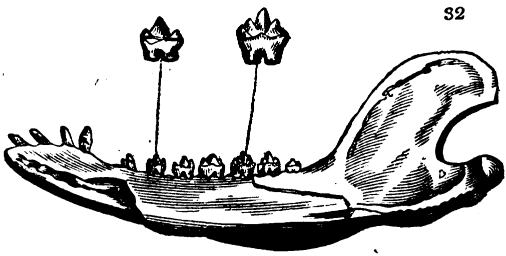

From Buckland's Bridgwater Treatise.

Those persons who, confiding in what are somewhat hastily called general views, believe too strictly in the gradual change and sequence of organic life on the globe, and have pictured to themselves the early land and sea as tenanted only by the simpler (and, as they are erroneously termed, inferior or imperfect) forms of life, while in each succeeding period new, more complicated, and more exalted plants and animals were called into being, till man was at last awakened to the supremacy of creation, will find this fossil quadruped of Stonesfield a very puzzling anomaly. On the contrary, the geologist who, in the full spirit of Cuvier, regards the systems of life as definitely related now, and at all past periods, to the contemporaneous physical conditions of the globe, and uses the remains of plants and animals as monu-

* Since transferred to the British Museum.

ments and guides to a right knowledge of these conditions, draws from this singular and extraordinary discovery the confirmation of a hope, that the state of the ancient land may not for ever be wholly concealed from patient inquiry.

That these are really the jaws of mammalia — that the genus was at least allied to Didelphis, we may safely admit on the competent anatomical authority of Cuvier and Agassiz, notwithstanding the easy conjecture, that they might belong to Pterodactylus, of which bones but not jaws occur at Stonesfield. When we regard the pointed lobes of the teeth, and consider the position of the incisors, and the shape of the condyles, there appears no reason to doubt that the animal was insectivorous. It is worth remarking that elytra of land beetles (Buprestis?) are found in the same deposit, with terrestrial plants and other indications that the laminated rock, in which the specimens lie, was formed near the sea shore. No other parts of the animal have yet been found than the lower jaw, — there is no ascertained or even very probable instance of the occurrence of land or marine mammalia in older rocks than the Stonesfield oolitic beds, — none have yet been discovered in any of the superior strata of the oolitic system, — it is merely a conjecture that some bones in the marls of the cretaceous system of New Jersey and Delaware may belong to Balæna. With the exception of Stonesfield, it is only in the tertiary strata and superficial deposits that we can positively admit the occurrence of fossil marine or land mammalia at all.

It is chiefly in anthracitic tertiaries, as near Zurich; in lacustrine sediments, as at Gmünd and Oeningen; — in gypseous deposits from fresh water, as at Montmartre; — in shelly marls, as at Market Weighton; — in diluvial clay or gravel, as at Harwich, — at Lawford, — at Hessle; — or in more recent peat bogs, as in Ireland, the Isle of Man, Lancashire; — or in caves and fissures of the rocks, as at Kirkdale, and Gibraltar, that the bones of mammiferous quadrupeds occur.

Some of these ossiferous deposits are of historical date, the others of greater but various antiquity, so as to permit the construction of the following table of the successive races of mammalia.

	Quadrumana.	Cheiroptera.	Carnivora.	Rodentia.	Edentata.	Pachydermata.	Solipeda.	Ruminantia.	Marsupialia.	Cetacea.
Historical or modern			*	*	?	?	*	*		*
Diluvial - - -		*	*	*	*	*	*	*	*	*
Tertiary - - -	*	*	*	*	*	*	*	*	*	?
Secondary - -									*	?
Primary - -										

The preceding table adds another to the proofs already given of the extreme analogy between the tertiary and modern periods of geology. We find in the tertiary formations remains of nearly all the great natural orders and groups into which systematists have divided mammalia: in most instances, however, the species, and often the genera, differ; yet it must be borne in mind that these differences are not greater than now obtain between the animals of the analogous climates of America, Africa, and India. Admitting for the moment, what must hereafter be discussed, the distinctness of the alluvial, diluvial, and tertiary deposits, we may observe that in the diluvial reliquiæ of mammalia, most of the genera, and some of the species, are the same or extremely like to living tribes: while in the modern accumulations it is rare to find an extinct species, though some specimens of the great Elk of Ireland are probably of this date.

But there is one remarkable exception to this analogy of the tertiary and diluvial fauna, with our present races of mammalia; no remains of Man have yet been found in any of these deposits—no trace of his works; and it is yet entirely doubtful whether the race of man existed at all during what are called the diluvial periods. The same exception almost extends to the order of quadrumana, which, in their animal nature and organisation, most nearly resemble ourselves; for these have rarely been recognised in a fossil state.* Perhaps, however, we ought not to insist very strongly on either of these negations: for the quadrumana could not be expected to occur often in a fossil state far from the tropical forests which might shelter and feed them; and man only braves the cold of northern climates by his superior knowledge of nature, and inventions to meet its variations. These arts and that knowledge must be supposed of slow growth; and we may consistently believe that, though mankind at the diluvial era might not have extended to these far northern lands, where, only, the ossiferous caves and deposits have been adequately examined, human remains may yet be discovered in those warmer regions of the globe, which seem more congenial to the easy existence of our race, and have not yet been searched for the bones of our progenitors.

The supposed exceptions to this law of the absence of the remains of man from tertiary and diluvial accumulations (the bone caves of Bize, near Narbonne, the valley of the Elster, &c.) may be discussed hereafter: suffice it now to say that they are not thought sufficient to establish the affirmative of this important proposition. It appears, therefore, that we must look upon the existence of man and many races of animals which, more strictly than he, are appointed to live under particular physical conditions, as characteristic of the last of several great periods of geological time, each marked by the creation of peculiar races of plants on the land and animals in the sea.

From what we now see of the dependence of animal and vegetable life on climate, moisture, soil, and other characters of physical geography, there can be no doubt that to every system of organic life in the successive geological periods belonged certain combinations of physical conditions. These conditions were, indeed, not the *cause* of those systems of life; but both are to be looked upon as mutually adjusted phenomena, hap-

* Quadrumana have been found by M. Lartet, in the lacustrine deposit of Sansan, Dep. de Gers.), and by Capt. Cautley and Dr. Falconer, in the tertiary strata of the Sewalik Hills, Hindoostan.

pening in a determined order as part of a general plan. Some changes in the constitution of the globe have brought in succession various combinations of the manifold influences of those chemical and mechanical agencies which govern inanimate nature; and such appears to be the law of God's providence, that to these combinations the forms of each newly created system of life should correspond. The several successive systems of organic life which have been discovered in the earth, were, therefore, really successive creations, and must be expected to differ in large and general characters.

Thus the species, genera, and families of fossil plants and animals vary from formation to formation, and system to system: yet as the constitution of different races, enjoying animal and vegetable life, is unequally adjusted to external circumstances, it does not follow that the creation of many new, should be always accompanied by destruction of all the old, forms. On the contrary, the extensive collections of fossils now made in England, prove this to be an erroneous notion: for many fossils, as Terebratulæ — Astacidæ — Modiolæ — Gervilliæ, generically, and certain species of them individually, existed during the deposition of great ranges of strata, and endured the changes, whatever they were, which brought into existence many new and remarkable forms. It seldom, however, happens that any one *species* occurs in more than one *system* of strata; and thus we may consistently speak of the *oolitio* fauna and flora, as distinguished from the whole series of plants and animals belonging to the *cretaceous* or *saliferous* period, satisfied from adequate inquiry that few species are common to any two systems.

Though at present geological investigations have not been prosecuted in all accessible parts of the land, so as every where to bring proof of the universality of these laws of successive systems of life, enough is known to assure us that in every country yet examined, the fossils of the tertiary, secondary, and primary strata differ essentially, and by large and general characters.

Everywhere the tertiary fossils are closely analogous to existing types; but in all countries the fossils of the primary strata appear to belong to a very different series. Wherever the systems of European strata can be paralleled,—in North America— the Himalaya— Australia— so much of analogy is evident in the organic reliquiæ, as to prove that the successive changes of physical conditions, and the coincident changes of organic life, were operated over very large parts of the globe; and nothing, yet known, forbids us to believe that they were universally felt, though in unequal degrees, and under differences of circumstances.

Could we suppose produced on the present globe some general change of conditions in the sea, on the land, and in the atmosphere — either simultaneously, or by communication from a central area of disturbance — the effects upon organic life might be everywhere manifested, though unequally and variously. The extinction of some tribes, the decrease or enlargement of others — the creation of new types to fill the void spaces of creation, and be adapted to the new conditions, might seem to us quite in harmony with the designs of providence, and fully in accordance with past geological effects. There would, however, be this difference in the cases: — the races of animals and plants of this modern period of the globe are more various in different countries than the fossils of any one older geological period appear to have been; there is now more of local diversity in organic life upon the globe, than formerly obtained; and from this we infer that the physical conditions of the globe in former periods were more general — more uniform over large areas than at present. This character of uniformity among the organic contents of a system of strata, augments continually from the modern period toward the older, and is greatest among the most ancient strata, whose organic contents, though less numerous, are more similar in all countries yet explored than those of later date.

Since it thus appears that general laws of variation connect the phenomena of all geological periods, from the most ancient to the most modern epoch, into *one grand system of natural revolutions*, it follows that we may look upon the present condition of our globe as one term of a magnificent series of appointed changes, to which others may from analogy be expected to follow, according to the same laws. The creation of intelligent man is indeed an event not in the calculation which man can make of the effects of such laws; nor, indeed, is it given to us creatures of a day exactly to know the laws of variation which bind all the phenomena of nature — past, present, and to come — into one great system of appointed effects, flowing from a predetermined cause, — much less to deduce these effects. Yet let not the search for these laws — which comprises the whole of geological theory — be censured as a chimerical inquiry. The augmentation of light that has already been poured on the dark pages of geology encourages perseverance; the extent of man's power to interpret the phenomena of nature may be vast, compared with his present knowledge, however small, compared to the amount of things unknown. In searching for general theory we shall at least find limited truth; and the experience of some thousand years has proved the labour, which seemed vainly tasked in abstract discovery, to be seldom unproductive of practical utility.

To understand rightly the daily accumulating stores of organic reliquiæ, requires more than a slight knowledge of existing nature,—more even than an acquaintance with animal and vegetable forms. The philosophy of their existence must be considered—the variations of their structure, with respiration in air or in water — life in fresh or salt water — in trees or on the ground— carnivorous or herbivorous food — their geographical distribution—dependence on climate and atmospheric conditions. Thus viewed, the present system of nature appears, when compared with the older periods, one in which local diversities of condition have gone to extreme — where all the peculiarities of climate and surface have given the fullest effect to the variety of nature, and yielded that astonishing complexity of dependent phenomena which incessantly engages the mind of reasoning man in an endless train of inquiry. These local diversities are so great, as to permit us to propose questions concerning the degree of resemblance which fossil remains may offer to the recent tribes of different climates and regions of the globe.

Where shall we look for the living analogues of the numerous fossil ferns, including arborescent species of great size, the sigillariæ, lepidodendra, and gigantic equisetaceæ, which fill the coal shales of England, — the cycadeæ, coniferæ of the oolites, and the palms of the tertiary rocks of France?

In what climate grow the modern coral reefs comparable to the fossil zoophytic rocks? where live the parallels to thousands of echinida, crinoidea, trilobites, brachiopoda, cephalopoda, sauroid fishes, crocodiles, pachydermata, ruminantia, which characterise different geological periods?

It is difficult to answer this inquiry with precision; for, though upon a comprehensive review, the most prevalent analogies in modern nature point to a tropical climate; yet as the species always, and the genera and families frequently, differ, and as, besides, other causes than climate limit the distribution of life, it is not possible to found such a conclusion on individual instances. A *prevalence* of ferns to the extent which we observe among the plants of the coal formation, is only known among the islands and on the shores of warm tropical seas; but if these fossil plants had been much drifted or long immersed before inhumation, such a predominance of ferns, cycadeæ, &c., might be expected to happen, whatever was the original proportion; for Dr. Lindley's experiments on recent plants prove, that long immersion in water would destroy the greater number of plants, but leave the ferns, cycadeæ, coniferæ, &c. comparatively uninjured, as we find them in the earth. Compared as to form, the tree ferns, palms, cycadeæ, &c. indicate growth in a warm climate, as do also the gigantic lycopodiaceæ, sigillariæ, and calamites; but this is not the case with coniferæ. Zoophyta, both spongoid and stony, lead us to the same conclusion; for the greater part of horny sponges and stony corals belong to the regions within 33° of latitude from the equator (except the S. E. coast of Australia). As far as can be judged by comparing fossil and recent radiaria (echinida, crinoidea, stellerida), the same inference applies. Molluscous remains teach us little in this respect, except the cephalopoda, which, by their size and abundance, *seem* to indicate a warm climate for the cretaceous, oolitic, and older deposits. Enough, perhaps, is not yet known of the relations of fossil and recent fishes, to justify any general conclusion; but the great families of fossil saurian reptiles prove, by their magnitude, and analogy to crocodiles, iguanas, monitors, the decided influence of a warm climate during the oolitic and cretaceous periods; for nothing can be more clear than the dependence of the numerous tribes of living reptiles generally, and the sauroid families in particular, upon a warm climate. More than a thousand species live in the tropical regions of the new and old world; but only a few dwindled races visit the colder zones of Europe, and mostly enter the earth in winter, a provision whereby the animals which generate little heat in their bodies are preserved during the periods when the sources of external warmth are too feeble to sustain their functions in activity. With regard to the degree of analogy, which the productions of different *regions* may be found to present with fossil reliquiæ, we are not aware that any investigations are on record; and yet it is impossible to turn to Australia without a suspicion that the anomalous productions of that region have more than the average resemblance to the primeval fauna and flora. For here, and near it, tree ferns, cycadeæ, araucariæ, casuarinæ, grow upon the land; corals and sponges abound on the coast even of Van Diemen's Land, — while trigonia, cerithium, isocardia, a cardium like C. hillanum of the green sand and quadrupeds of the peculiar marsupial races to which the Stonesfield animal is referred by Cuvier, seem to invite attention to the yet unexplored sea and land of this prolific region, as likely to yield still farther analogies to ancient animals and plants, and, by consequence, to furnish new and important grounds for determining the ancient physical conditions of the globe.

CHAP. VI.

HISTORICAL VIEW OF THE STRATIFIED ROCKS IN THE CRUST OF THE EARTH.

In describing the successive phenomena visible in the crust of the earth, we may either begin at the surface, and pass from the operations of to-day, through the monuments of changes performed in historic periods, to those of earlier date; and thus, proceeding from the known to the unknown, approach by an easy gradation to the remote eras and obscure conditions of our planet, which were once degraded by the misapplied title of "Chaos;" — or take our departure at the most ancient recognisable point of geological time, and trace the events which happened on the globe in the order of their occurrence.

The former process offers some advantages to the student who, unaided by or distrustful of the generalisations already arrived at, is desirous of acquiring by his own labours a correct view of the relation of the present to earlier conditions of the globe: for thus, proceeding from diurnal operations to primeval phenomena, he is able to classify his observations with reference to causes really acting, to assemble partial truths into laws of phenomena, and by mere comparison of these with the actual condition of nature to arrive at the knowledge he is in quest of.

But for the purpose of clearly unfolding the series of geological phenomena whose laws are known, the contrary method is to be preferred. To describe what is known of the structure of the earth in the order of the occurrence of the phenomena — to present a series of pictures of its successive conditions — to exhibit these conditions as influencing others which succeeded them, till the present aspect of nature appears as a consequence of all the previous changes, is in fact to write the physical history of our planet upon the same plan as that universally adopted for histories of its human inhabitants.

Granitic Basis of the Crust of the Earth.

This geological history of the earth must necessarily commence with the earliest (*i. e.* lowest) stratified formations; and the first things to be determined are, the extent to which they can be traced, and the nature of the basis on which they rest. Sufficient information is already gathered on these points to allow of a distinct affirmation, that below all the series of strata existing in any country, masses of crystallised but unstratified rocks exist so as to form a general floor, most irregular in surface and of unknown thickness, on which the strata successively rest. These rocks are generally of the nature of granite, that is to say, largely crystallised aggregates of felspar with variable admixtures of mica and quartz — or more rarely quartz and hornblende — or quartz and hypersthene. Examples of the first kind of granitic basis of the crust of the earth, are almost universal in mountainous regions; *e. g.* the Grampians, the Mourne and Wicklow mountains, Cumbria, Cornwall, Pyrenees, Alps, &c. Sienitic granite (holding hornblende with or instead of mica) occurs about Strontian and in Ben Cruachan; and hypersthenic granite shows itself in the Val di Fassa (Alps), gradually changing to common micaceous granite.

Seeing then the probably universal extent of the granitic floor beneath the stratified parts of the earth's crust, it becomes of great importance to ascertain if the law which is allowed to hold for all stratified rocks (viz. that the lowest are the oldest), is extensible to the subjacent granite, so that it may be ranked as *an older rock than any of the strata which rest upon it.* A

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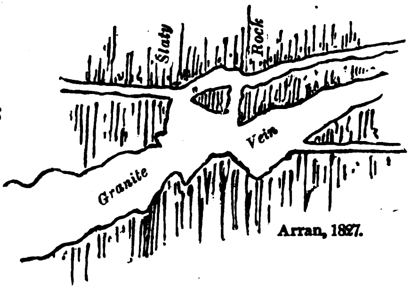

striking change has taken place in respect to this matter of late years: formerly, when granite was by many geologists thought to be of aqueous origin, its inferiority of position was held to be sufficient proof of anterior production; now, when it is known to have been formed by the action of heat, this argument is of no value; and other circumstances have been observed which leave no doubt that in very many cases the granite has been in a state of fusion since the deposition of several of the older formations, so that it has actually been injected into fissures and cracks of these strata, or been raised up in a fluid mass amongst them. (Diagram No. 33.) Granite veins, as these injected portions, once thought so rare, are called, have now been observed in almost every region of old strata; entering hornblende slates, and primary limestones in Glen Tilt (Blair Athol), and clay slates in Arran, Skiddaw, and Cornwall. Granite which we thus see irrupted through and into the stratified rocks, is, in fact, of no one particular or determinate age, but is the local result and evidence of many independent excitements or periods of critical action among the subterranean agencies of heat. We may, therefore, consistently admit granite, as well as other igneous rocks, to be of any, that is, of all ages; some of that which is visible in the crust of the globe may have been solidified from fusion before the production of any of the strata; other granite has been melted or re-melted at various later periods; granite may yet be forming in the deeper parts of the earth, round the centres of volcanic fires; but, in general, we must look on this rock as characteristic of particular circumstances accompanying igneous action, not as belonging to particular periods of geological history.

These circumstances appear, however, to have occurred universally, if not simultaneously; and the tendency to produce fluid compounds which subsequently admit of granitic crystallisation, is a characteristic effect of subterranean heat in all past geological periods. It appears, therefore, a probable inference, that the formation of granite was a process which began before the production of any of the strata; was continued during the accumulation of primary, secondary, and tertiary rocks; and is yet in action under particular circumstances in the deep parts of the earth. One of the most remarkable speculations of modern geology is that advocated by Mr. Lyell, who, in his "Principles of Geology," defends the somewhat startling speculation, that the granitic floor of the stratified crust of the earth, is nothing else than the fused and re-consolidated materials of older strata than any which are now visible,—that at this time granite is forming in the same manner by the fusion of the lower portions of the strata,—and that as new stratified rocks, the fruit of water, are slowly deposited above, the older ones which they cover are slowly re-absorbed by the antagonist element of interior heat, and converted to crystallised granite.

Those who adopt this view must of necessity look on the stratified rocks as an incomplete series of monuments of watery action, the earliest being wholly consumed by heat. According to them, the history of the globe must unavoidably be imperfect; it can, as Dr. Hutton remarked, show no trace of a beginning, no prospect of an end; the appointed agencies of terrestrial nature are bound in a perpetual circle of compensation and not united by a continuous chain of effects flowing from some one primal condition toward a determinate and permanent state. It is certain, that the study of igneous rocks alone will never enable us to decide how far this speculation is well founded, since they are not characteristic of time, nor capable of giving the least information as to the organic enrichment and atmospheric investment of the globe, except by combination with the data afforded by a study of the stratified rocks. To these, therefore, we must immediately apply.

PRIMARY SYSTEMS OF STRATA.

Gneiss and Mica Schist System.

Composition. — It is a general truth, that to every principal mass of stratified rocks belong some remarkable mineral types of composition. The primary strata, viewed together, distinguish themselves by the superabundance of hard siliceous and argillaceous rocks, with crystallised or concretionary limestones; the secondary rocks have more variety of arenaceous and calcareous members; in the tertiary strata loose sands, marls, and clays abound remarkably, while these scarcely occur at all among the primary rocks.

The same truth is, perhaps, even more clearly perceived by comparing the successive systems and formations, and deserves more attention than has of late been given to it, since the study of organic remains has opened so many brilliant views of another kind, though equally related to, and characteristic of, geological time.

The materials of the rocks which enter into the composition of the gneiss and mica schist systems, are such as to form siliceous, argillaceous, and calcareous aggregates, somewhat resembling those of the later systems of rocks; but they are usually in a very different state of molecular aggregation. The siliceous strata of these ancient rocks (gneiss, mica schist, &c.) consist of the same minerals as those which abound in secondary sandstones, viz. quartz, felspar, and mica principally; but they are far more distinct in their characters, less worn by watery attrition, and more evidently allied to granite. The argillaceous rocks, which often accompany them, (clay slate, grauwacke slate, &c.) have nearly the same chemical composition as common clays and shales among the secondary rocks; but the degree of induration and the whole structure of the rocks require the supposition of their having undergone the influence of very different circumstances. In the same way the primary calcareous rocks, though chemically undistinguishable from secondary limestones, are so crystallised in texture as to leave no doubt that modifying agencies of great importance have operated on them since their deposition.

If we seek to ascertain the origin of the materials of the oldest or lowest of all the known systems of strata, and take characteristic specimens of gneiss and mica schist for the purpose, we shall be struck with the great resemblance they offer to granite, in the kind, proportionate abundance and admixture, even colour and aspect, of the constituent quartz, felspar, mica, hornblende, &c. So close is the resemblance, that some writers appear disposed to allow for these stratified granitoid rocks, an origin not very distinct from the igneous origin of granite; but careful attention discloses points of disagreement which are equally important, and tend to a different opinion. Let any one, for example, compare in well characterised granite and gneiss the constituents, felspar and mica: in granite these are always perfectly crystallised within, and have regular external geometrical figure; in gneiss the internal crystallisation remains, but the felspar is rounded like sand or small pebbles, or fragmented like a broken crystal, and the mica is bent and contorted by irregular pressure among the felspar and quartz. Add to these circumstances the lamination of the masses, and we see clearly that the ingrédients of gneiss and mica schist resemble granite, because they have been derived from granitic rocks; but they differ because they were accumulated under the mechanical influence of water, and not aggregated by chemical forces from a state of igneous fusion.

The divisions of the gneiss and mica schist system are, to a considerable degree, based on the mineralogical differences of the ingredients in the predominant rocks. Gneiss, for instance, is principally composed of the same materials as common granite, viz. quartz, felspar, mica (occasionally hornblende, augite, garnets occur in it); mica schist is principally formed of mica and quartz, with garnets, hornblende, &c.): in both, the ingredients are arranged in laminæ; the mica forming generally continuous sheets in mica schist, but interrupted patches in gneiss. Chlorite schist differs from mica schist by the substitution of chlorite for mica. In hornblende schist the mineral associated with quartz is hornblende or actynolite. In quartz rock, only a little felspar or mica is mixed with the granular quartz, and not generally arranged in layers.

In gneiss, mica schist, chlorite schist, and hornblende schist, the magnitude of the grains is indefinite; and it consequently happens that all of them admit of numerous variations, to which it is useless to give names, from largely granular or even conglomerated gneiss (Zetland), to a fine-grained nearly uniform admixture of mica, quartz, and felspar — mica and quartz — felspar and quartz — (with or without chlorite, hornblende, &c.) In this state these siliceous rocks become very similar to certain argillaceous slates, which, in fact, in some cases, seem to bear exactly the same relation to gneiss, mica schist, &c., that common clays do to common sandstones: there is every gradation between them; their origin is undoubtedly similar — it may even be called the same; since one land flood or sea storm will form both stratified sands and laminated clays from the same wasted land or broken cliff, according merely to the difference of circumstances under which the materials are accumulated. Now it is impossible to doubt that clay slates and grauwacke slates have been deposited in water: it is equally certain that the gneiss and other felspathic or quartzose rocks, which are associated with it, and occasionally with clay slate, are also of aqueous production; and the composition of gneiss, &c., completes the evidence wanted to prove that the primary strata analogous to sandstones and clays were formed from the waste of granitic rocks.

The structure of the rocks which compose the gneiss and mica schist system varies considerably, both in relation to lamination and stratification, which depend on the mode of aqueous deposition, and to joints and fissures, which are the result of subsequent agencies.

Lamination prevails amongst all the varieties of gneiss, mica schist, chlorite schist, hornblende schist, &c. It is often observable in primary limestone and sometimes in quartz rock. In gneiss, mica schist, and chlorite schist, but especially in the former, the laminæ are usually contorted, sometimes excessively so, indicating a troubled condition of the water from which the ingredients fell, or a source of agitation in the still yielding sediment which seems scarcely ever to have occurred among the secondary and later strata. The only plausible explanation of this remarkable circumstance which has occurred to us, is the agitation of the sea, or the soft sediment on its bed by heat; exactly as in the bottoms of steam boilers, the calcareous sediment is formed in irregular undulating laminæ, which appear on a cross section very similar to the flexures in the laminæ of gneiss. It will appear hereafter that this speculation derives some corroboration from other circumstances, tending to show what was the condition, as to heat, of the ocean in which the ancient rocks were formed.

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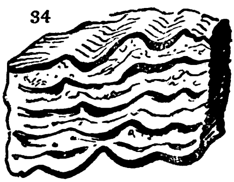


Dr. M'Culloch informs us (Memoir on Map of Scotland, p. 65.), " wherever there are numerous and conspicuous curvatures the gneiss is granitic; and it is the same, with little exception, where the position is angular. It is the same also, almost universally, when the beds are in the vicinity of granite.

"On the contrary, extensive and prolonged beds are very generally schistose or laminar: the strata, also, are of this character when alternating and continuous with mica slate and quartz rock."

Stratification, or bedding, independent of lamination, is less easily traceable in the gneiss and mica schist system than in most other aqueous rocks: yet sometimes in the gneiss of Strontian, the mica schist of the Trosachs, the chloritic schists of Loch Lomond, it is sufficiently plain, to be satisfactory proof of intermitting deposition of the rocks. This intermission of deposit is, perhaps, the true cause of the bedded or stratified structure in all rocks. When different sorts of matter are alternately deposited the bedding is most perfect; but the reality of aqueous deposition is often satisfactorily shown by mere variation of colour in a mass of rocks, otherwise of continuous and uniform character. Quartz rock (Balachulish) and limestone, (Loch Earn, Inverary) associated with gneiss and mica schist, generally show stratification, but less perfectly than among more recent strata. A full examination of primary tracts will, probably in every instance, satisfy a candid inquirer that the gneiss and mica schist rocks are stratified; but he will certainly notice cases where the bedding of gneiss is lost, the lamination of mica schist unintelligible, and the proofs of aqueous deposition far more obscure than among later rocks. Does this prove a difference of condition in the agencies concerned in accumulating these earliest strata, or can it be explained by considering the original structures of deposition to have undergone partial or entire obliteration through the pervading influence of heat, or local proximity of igneous rocks? for both these causes are known to have produced important effects in this respect.

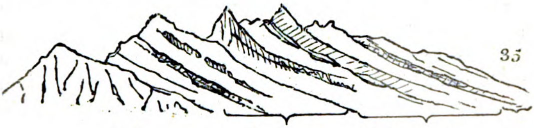
Superposed Structures.—So many circumstances have occurred to change the condition of rocks since their first deposition, that it is probable few or none of them now appear with their original characters of texture, structure, or position. If we represent to ourselves an extended mass of arenaceous, argillaceous, or calcareous sediment, becoming gradually consolidated under the pressure of water, partially dried by the superposition of other strata, and further subject to the influence of molecular aggregation (aided, perhaps, by subterraneous heat), we shall clearly perceive that the induration of the rock must be accompanied by such a degree of shrinking in a horizontal direction, as well as compression vertically, that numerous fissures and cracks must be formed. According to some peculiar circumstances in the different *sorts* of rocks, the cracks and fissures assume *different* appearances in them; there are distinct though not easily defined characters for these divisional planes in arenaceous, argillaceous, and calcareous rocks; and in each of these the fineness, or coarseness of grain, and the thickness of the beds make important difference.

Considering further, that rocks have been, according to difference of age, proximity to the surface of the sea, and other causes, unequally subject to the modifying influences alluded to, we must be prepared to find some characteristic differences of the cracks, joints and fissures, according to the *antiquity* of the strata.

In the rocks of the gneiss and mica schist system, we find these general results perfectly exemplified — the coarse grained gneiss and mica schists show very little of either cracks or fissures across the beds; fine grained examples of these rocks are, however, crossed by many regular divisional planes. The thick beds of crystallised primary limestones (Inverary, Glen Tilt) are less perfectly and regularly jointed than the thin bedded limestones of Loch Earn and the Crinan canal. Argillaceous schists, included among the gneiss or mica schist rocks, are always much more completely or symmetrically fissured than any others of the series, apparently because they are of finer grain. It might appear from these observations that divisional planes were, upon the whole, less common in the oldest systems of strata than in those of more recent date; but it would be a more correct inference, that the rocks are generally not of a nature to admit these structures.

Succession and Thickness of Strata.

In the British islands we have but few opportunities of beholding a complete section of the gneiss and mica schist system; the Scottish Highlands, in fact, must alone be appealed to — and from these, perhaps, the most satisfactory result which can be gathered, is that which is derived from a general view rather than from any one district, like Braemar, Loch Sunart, or Loch Tay.



In the accompanying diagram the two great formations of which the system consists, viz. gneiss and mica schist, are placed in their order of succession above the granite. The gneiss is generally the lowest, thickest, and most extensive: it includes primary limestone (Iona, Assynt), quartz rock (Assynt, Loch Eribol), hornblende schist (Glen Tilt). Estimates of its thickness must be wholly conjectural; but we may believe it to exceed many thousand yards.

Passing to the south-east from the granite of Strontian King's House, or Cairn Gorum, we traverse the gneiss and reach the mica schist, near the base of which (Schihallion, Ben y gloe, Balachulish) quartz rock usually occurs. In different parts of the mica schist, primary limestone occurs in stratified masses, of limited extent and, sometimes, lenticular shape (Balachulish, Killin, Loch Earn, Inverary); and it seems probable these might be employed to subdivide the great mass of mica schist, were it likely to be of any use or interest where no organic remains and few mineral variations are to be recorded. The mica schist rocks are some thousand yards in thickness.

The upper parts of the mica schist (Loch Earn, Loch Lomond) become chloritic, and might, perhaps, deserve to be considered as a separate formation of less extent and thickness than the others.

Organic Life.—In all the enormously thick masses of gneiss and mica schist, and in all the included limestones and quartz rocks, we find few or no traces of organic beings.* To judge from this extraordinary, and, perhaps, complete deficiency, we should say there were neither plants nor animals in existence on the globe at the time of the deposition of these rocks. But, before admitting this conclusion, it is necessary to determine whether any thing that is known of the history of these rocks would justify a suspicion that the traces of organic remains were peculiarly liable to be extinguished in them by heat or any other cause. It is a favourite speculation among a certain class of modern geologists, that the peculiar mineral, and structural characters of gneiss and mica schist are not original, but derived from the influence of heat upon common sandstones and shales—a greater effect of which heat would convert the gneiss to granite; and they suppose that such transformation of the substance of the rocks was accompanied by a complete extinction of the substance and impressions of the imbedded organic fossils.

Were this speculation of the origin and metamorphism of gneiss true to the extent stated, the supposition depending upon it, with regard to the contemporaneous extinction of all traces of organic fossils, would become plausible, perhaps probable; but if the view which we have given of the origin of gneiss, from disintegrated granite, be correct, there is no need of supposing any considerable change of the texture of the rock by heat, and the supposition concerning organic remains is of no authority. Independent of this circumstance, we know, *first*, that the forms of plants, crinoidea, and shells, do remain among limestones rendered completely saccharine by heat (Teesdale); among shales indurated to a great degree (Coley Hill Dyke); among coarse and fine slaty

* The notices of orthoceratites at Loch Eribol, by M'Culloch, and of zoophytic remains, in clay state, associated with gneiss in the Riesengebirge (Von Dechen's Transl. of de la Beche), require further consideration.

rocks (Snowdon), which are also classed among metamorphic rocks: and, *secondly*, as we ascend in the series of strata, organic remains gradually appear (in the clay slate system), and become continually more and more numerous, as the circumstances of the land and sea more approximated to the present. In the actual state of knowledge the most probable conclusion is, that during the deposition of these most ancient rocks the globe was so circumstanced with regard to heat, or some other agency, that organic life, if it had commenced at all, was exhibited at very few points on the surface of the globe. (See Table, p. 80.)

Extent of Country.—Within the British islands, it is to the highlands and western isles of Scotland, and to the mountains in the north-west and south-east of Ireland, that we must look for the great masses of gneiss and mica schist. The Hebrides, with Coll and Iona, and nearly all the north-western highlands from Sutherland to the Sound of Mull, a length of 120 miles, are composed of gneiss: if lines be drawn from the head of Loch Awe to Aberdeen, and to the Moray frith, the greater part of the large included area is filled with gneiss resting irregularly on the granites of Ben Cruachan, Loch Rannoch, Dalwhinnie, Cairn Gorum, Aberdeen, and Peterhead. Mica schist lies along the south-east side of the great valley from Fort Augustus to Lismore, spreading around Ben Nevis; a much larger space is filled by this formation on the south east flank of the gneiss, from Stonehaven by Killicrankie and Dunkeld, to the head of Loch Awe and the mouth of Loch Long; it fills all Cowal, the north side of Loch Fyne, Colonsay, and great part of Cantire, appearing likewise in Arran, Bute, and the south-western sides of Islay and Jura. Quartz rocks occupy large spaces (north-east and south-west) in Islay, Jura, and Scarba — range in a narrow line (north-east and south-west) through Breadalbane by Loch Lyon and Schihallion. From Ben y Gloe to Braemar, and between the Spey and the Doveran to Cullen, is a mass of quartz rocks, ramified among the gneiss and granite. An interrupted line of quartz rocks borders the western side of the gneiss tract from Loch Eribol to the southern parts of Skye. The primary limestones occupy but little surface.

From the Argyleshire highlands the mica schist may be considered as crossing the Channel, south-westward, to Derry and Donegal, where it expands into the large area adjoining the sea, from Lough Foyle to Ballyshannon, and stretches inland nearly to border the basaltic platform of Antrim, being associated with granite, quartz rock, limestone, and old red sandstone. From Donegal Bay to the Bay of Sligo, and from this nearly to the Bay of Galway, mica schist with quartz rocks occupies a great part of the mountainous borders of the Atlantic. The Wicklow granites are bordered by narrow belts of gneiss. Excepting very insignificant traces in Skiddaw, there is hardly any real gneiss or mica schist in England or Wales.

To describe the extent of country occupied by gneiss and mica schist on the continent of Europe, would, perhaps, be impracticable, and certainly, in an English treatise, of little use; the Pyrenees, the Alps, and the great chains of Bohemia and Scandinavia, are full of these rocks, which have much the same characters as in the Grampians and Connemara; rest in the same way on granite (which enters them in veins); are similarly associated with limestone, quartz rocks, and serpentine; and are equally deficient of organic remains. Most of the great mountain chains of the world contain these rocks, and they may be considered as the most nearly universal strata that we are acquainted with.

Physical Geography. — Usually exhibited at high angles of inclination along the axes or flanks of great mountain elevations, gneiss and mica schist, with their associated rocks, derive from this circumstance a grandeur of position which gives full effect to the bold summits, abrupt precipices, deep glens and lakes, which abound in these tracts. The pointed gneiss rocks near Mont Blanc (Aiguilles), — the conical tops of the quartz mountains of Schihallion, — the Paps of Jura,

— the Sugarloaf in Wicklow, — the wildly broken crags of mica schist in the Trosachs, are too familiar to need description; but, picturesque effects of this high order depend on a combination of circumstances; the position and hardness of the rocks — relative depth of valleys and other causes; and large tracts of gneiss in Ross and Sutherland, and of mica schist in Argyle, can by no fancy be transformed into the sublime or beautiful. Yet, even in the dreariest wastes around the heads of the highland glens the hills of gneiss, mica schist or quartz rock, contain elements of form and colour which the artist knows how to value. Monotonous as they sometimes are, the irregularity of their outline prevents formality; the immensity of the mountains fills while it saddens the mind; and if the scarcity of wood gives a wildness to the fairest lakes, the partial herbage, lichens and mosses, cover the hills with tints suitable to the other features of the landscape. It is not prettiness nor gentle beauty, nor antithetic effect of colour or outline, which reward the wanderer among the Grampian Hills; but a deep feeling of the grand and awful harmonies of nature is sure to steal into his mind, and linger there even after he has climbed the snowy Alps or sunny Pyrenees.

Igneous Rocks.—Granite, as was stated before, is found almost universally beneath gneiss and mica schist, — sometimes touching one (gneiss most frequently), sometimes the other. It generally appears to have been in a state of fusion since the deposition of these superincumbent strata, force veins of it are injected into their cracks and fissures. (Examples may be seen in Glen Tilt, in Arran, in Skiddaw, in Wicklow, &c.) Porphyritic dykes divide mica schist under Ben Cruachan, and gneiss in Glen Coe. A mass of porphyry has perforated the granite and mica schist of Ben Nevis. Greenstone and other trap dykes are frequent (Perthshire). Serpentine occurs at Portsoy, in Iona, Lewis, and Zetland, in Connemara, &c. Very long and remarkable trap dykes run east and west through the mica schist and carboniferous limestones of Mayo and Sligo. Mineral veins are not so abundant in these rocks in Scotland, as in Saxony, Bohemia, &c.: it is generally near the granitic masses that they occur at all. The lead mine of Strontian is one of the most remarkable; it may be looked upon as a metalliferous dyke. Neither hot springs nor mineral waters are common in the British tracts of gneiss or mica schist.

General Inference. — The preceding statements are sufficient to allow of our forming an incomplete notion of the origin and formation of the rocks contained in the gneiss and mica schist system. On a first view of the phenomena, granitic rocks of various composition appear to have been disintegrated, the separated minerals, quartz, felspar, mica, &c., agitated in a peculiar manner in water, re-aggregated in laminæ, and partially collected into beds. At intervals in this process there was formed in the water a chemical precipitate, limestone, seldom in extended strata, frequently in limited lenticular masses, implying a merely local agency. There is no proof, nor any very high degree of probability, that organic beings had been created — no proof of the emergence of land; but evidence of watery movements, different from the agitation of currents or the tide.

To connect all these circumstances together, the least unreasonable *speculation* appears to be that the globe had cooled at the surface, so as to allow of the ocean collecting itself over the granitic basis of the strata; that this ocean was warm, agitated by somewhat like ebullition, traversed by certain gases from below, which aided in the general disintegration of the granite and in the partial precipitation of limestone; and that the general surface of the earth was hotter than the limits of temperature within which organic life has been restricted by Providence.

The general condition upon which all this explanation might be made to depend is the *hypothesis* that the earth at the time of the production of this earliest system of strata, retained within, and communicated to the surface, a much larger portion of its original heat than is now experienced.

But to this *speculation*, and indeed to almost all the partial inferences which it is intended to embrace, there is the general objection made, that the present mineral aspect of the gneiss and mica schist does not prove their origin from granite, but their partial re-conversion to that rock; that the absence of organic remains in these ancient strata is a fruit of such re-aggregation of the mass of the rocks; and that thus the whole basis of the reasoning and speculation changes, gneiss and mica schist become types of *metamorphic* rocks, and the monuments of the origin of watery action and organic life on the globe are wholly and irrecoverably lost. It must be confessed, that the doctrine of metamorphism of rocks has well explained the changes near trap dykes, in sandstones, shales, and limestones,—has fully explained the production of crystallised minerals among sedimentary strata (Teesdale, Plas Newydd); but the condition of the grains in mica schist and gneiss is not such, nor is the manner of their aggregation such as to justify a belief that these strata have undergone so complete a metamorphosis as Mr. Lyell's doctrine teaches. They are generally indurated; near granite rocks specially changed: every where they have suffered the influence of pervading heat, but not enough to recrystallise the fragmentary mica, quartz, and felspar, for these are not re-crystallised. Moreover there are cases where organic remains do occur (Dauphiné), among strata of analogous composition though different antiquity. The absence of organic remains in these ancient strata is still a fact to be explained otherwise than by the action of heat. The watery origin of these rocks is a truth; the alterations which they have since undergone are intelligible; and, thus, we appear to be justified in rejecting the doctrine which denies the power of discovering monuments of the commencement of watery action and organic life upon the earth.

Slate System, or Clay-slate and Grauwacke System.

Composition.—The type of this system is upon the whole eminently argillaceous, as that of the older systems is arenaceous: but between these two terms the difference is not always very clear. Some proportion of alumina must, indeed, be present in argillaceous rocks, but it is seldom absent from arenaceous compounds: such a substance as felspar, reduced to fine particles in water, might make a good substitute for clay; if left in a state of granulation it might constitute an arenaceous rock, and be even called sandstone. The former is, perhaps, almost really true with respect to clay slate; for this substance is not very distinct, chemically speaking, from decomposed felspar which has lost or changed the condition of its potash by the operation of water: hence it happens under particular circumstances (which permit the access of alkali and the agency of great heat), that powdered blue slate is actually transformed to white and glassy crystalline grains of felspar. This is one of the results of the yet uncompleted experiments on the effects of long continued heat, instituted by Mr. W. V. Harcourt in Yorkshire.

Clay slate, the simplest form of argillaceous fissile rock, is so uniform in its appearance, fineness of grain, colour, hardness and chemical composition, that mineralogists have often included it in their arrangements as a peculiar mineral species. Imbedded in it we sometimes find certain crystallised minerals, as chiastolite or hornblende (in Skiddaw), cubic pyrites (Dunolly, near Oban, Ingleton, in Yorkshire); its colour is black (Skiddaw), purple (Snowdon), green (Langdale), yellow (Charnwood Forest), mottled (near Ambleside): some varieties (Westmoreland) are translucent at the edges: others (N. Wales) opaque: there are variations of hardness, from the soft perishing slate of Skiddaw to the hard durable rocks of Langdale.

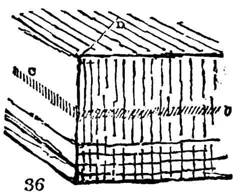
If we imagine the substance of clay slate diffused amongst and around grains of quartz, felspar, mica, bits of jasper or other minerals, and the whole indurated considerably, the general title applicable to the whole series of rocks thus composed is Grauwacke,—which varies in fineness of grain from what emulates clay slate to a conglomerate with quartz pebbles half an inch in diameter. Examples may be found in Ben Ledi,—the Lammermuir,—the Cavan district,—in Snowdon,—and in the Salopian border of Wales. In colour and hardness the grauwacke rocks vary through as great a range as the clay slates.

With these, which compose in every country by far the greater portion of the system of argillaceous slaty rocks, are associated limestones of dark colour, concretionary texture, and laminated structure (Bala, Coniston), and quartzose grits and conglomerates which may with some inconvenience be called grauwacke (Haymond Hill, Shrewsbury).

The fragmentary character of these coarse grauwacke grits is merely an extreme case of the appearance of these rocks, which universally impress upon the beholder a notion of their derivative origin from the waste of older argillaceous and siliceous rocks.

Structures.—Amongst these rocks the evidence of successive deposition is sometimes most clear and decisive, especially amongst the arenaceous and calcareous compounds; in other cases, particularly among the thick masses of uniformly fine grained clay slate, very obscure. Yet, in no case, have our personal investigations among the slates of Wales or Cumbria been unsuccessful in verifying the statements of Sedgwick, and detecting certain though not obvious proofs of consecutive depositions among all the complication introduced by later agencies.

As a general rule it may be stated that *lamination* prevails most in the rocks of finest grain; *beds* are most distinct and continuous among the coarser grauwackes; but the *laminæ* observed in slate rocks are not always, nor indeed frequently, the effect of intermitting subsidence of the particles from water; for, in almost all clay slates, the predominant lamination and fissility arise from a change of molecular arrangement by influences acting since the deposition of the rock. To illustrate this let the subjoined diagrams represent portions of clay slate and grauwacke slate, alike in all respects of structure, except the nature and direction of the lamination, D being in each a plane of stratification. In grauwacke slate (No. 37.) the laminæ of deposition show on all the vertical planes, being all parallel or nearly so to the plane of stratification; in clay slate laminæ of deposition are not seen,



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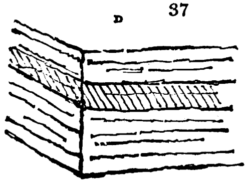

other laminæ, viz. those of cleavage, induced by some process since the deposition of the rock, cross the planes of stratification (seldom at right angles), so that the stone may be split by wedges almost indefinitely into thin plates, nearly in a vertical direction. In some cases, as shown in the lower part of No. 36., the laminæ of deposition remain in clay slate; and instances occur in grauwacke slates where one or more fine grained bands have the cleavage structure, and other coarser bands have not. But the most obvious and constant marks of interrupted deposition from water traceable across cleavage planes are stripes of *colour* different from the mass, or thin *bands* of harder matter, or layers of coarser ingredients. The most perfectly cleavable slate rock, though it be almost a crystal in respect of its regular structure, shows in the quarry indubitable marks of stratified deposition; and where fine grained and coarse grained slate rocks alternate, a very common circumstance about Snowdon, the fact is perfectly obvious.

Cleavage must be viewed as a structure imposed on the rock by agencies subsequent to its accumulation as sediment. What was exactly the nature of these is a problem of some delicacy, which may be better discussed hereafter: in the mean time, the following laws have been established with respect to it. First, it is never so perfectly exhibited as in the ancient argillaceous strata; is most conspicuous among those of finest grain and most uniform nature; disappears in very coarse rocks; ranges in almost exact parallels over many square miles of country; preserves these parallels even across contorted stratification (as Plate IV. fig. 17. 'Guide to Geology,' edit. 3.); and mostly coincides in horizontal direction with the great axes of elevation and depression of strata in the region observed. Finally, imperfect cleavage structures are produced in argillaceous rocks of later date near trap dykes (Coley Hill, Newcastle), and near great granitic irruptions (Vale of Chamouni).

Succession of the Strata.—It is only of late years that the real nature of the proof of the stratification of slate rocks has been sufficiently understood, to permit of its application to particular districts for the purpose of constructing a section of the series of the strata. As yet only two districts in Great Britain can be considered as at all completely investigated, viz. the region of the Cumbrian Lakes, and North Wales; but they are, perhaps, the very best for the purpose that are any where known.

Between Skiddaw and Saddleback the base of the clay slate system is found resting on very thin mica schist and gneiss; and declining to the south-east from an axis of elevation which ranges N. E. and S. W. The dip, judged of by appearance on Derwent Water, in Borrowdale and Grasmere, appears to be considerable, yet not very steep: probably not exceeding, on an average of many miles, 10°.

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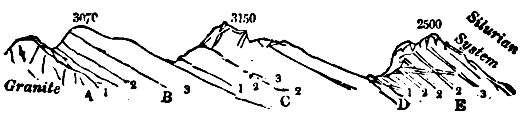


The above diagram represents the whole series of rocks of this system, in their real order of superposition. The following reference will be sufficient to aid the reader's conception.

E. Uppermost system (Hougill, Kentmere), 1000 yards or more.	Great mass of grauwacke (3), above alternations (1 and 2) of grauwacke and grauwacke slate.
D. Slaty limestone (Coniston, Low Wood), 100 feet.	Dark argillaceous limestone, with shells and corals.
C. Middle slaty group (Langdale, Borrowdale), 1000 yards or more.	In the upper part (4) are dark, flaggy, and slaty rocks; the middle (2) abounds with fine green slates; near the bottom (2) most of the rocks are mottled, amygdaloidal, or fragmentary; 1 is a red argillaceous mottled rock, which sometimes appears like a conglomerate.
B. Lowest slaty group (Skiddaw) 1000 yards.	It consists almost wholly of dark, soft, useless slate: toward the lower parts chiastolite abounds in it (2), and near the base hornblende.

A. Of the gneiss and mica schist system is a mere trace, over granite.

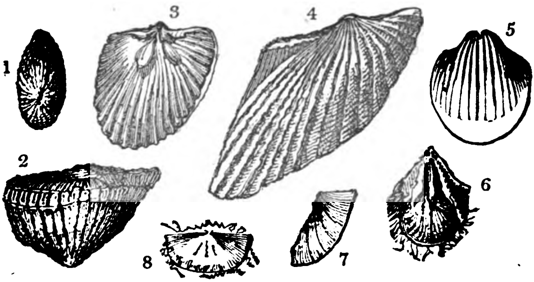
The series in North Wales is considerably similar, but appears less complete in the lower part.— The following is Sedgwick's arrangement.

E. Plynlymmon Rocks, probably several thousand yards thick.	Grauwacke and grauwacke slate, of great thickness, with some beds of conglomerates.
D. Bala limestone.	Dark limestone, associated with slate, yielding shells and corals.
C. Snowdon rocks, probably several thousand yards thick.	Various fine grained purple, blue and green slates, fine and coarse grauwacke and conglomerates, often alternating, mostly possessing slaty cleavage. — Organic remains in particular beds.

Organic Remains.—This is the oldest system of strata in which organic remains are certainly known to occur: they are not found in the lowest group of Skiddaw, but occur to the extent of a dozen species (our own observation) in Snowdon; and, perhaps, twice that number are found in the limestone of Bala and Coniston, and in the slates of Cornwall, supposed to be of nearly the same antiquity as the rocks of Snowdon. It may surprise the speculators in cosmogony to hear that these, the most ancient forms of life known to us, should be, not plants but animals; not merely zoophyta, but conchifera; not the lowest grades of their respective classes, but perfectly developed lamelliferous zoophyta, and brachiopodous mollusca. No gasteropods or cephalopods are, however, as yet mentioned in these rocks in Britain, and we do not feel sufficiently acquainted with the geological age of the limestones of the Harz, to introduce any of the fossils of that argillaceous range of mountains. Whether at the time of the formation of these ancient rocks in the sea, plants were growing on the land (whether, indeed, there were any neighbouring dry land), we must not even conjecture: that plants might be growing in the sea, which nourished the shells and zoophyta of Snowdon, is a probable but not a certain inference; since sea-weeds do not alone constitute the food of conchifera or zoophyta. We found no *satisfactory* trace of plants in the fossiliferous rocks of Snowdon, nor are they common in Cumberland.

We cannot, from the twenty or thirty species of fossils (yet very imperfectly known) which have been obtained from these ancient rocks, learn the conditions under which they lived: but they are of great value as the oldest monuments yet discovered of the creation of living things. The very rarity of their occurrence and the paucity of species confirm the general views advanced as to the cause of the absence of organic fossils from the still older systems of gneiss and mica schist; for these few remains, scattered through as many miles of stratified rocks of different nature, appear to indicate that only at a few exceptional points were the conditions established which allowed of organic life being developed. Limestones, in later strata full of fossils, involved very few in these ancient periods.

No clear or general differences of form distinguish the fossils of Cornwall, Snowdon, and Bala, from those of the Silurian system next above: the same predominance of brachiopoda among the shells, the same comparative abundance of zoophyta, and the same rarity of plants, appear to show that the circumstances affecting organic life differed only by degrees. We may perhaps consistently view the organic beings of the clay slate and Silurian periods, as belonging to one long succession of creative energy, — the first, if our views as to the origin of the gneiss and mica schist be correct, which was established upon the globe.



Fossils from Snowdon, 1836.

Fig. 1. Cyathophyllum.
2. Cyathophyllum apparently the same as one found in the Silurian system.
3. Terebratula distinct from T. prisca, of Schlotheim.
4. Spirifera with knotted ridges.
5. Producta (or Leptæna).
6. Terebratula.
7. Spirifera with fine radiating striæ.
8. Leptæna like L. lata of the Silurian rocks.

Geographical Extent.—In the British islands, fortunately, this valuable system of rocks is extensively developed along the flanks of the great mountain ranges. A narrow band of clay slate and grauwacke accompanies the south-eastern flank of the Grampians, from Stonehaven, by Dunkeld, Comrie, Loch Venacher, Luss on Loch Lomond, the lower end of Loch Long, part of Bute, and the north-eastern part of Arran. Detached portions occur in Aberdeenshire, at Balachulish, about Dalmally, &c.

The Lammermuir hills and the connected ranges from St. Abb's Head to Port Patrick, consist principally of these rocks: a range of similar rocks, in the same direction, extends from Donaghadee to Longford; and, with the exception of the Mourne mountains, occupies the sea-coast to the mouth of the Boyne. East of the granite of Wicklow and Carlow is a large tract of argillaceous slate and associated quartz rocks, from Bray to Waterford, and a much larger tract in the south of Ireland, from Dungarvon to Dingle Bay. Detached masses occur about Dingle and in Tipperary.

The Isle of Man is principally composed of slaty rocks.

Nearly the whole of the lake district of Cumberland, Westmoreland, and Lancashire, is formed of clay slate, and grauwacke. Charnwood forest, considerable parts of Anglesea, an immense crescent stretching from Great Orme's Head, by Ruthin, Welshpool, Rhayader, Llandovery, and St. David's Head, belong to this system, as well as a band on the north of Devon, and, with the exception of igneous rocks, almost all Cornwall and Devon, south of a line from Tintagel, by Launceston to Exeter.

On the continent of Europe, Brittany, the Ardennes, the Harz, parts of Norway; in Africa, the ranges of Atlas; in America, the Alleghanies contain considerable portions of this class of rocks.

Physical Geography.— The slate system, though but a very inferior feature along the Grampian ranges of Scotland, rises to great importance in the south of Ireland, and forms the most elevated points of land in England and Wales. Supported by granite, and mixed with igneous masses, the slaty rocks of the English lakes rise to more than 3000 feet in height (Sca fell is 3160, Skiddaw 3022), and present a variety of outline, and intricacy of combination, which, in connection with clear lakes and considerable waterfalls, leave to Switzerland little superiority, except that beauty and grandeur imparted by their mighty summits of snow, which is perfectly inconceivable to an English tourist, who might shudder by his fireside at the very mention of a wintry view of Helvellyn.

Each of the slate formations of Cumbria has its own characters of scenery: broad swelling forms accompany the Skiddaw rocks; enormous crags and fearful precipices, with broken waterfalls, characterise the middle division, and the upper has, generally, a number of serrated hills of very inferior effect in the scenery. The lakes of the Cumbrian region are often so deep as to preclude wholly the notion of their having been eroded by water. The valleys are, according to Sedgwick, usually accompanied by great dislocations, radiating from the central elevations of the rocks.

The slaty regions of North Wales are superior in the breadth and grandeur of their effects, though not in picturesque beauty, to the districts of the English lakes. Their effective height is greater, from the entrance of many arms of the sea into the midst of the mountains: there is, besides, something deeper and richer in all the colouring, a greater expanse of surface, largeness of feature, and freedom of outline, which reminds us of the best parts of the Grampians; while the valleys, sometimes richly wooded and watered (Festiniog, Dolgelly), and sometimes dreary and solitary (Llanberis, Beddgelert), furnish, even without their wild lakes and rough cascades, every possible variety of pictorial accompaniment.

If we consider how all these circumstances depend upon the general conditions of a forcible elevation of rocks of different qualities into an atmosphere competent to produce upon them unequal chemical effects, and on their disintegrated particles to nourish correlative vital phenomena, we shall see how trifling is the enjoyment of beautiful nature which they experience who are satisfied to gaze on effects with the painter, and seek not their appointed causes with the geologist.

Igneous Rocks are associated with the argillaceous slates in every district where they appear in the British islands. Granites touch the slates (called "killas") in Cornwall, in Cumberland, in Cavan and Arran; serpentine occurs at the Lizard, in Cornwall; porphyry and greenstone are abundant in the Lammermuir, the Cumbrian mountains, and Snowdonia, both in dykes and partially stratified masses. Mineral veins are found no where so abundantly as in the Lead Hills, and in Cornwall, nor there any where so plentifully as near the granites, or other igneous rocks; a circumstance which combines with many other facts to demonstrate the dependence of mineral veins on some peculiar agency of subterranean heat. Quartz, the most frequent matrix or vein stuff of these mineral veins, is very often found ramifying into the fissures and cracks of the slate rocks, without any metallic admixtures.

Judging from personal observation, as well as recorded phenomena, we should say the effects of locally developed igneous agency are much more frequent among the rocks of the slate system, than in those of earlier date, and that dykes, veins, and interspersed beds of porphyry and greenstone, are more abundant and varied. The circumstance observed in Cumbria and North Wales of the porphyry beds being subject to the same flexures and inclinations as the slates, leads to the inference that they were effused as lava sometimes is on the bed of the sea, at intervals during the deposition of the slates; the dykes of course are of later origin, and the same is generally (we think) true of the mineral and quartz veins, but some metallic and quartzose masses are probably contemporaneous with the rocks which enclose them. Circumstances known concerning the arrangement and contents of the veins in slate in the "killas" of Cornwall, induce many of the intelligent mining gentlemen and geologists of that interesting county to deny, generally, any distinction of age between the veins and the rocks. We shall probably examine this subject in a future section.

Besides these local effects of subterranean heat, the whole structure of the slaty rocks appears to be the result of a general pervading heat, operating on the argillaceous sediments so as to overcome their natural horizontal lamination, and induce a new, almost crystalline, fissility in vertical or highly inclined planes, having one constant direction. We may consistently view this remarkable *polarity* of the cleavage as a characteristic effect of some very general agency, directing the results of molecular attraction: it is certain that this directive energy was never displayed in the same general way on the argillaceous rocks of later systems, and that even among the rocks of the slate system itself, the lower ones are almost universally cleavable, the upper ones only partially so, and that chiefly along the line of great disruptions of the strata, as *e. g.* the Craven fault, to whose plane of fracture (E. S. E.) the cleavage planes of the slates are parallel. Indeed, we think there is good reason to adopt, provisionally, the rule stated by Sedgwick—that the strikes of cleavage correspond to the strikes of the strata, though their inclination differs in amount, and even in direction; and this leads almost positively to the inference that the one is dependent on the other. My own observations have led me formerly to adopt the opinion that the divisional planes of slate determined the line of a remarkable elevation of strata (Craven fault *); but the parallelism of cleavage planes across contortions of strata, of which striking examples are given by Sedgwick, in his Memoir on the Structure of Rocks (*Geol. Transact.*), seems to complicate the question. † Numerous observations should therefore be made upon the plan proposed in the Guide to Geology, 3d edition, for the procurement of geometrical data on this curious subject.

Silurian System.

Composition.—The rocks of the Silurian system, as it is exhibited in the country investigated by Mr. Murchison (the whole Welsh border and large tracts in South Wales) may be said to contain types of the usual sedimentary aggregates — argillaceous, arenaceous, calcareous; nor is there any very clear or exact definition by which they can be discriminated in the

* It is curious to observe, along the side of this magnificent fault in Giggleswick Scar (Settle), the mountain limestone crossed by many divisional planes, which cause it to split parallel to the fault, with a kind of rude cleavage.

† A trap dyke in the Penrhyn quarries does not affect the slaty cleavage which it traverses at right angles.

cabinet, as a mass or individually, though in the field they are easily and accurately traceable, for limited ranges of country. Compared with the older systems, the argillaceous rocks, in general less indurated, less complicated by divisional planes, and only locally endowed with cleavage, retain their original lamination: the arenaceous rocks deviate from the character of grauwacke, toward ordinary sandstone and conglomerate; the calcareous rocks are not usually so crystalline as in gneiss, nor of so earthy a substance as many of the later secondary limestones, but have a concretionary subcrystalline texture.

Examined in detail, however, considerable variations appear among the different members of the Silurian system: some of the argillaceous beds are black, others of a liver or grey colour: some arenaceous beds fine-grained, and argillaceous (Ludlow) were aptly named by Mr. Murchison "mudstone": others are like common hard gritstone (in the Caradoc): some appear to be principally composed of volcanic ashes, or the disintegrated particles of trap rocks, and are called "volcanic sandstones" (Malvern hills, the Caradoc, &c.). Some of the limestones (Llandeilo) resemble the flaggy beds of the slate system at Coniston and Bala: others (Aymestry, Wenlock) are purer, more concretionary, and more analogous to the calcareous rocks of the carboniferous system above.

Structure.—In general the accumulation of these rocks appears to have been regular and tranquil; the whole series of argillaceous and most of the arenaceous rocks are full of laminæ of deposition: beds are very distinct in the sandstones: the limestones are also regularly stratified, though nodular and uneven on their surfaces, and sometimes partially lenticular or included among shales, like other calcareous rocks supposed to have originated as coral reefs. According to what we have found to be a general law, that divisional planes abound and are regular in proportion to the regularity of the laminæ of deposition, the argillaceous beds of this system are seen to be very exactly divided by joints and fissures, some of which seem frequently to coincide with the axis of elevation of the country (in Wales this is frequently N. E.), and others to be rectangulated thereto. In this respect, however, variations occur, so that Mr. Murchison has often found two sets of joints, both forming oblique angles with the strike of the strata. In the Wren's Nest at Dudley the long joints *in the limestone,* observed with care, July, 1837, appeared to me to be nearly parallel to the axis of elevation, which is N. and S., or, on the east side of the hill, N. 10° E. The *joints* in other directions were few and irregular; and though *cracks* were not unfrequent in the thinner layers of "Baven" (argillo-calcareous and fossiliferous), the most general direction of the long *joints* in this also was N. 10° E. The planes of these joints are not always even nearly rectangled to the stratification—they are sometimes waving in their outline, and present other circumstances of interest, particularly *striations* and associated strings of calcareous spar. The *faults* in this hill obey the law of displacement, which is given in the '*Geology of Yorkshire,*' and illustrated p. 40. *sup.*

The planes of the joints and fissures are stated by Mr. Murchison to be nearly rectangled to the planes of the strata.* In the country near Llandovery the lower Silurian rocks are metamorphic slates; the slaty cleavage, induced since their aggregation, predominating over the yet traceable surfaces of deposition. This is sometimes expressed by the convenient though somewhat unlearned word, "slatified."

The nodular uneven surface of the limestones of this system is so remarkable, as to be of great importance in reasoning on the circumstances concerned in their production. It is extremely difficult to resist the notion that in many instances the limestone has been collected by molecular attraction from a mingled mass of argil-

* See Guide to Geology, 3d edit., for an example of joints reduced by calculation to the plane of stratification, from observations made with Mr. Murchison on the ridge of Corn y Vaen, near Brecon.

laceous and calcareous sediment, round corals, and other organic marine exuviæ. The great abundance of corals in these rocks (Aymestry, Dudley, Wenlock, &c.) leads further to the supposition of their being really formed, like a coral reef, in the present seas. If this were correct, the whole of the substance of the rock must be supposed to have been abstracted from sea-water, by that vital action which dissolves the strongest chemical aggregations, and fixes the unwilling elements in new combinations. The perfectly laminated or bedded structure of the rock requires, further, the admission that the materials were arranged in obedience to the fluctuations of water: this, which implies the removal and partial drifting of the corals and shells, is strongly confirmed by the worn and rounded forms of some corals (Aymestry), the unattached condition of almost all (Dudley), the broken and crushed condition of many. If, therefore, we must compare the origin of the Wenlock and Aymestry limestones to that of a modern coral island or group of islands, the Bermuda group, where vital action furnishes the substance, and oceanic currents determine the form and arrangement, offers us the best analogies. The coral islands of the South Seas are in this respect very dissimilar.

Succession and Thickness of Strata.

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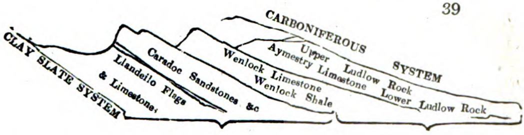


The best, or rather the only, complete series yet known of these rocks is that of the Welsh border, of which the above section is a sketch: below is Mr. Murchison's summary.

		Thickness.	Subdivisions.	Lithological Characters.
Upper Silurians.	Ludlow Formation.	2000	Upper Ludlow rock.	Slightly micaceous, gray coloured, thin-bedded sandstone.
			Aymestry limestone.	Subcrystalline gray or blue argillaceous limestone.
			Lower Ludlow rock.	Sandy, liver and dark-coloured shale and flag, with concretions of earthy limestone.
	Wenlock Formation.	1800	Wenlock limestone.	Highly concretionary subcrystalline gray and blue limestone.
			Wenlock shale.	Argillaceous shale, liver and dark gray coloured, rarely micaceous, with nodules of earthy limestone.
Lower Silurians.	Caradoc Formation.	2500	Flags.	Thin-bedded, impure, shelly limestone, and finely laminated, slightly micaceous, greenish sandstone.
			Sandstones, grits, and limestones.	Thick-bedded, red, purple, green, and white freestones; conglomeritic quartzose grits, sandy and gritty limestones.
	Llandeilo Formation.	1200		Dark-coloured flags, mostly calcareous, with some sandstone and schist.

On a careful examination of the vicinity of Ludlow, all the upper parts of the Silurian rocks may be perfectly traced and clearly discriminated: it is in the vale of the Towey (Dinevawr) that the lower formation is best exhibited. If we were to introduce among these rocks the same principles of classification as those adopted among the secondary strata, perhaps it might appear doubtful how far the Silurian rocks really deserve to be classed as a "system" in the sense in which this term is now generally employed. The characters of the whole series graduate from one group to another so completely, and there is so great and real an analogy between the Llandeilo, Caradoc, Wenlock, and Ludlow formations, as to permit our viewing them all as one varied series of deposits effected by one general system of mechanical, chemical, and vital agencies. The succession of the deposits is very simple. The length of geological time which elapsed in their production, if judged of by the merely mineral character of the masses, does not require to be thought greater than that which must be assigned to such a varied formation as the lias; nor does the inference that might be drawn from this comparison fail with respect to the organic remains: for the different mineral groups of the lias formation are quite as well distinguished *locally* by their different suites of fossils as are the successive formations of the Silurian system.

Organic Remains. — In accordance with the view of the gradual introduction of organic life on the changing globe, which was stated while discussing the history of the slate system, we find in these newer rocks a far greater abundance of forms, a far greater predominance of numbers, among the lower orders of animals, but yet few plants. From the Silurian system in England and Wales, the Eifel, Norway, the Harz, and N. America, several hundreds of organic fossils have been collected, and partially or completely described, by Goldfuess, Münster, Dalman, Green, Brongniart, Sowerby, Murchison, and others. In 1831 tables were drawn up to the extent of 553 species (*Encyc. Metrop.*). The following summary of those tables is all that can here be introduced:—

Plants, 14 species, viz.:		
Algæ	4	The algæ are chiefly from Christiania, the others mostly from the anthracitic deposits of Baden. It is important to ascertain, exactly true geological place of the latter since the similar culm series of Devon, usually ranked as grauwacke, is thought by Murchison and Sedgwick to belong to the carboniferous system.
Equiestaceæ	2	
Filices	5	
Lycopodiaceæ	2	
Asterophyllites	1	

Should this suggestion prove correct, a considerable anomaly will be removed from Geology, for all the genera found on the Rhine occur more plentifully in the carboniferous system, and are not known elsewhere in the

Silurian rocks. Several of the species are also identical (Sphœnopteris dissecta, Pecopteris aspera) with plants of the carboniferous deposit of St. George Chatellaison and Montrelais. The plants found in the culm series of Devon appear identical with those of the ordinary coal measures.

Polyparia, 87 species, viz.	These are all, or nearly all, distinct from the corals of the carboniferous system.
Fibrosa - - 7	
Corticifera - 2	
Cellulifera - 44	
Lamellifera - 34	

Crinoidea, 34 species, which are mostly distinct from those of later date.

Conchifera, 206 species, viz.	Mostly (or all ?) distinct from the shells of the carboniferous rocks. The Plymouth and South Devon shells, supposed to be identical with species of mountain limestone, are in general, excepting, perhaps, some from Newton Bushel, quite distinct, as I learn from a sight of Mr. Hennah's and other specimens.
Plagimyona - 55	
Mesomyona - 23	
Brachiopoda - 128	
Gasteropoda, 64 species, viz.	
Holostomata - 58	
Solenostomata 6	
Cephalopoda, 79 species, viz.	
Monothalamia 11	
Polythalamia - 68	

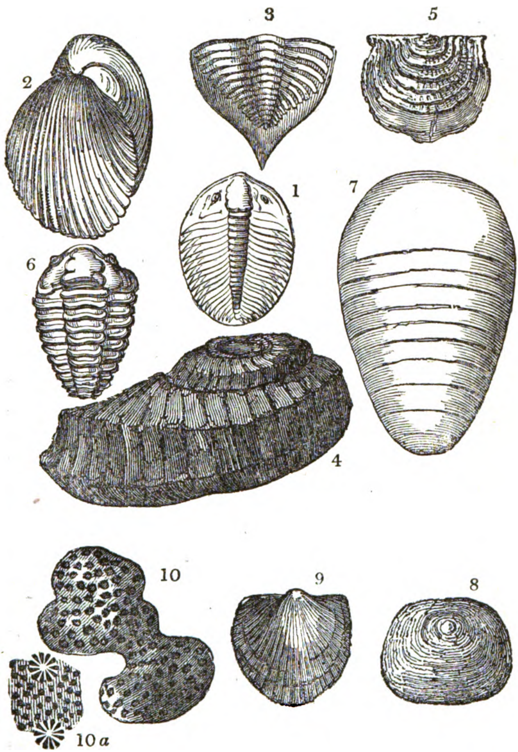
Annulosa, 4.

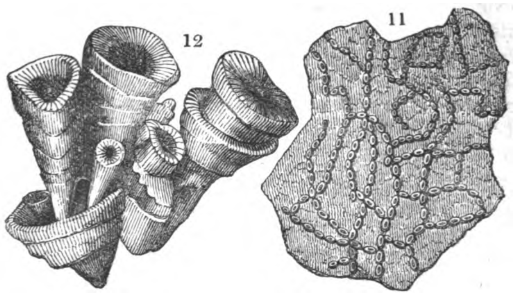
Crustacea, 65, mostly distinct from those of the carboniferous system even generically.

Fishes.—A bed of fragments of fish-bones and teeth occurs in the Ludlow formation.

The distinctness of the organic fossils of the Silurian rocks from those of the carboniferous formation, as far as regards the marine races, is an important truth which has received further and exact confirmation from Mr. Murchison's researches. To what extent the few fossils of the slate system are analogous to the Silurian reliquiæ is not accurately known; but there appears a sufficient resemblance between them to justify a belief that the physical conditions of the ocean were not greatly changed, though evidently rendered more favourable to the development of a varied system of organic life. Mr. Murchison believes that each of the four formations of the Silurian system contains distinct suites and characteristic species of fossils. The following are among the most common or remarkable: —

Homonolotus Knightii, *fig.* 1. Leptæna lata. Pentamerus Knightii, *fig.* 2. Terebratula Wilsoni. Terebratula risca, *fig.* 9. Asaphus caudatus, *fig.* 3. Euomphalus rugosus ε discors, *fig.* 4. Producta depressa, *fig.* 5. Calymene Blumenbachii, *fig.* 6. Orthoceras annulatum. Orthis callactis. Lingula Lewisii. Orbicula rugata, *fig.* 8. Phragmoceras. Cardiola. Asaphus Buchii, *fig.* 7. Actinocrinus moniliformis. Cyathocrinus rugosus. Rhodocrinus verus. Calamopora polymorpha. Favosites gothlandica. Catenipora labyrinthica, *fig.* 11. Retepora. Heliopora porosa, *fig.* 10. Cyathophyllum cyathus, *fig.* 12. Fucoides serra.





Geographical Extent.—Ranging on each side of the Vale of Clwydd, the Silurian system continues by Llangollen, widening southwards to the valley of the Severn, which runs in it from Newton to the plain of Shrewsbury: it borders on the south the coal fields near Shrewsbury, and the Longmont and Stiperstones hills (of older rocks), and enters between these hills and the Clee hills in a long tongue directed N. E. to the Severn at Buildwas. This strike of the Silurian rocks, prolonged in the other direction to the S. W., passes by Knighton and Builth to Llandovery, Llangadock, and Llandeilo: it hence turns in the vale of Towy in a narrow course nearly west to Caermarthen, and with the same range passes Haverfordwest to St. Bride's Bay. From this central line the system expands on the south-east to Ludlow, Aymestry, and Knighton; and this straight south-eastern border extends parallel to the range from Builth to Llandovery, into a curious narrow tongue or broken anticlinal ridge, which crosses the Wye between Builth and Hay, and ranges towards Trecastle. (From Mr. Murchison's Observations.)

In Devon and part of Cornwall the Silurian system is with difficulty separable from the grauwacke and culmiferous rocks of Plymouth and Barnstaple, &c. About Dudley and Walsall the Ludlow formation is admirably exhibited in singular narrow and short anticlinal ridges, rising in the midst of the coal formation of South Staffordshire, near the hills of basalt called Rowley Rag. These anticlinal ridges run north and south, in parallel courses (Sedgley, Hurst Hill, the Wren's Nest, and Dudley Castle Hill make four such ridges, the two latter being extremely clear), and against them all the coal strata rest at considerable angles of inclination. The diagrams *fig.* 40. and *fig.* 41. are intended to illustrate the curious structure of this region.

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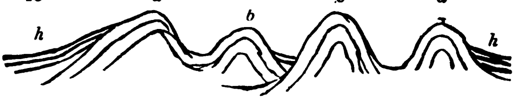

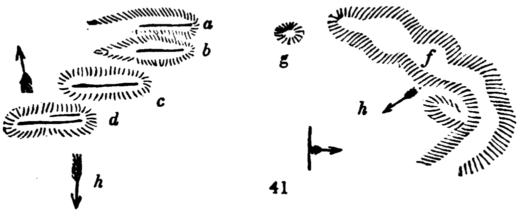

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a. Sedgley ridge, or anticlinal, containing the Aymestry limestone.
b. Hurst ridge.
c. Wren's Nest, Wenlock limestone.
d. Dudley Castle ridge, Wenlock limestone.
e. The Hayes, upper Ludlow formation.
f. Rowley hills of basalt.
g. Barrow hill of basalt.
h. Coal deposit, resting somewhat unconformedly on the Wenlock formation, and partly resting on, partly passing under, the Rowley basalt which chars it.

In Westmoreland and Yorkshire the upper Ludlow formation occurs near Kirkby Lonsdale, yielding fossils, and what I have supposed to represent the Llandeilo rocks in Ribblesdale; but from a recent examination of the Ludlow rocks, in company with Mr. Lewis of Aymestry, whose judgment in the matter is very important, I think it not improbable they are the equivalent of the lower Ludlow rocks.

In the south of Ireland the Silurian system occurs;

but we cannot particularise the formations: in M. de Bonnard's description of the Harz limestones, we seem to behold the Silurian rocks: the Eifel limestone is exactly equivalent to the Wenlock formation: in Brittany Silurian fossils occur: the Christianian limestones certainly belong to this system. It is said by Mr. Strickland to occur about Smyrna with asaphi. Perhaps it is from these rocks that trilobites are obtained near the Cape of Good Hope, by Sir J. Herschel. In North America the borders of the great lakes (Huron, Superior, &c.) show limestones of the Silurian system.

Physical Geography.—Lying on the sloping sides of the slate systems of Wales, the principal masses of the Silurian rocks show but little boldness of feature, compared to these older rocks: frequently, as in the beautiful neighbourhood of Ludlow and Aymestry, and in the Vale of the Towy, they are richly covered with woods, as ancient, perhaps, as Caractacus. The Devonian portions of the Silurians do not, we believe, offer any very remarkable characters of scenery: the limestones about Torquay and Plymouth are romantically broken; the limestone country about Dudley is pleasingly varied.

Igneous Rocks.—These are abundantly exhibited in irruptive axes and points throughout the Silurian formations. Lilleshall Hill, the Wrekin, and other points about it, consist of compact felspar, ranging N. E. and S. W., and they convert sandstones into quartz rock. Caer Caradoc, the Lickey, Helmeath, &c. constitute a similar and parallel group of hills, in which greenstone, actynolitic, trap, &c. occur: similar changes happen to the sandstones which touch the trap: the argillaceous rocks are indurated and much altered. The Breiddin group of hills consists of porphyries, compact felspar, greenstone, &c.; and near these the strata of the Silurian system are indurated and fissured. The same range (N. E. to S. W.) is noticed in the trap rocks near Old Radnor, Builth, and Baxter's Bank, near Llandrindod. Hypersthene abounds in traps near Old Radnor, and great changes happen to the Ludlow and Wenlock rocks near them: limestone becomes crystallised; shale is indurated; anthracite, copper ore, iron pyrites, and bad serpentine, are generated at the contact. The large trap district of Llandegley, Llandrindod, and Builth, present a variety of such phenomena, and the mineral springs of Builth, Llandrindod, &c., are supposed to be residual effects of the same igneous agency. In Brecknockshire and Caermarthenshire, similar phenomena are repeated around several erupted masses of trap.

The Malvern and Abberley Hills consist chiefly of sienitic rocks, which have burst up among the Silurian strata, and partially thrown them into retroverted positions. The grauwacke rocks are much altered (so as to assume the aspect of chloritic and micaceous schists) by the trap which is protruded among them.

Mineral Veins.—In the Shelve district of Shropshire, and at Nanty Moen, seven miles north of Llandovery, the lead mines are so related to the axis of irruption of the igneous rocks, as to leave no doubt of the propriety of classing them as an effect of the same volcanic excitement, not perhaps contemporaneous with the irruption of trap, but certainly and strictly associated with it, and dependent upon it. Sulphate of barytes, sulphuret of iron and carbonate of lime, accompany the ores of lead.*

Close of the Primary Period. — *Ensuing Disturbances of the Crust of the Globe.*

There is almost a total absence of proof, in the mineral composition and organic contents of the primary strata, of the contemporaneous existence of dry land: for all the early periods at least, the absence of land plants, and the non-occurrence of conglomerates, seem to justify a doubt whether the sea of that period was subject, in the regions now dried, to any thing of the nature of land flood, or littoral agitation. In the slate and Silurian systems the marks of agitation in the sea become

* Murchison, Proc. of Geol. Soc. 1834.

more distinct; and from the land plants referred by Brongniart to the grauwacke rocks of the Rhine, with those which really belong to them in North Devon, the proof of upraised land is conclusive, though we know not where it was situated.

There is no sufficient evidence to be gathered on the question, whether such uprising might be sudden or gradual; the general conformity of the whole series of rocks of the Cambrian and Silurian systems would not justify an inference that no violent elevation of land had happened elsewhere; especially as some unconformity is supposed to have been observed by Mr. Murchison, between the Plynlymmon and Silurian rocks, south of Shrewsbury. There is, however, nothing to contradict the assumption that, till the close of the primary period, nearly all the strata of the British Isles and the continent of Europe, were covered by the sea in which they were formed: indeed, it may be doubted, whether any certain proof can be shown that any part of the European region was subjected to great displacement during the primary period.

It is true that a survey of the porphyries, greenstones, and other igneous rocks, so strangely interlaminated among the clay slates and grauwacke slates of Snowdon, and the middle Cumbrian region, from Black Comb to Ulswater, appears to prove that at certain periods during the formation of these rocks, eruptions of melted rock occurred over a great extent of the oceanic bed; and such we must suppose were accompanied by considerable, if only transient, movements of the solid crust of the globe. Elie de Beaumont has supposed that some of the most considerable displacements of primary strata which are observed in Europe, happened before the completion of the newest of those strata; but it cannot be satisfactorily proved by examples taken from the British Islands. Indeed, every fresh inquiry into the geological dates of particular disturbances of the strata, shows the difficulty of arriving at accurate conclusions on this important subject.

The evidence is sometimes insufficient; in other instances, complicated with the effects of convulsions of later date, but similar geographical positions; and however strange it may appear, it is nevertheless true, that the strongest arguments in favour of the convulsions having occurred within particular limits of geological time, have been based on comprehensive views of a whole physical region, rather than on a minute scrutiny and complete survey of the details of the position of the strata, at the line of junction of the displaced and the undisturbed rocks.

After the lapse of most part of the primary and before the commencement of the secondary period (whatever the interval of time was), great disturbances happened, which uplifted large parts of the bed of the sea, and either raised them above the surface into dry land, or, at least, placed them in such situations that no further deposit of strata was spread upon them at later periods. In many instances the primary and secondary strata are unconformedly situated with respect to one another, as in the subjoined section (*fig.* 42).

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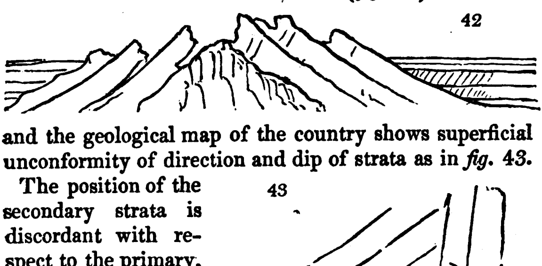
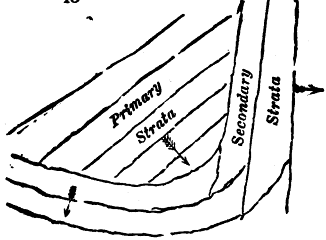


and the geological map of the country shows superficial unconformity of direction and dip of strata as in *fig.* 43.

43



The position of the secondary strata is discordant with respect to the primary, both in dip and direction; because these latter were disturbed from their original position by subterranean forces, and the bed of the sea upon which the secondary rocks were subsequently spread, entirely altered in form. The unconformity, above exemplified, is the geological proof that the older strata had been disturbed previously to the formation of the newer; and the reason for thinking they had been in many cases actually raised into dry land, is the total absence of any later deposit upon them: the former is a most certain conclusion; the latter is frequently a highly probable inference.

In the British islands we have magnificent examples of these ancient disturbances. The range of the Grampian mountains from Aberdeen to Cantire, and indeed most of the Highlands, appear to have been uplifted at this early period, if not to the surface, yet so as to prevent any depositions upon them; though round the east and west coasts of Scotland, the south border of the Grampians, and in the great valley of the Caledonian canal, the old red sandstone rocks abound. It is supposed that about the same period the Lammermuir hills were raised; and the Cumbrian mountains received one of their great upward movements. It is important to remark in connection with this subject, that along the borders of the Grampian, Lammermuir and Cumbrian ranges, the red conglomerates contain enormous quantities of pebbles, which appear to have been gathered by inundations from the surface of the broken rocks of the neighbouring slates, gneiss, &c.: if in addition we remark the fact that, especially in Cumbria, these conglomerates fill *valleys* at the border of the tract of the slate mountains, we shall see the probability that the slate rocks were raised above the surface to be washed by atmospheric rains, or else so near the surface as to be exposed to the agitation of shallow water. — The former is the most probable view. The slate and mica schist tracts of the Isle of Man, Donegal, Galway, Cork, Wexford, Wicklow, Cavan, and Down, appear to have been similarly raised; and the same is supposed to be true for the Snowdon and Berwyn ranges in North Wales, and the Ocrynian chain of Devon and Cornwall.* We

* Sedgwick, in Address and Memoirs to the Geological Society.

must, however, remark on these last-mentioned cases that, on the south-east border of Wales certainly, and in Devonshire probably, there is no observable unconformity between the old red and the Silurian rocks, and hardly any between these and the Plynlymmon series.

Were the displacements thus shown to have happened in the bed of the sea over so large a portion of the British islands, sudden or gradual? To decide whether violent uplifting, or a gentle intumescence of the rocks, lifted the Grampians or the Cumbrian mountains, would be difficult in the present state of our knowledge; yet there are considerations which would render it probable that a considerable time elapsed in the process. Amongst others, this appears worthy of notice: the secondary strata, around these and other tracts, dip at high angles from the centre or axis of the older rocks, the most modern rocks occupying the lowest ranges; and thus appear to teach us that the elevatory action, whatever might be its first violence, was continually exerted in the same localities, late into the secondary period.

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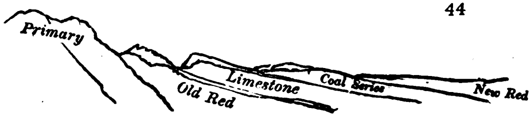


The surface of the earth has, however, undergone since so many changes, that it is difficult to say how far this argument can be safely trusted. Another highly interesting problem arises out of the admission that all the displacements of rocks, previously noticed, were nearly contemporaneous: they are found to be all raised on axes nearly parallel to a line from S. W. to N. E.; and it is required to be determined whether this proximate parallelism of contemporaneous axes of elevation is a general law of the phenomena. M. E. de Beaumont is the geologist who has most strenuously advocated the affirmative of this question; but it is certain that more rigorous investigations are needed on the subject, before any physical theory, like Mr. Hopkins's ingenious view, can be safely applied to the data. It is extremely difficult to assure ourselves that the elevations above noticed, as on parallel axes, were really contemporaneous, or even very quickly succeeding, because nothing can be more complete than our ignorance of the duration of past geological periods; and, in order to render the explanation of such parallelism consistent with Mr. Hopkins's demonstrations, the occurrence of parallel elevation must be really synchronous.

The elevations on the continent of Europe of or about this ancient period (anterior to the formation of the carboniferous rocks) are located in Brittany, the Harz, the Hundsrück, the Eifel, the Ardennes.

Whence came the materials of the great mass of deposits which rest upon the primary gneiss and mica schist?

Probably the true answer to this, though we cannot now give adequate proof of it, is that the disintegration of granitic and other igneous rocks, to which, on what seem good grounds, we have already ascribed the origin of gneiss and mica schist, has been the prolific source of all these sedimentary strata. Analysis of the principal rocks of the slaty systems does certainly not contradict this view; which neither those who admit with Leibnitz the first solid covering of the globe to have been a mass of rocks cooled from fusion, or, with Lyell, that strata added above, are melted and reabsorbed into granite below, have any reason to deny.

Moreover, we see daily, on the slopes and at the foot of hills composed of trap rocks, considerable quantities of loosely aggregated sands, which to all appearance, if agitated in water, might be undistinguishable from various secondary or Silurian sandstones. The abundant detritus which surround the basaltic hills of Rowley, the sienites of Mount Sorrel, and the granites of Arran, are in this respect very worthy of attention, and may suggest to those who have the opportunity a train of valuable research, which might elucidate many points now obscure in the history of the disentegrated materials of igneous rocks.

SECONDARY SYSTEMS OF STRATA.

Carboniferous System.

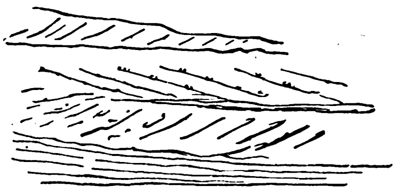
Composition. — Six substances are interstratified in this system: arenaceous, argillaceous, and calcareous rocks form the principal masses, and are associated with beds of chert, ironstone, and coal. Some of the arenaceous rocks are conglomerates, as millstone grit, which is partially filled with quartz, felspar, and fragments of shale, and old red conglomerate, which is full of rock fragments; others are freestones of an open grain and equal texture, breaking equally in all directions; others are compact close grits, called hazle; or still finer grained, called calliard; or laminated with mica, or carbonaceous matter, as flagstone. In colour these rocks are white, brown, grey, greenish, yellow, or red. There is almost every possible gradation between the sandstones and argillaceous deposits; which latter are frequently much laminated, and are then called plate, or bass; less remarkable lamination causes shale; deficiency of lamination belongs to some varieties, associated with coal, called clunch, bind, and other local names: most of them are more or less bituminous; colour blackish, greyish, bluish, yellowish. The limestones are compact or oolitic, or granularly crystallised; mostly pure carbonate of lime (except the granular sorts, which usually contain magnesia), white (rarely yellowish), grey, blue, black, red, or mottled. Some beds contain quartz pebbles. Nearly all are of marine origin, but some exceptions occur.

Chert nodules and beds, of white, black, yellow, or red colour, lie in the limestone, like lumps and layers of flint in chalk; and require similar suppositions to explain their occurrence. Some considerable beds of chert occur in the north of England (Swaledale), and many sandstones are of a cherty nature (Harrowgate).

Ironstone (a carbonate of iron) often accompanies the thick dark plates and shales, in rows or layers of nodules (see *Diag.* No. 21. p. 61.), aggregated round shells (unio), fern branches, &c. Coal lies always in beds. Its quality varies from nearly pure carbon to a consumable mixture of carbon, hydrogen, oxygen, and azote; and it is often mixed with layers of woody fibre, like charcoal, and laminæ of earthy matter.

Structure.—Throughout all this mass of varied deposits in the carboniferous system, the most decided proofs of aqueous deposits constantly present themselves. *Lamination* belongs, but not equally, to every one of the six constituent members; being often conspicuous in sandstones (flagstones), almost always so in argillaceous rocks and coal; frequent in black limestones, but rare in ironstone. Real beds occur in all these rocks; but in the argillaceous plates and shales they are often indiscernible; in sandstones they are commonly irregular; thick-bedded limestones have nodular or uneven surfaces.

The coarse sandstones (as millstone grit) frequently present oblique lamination, which, added to the irregu-



larity of the beds, renders it often embarrassing to say what is the true dip of such rocks. (*Diag.* No. 45.)

The divisional structures or cracks, joints, and fissures, vary much in relation to the nature of the rock — its fineness or coarseness of grain, the thickness or thinness of its beds, and the position of the point with regard to axes of elevation and perhaps other causes.

In the accompanying diagram, L may represent limestone, P plate, G gritstone. The joints in L are generally rectangular to the bed (in thin-bedded limestones L′, the joints are more numerous.)

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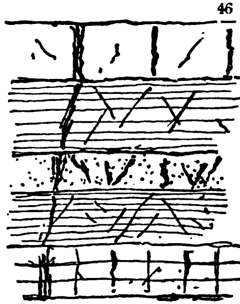

In plate they are often oblique to the bed; in gritstone less regularly formed, being mostly cracks: this is especially the case where the beds are thick. The principal fissures F, which sometimes go through many beds, are most open and regular in the limestone.

Coal has sometimes joints of the same kind, (called 'ends' or 'backs,') and, in addition, a minute fissility, generally in one certain direction across the bed, which does not occur in the shales above or below. It is a sort of crystallisation. Ironstone sometimes shows concentric laminæ, and often sparry divisions, when it becomes a septarium.

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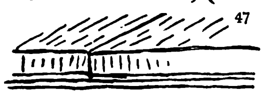

A very singular structure is frequently noticed in the argillaceous iron ores of a coal district, without however

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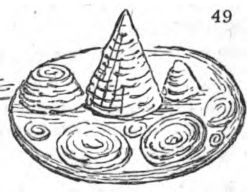


being peculiar to them, which is represented in *fig.* 49. The substance of the iron ore is formed into conical sheaths, involving one another, and marked by concentric undulations and radiating striæ. Large spheroidal masses of iron ore, weighing at least a ton, are thus found, in connection with the coal, at Ingleton, in Yorkshire; and in the coal fields of Staffordshire and South Wales, it is a well known form of aggregation. This structure also occurs in many other formations, as in the slate of Skiddaw, the lias, oolites, &c., though with considerable variations. It is usually called 'cone in cone,' 'cone coralloid,' conical limestone, conical ironstone, &c.

A different but yet closely allied phenomenon, noticed by Mr. Dillwyn in the substance of the coal of Swansea and other parts of South Wales, which we have also seen at Ingleton, is represented in *fig.* 48. Such a mass of coal, however solid, is found to separate not along a plane, parallel to the bed, but with deep hollows, and acute sinuous ridges, situated on their slopes, and undulated on their edges. The striations on the slopes are very similar to those on the conical ironstone; and though the differences are in other respects great, they both probably depend on some general law of concretionary action, modified in operation by the nature of the substances acted on: but we are quite ignorant of the circumstances which determine this peculiar structure in coal.

Succession and Thickness of Strata.

Considered in its greatest generality, and with reference to countries where the masses appear in the greatest simplicity (as in the south of England), the carboniferous system consists of three formations: viz.—

Coal formation.—A mass, 1000 yards or more in thickness, consisting of indefinite alternations of shales and sandstones of different kinds, with about 50 feet of coal in many beds, some ironstone layers, and (very rarely) thin layers of limestone.

Mountain limestone.—A mass of calcareous rocks, with very few partings of argillaceous matter,—almost no grits,—no coal,—some chert nodules,—and occasionally layers of red oxide of iron—500 to 1500 feet in thickness.

Old red sandstone.—A mass of arenaceous and argillaceous rocks, — the former containing conglomerates of extreme or moderate coarseness, and sandstones of many kinds: among the argillaceous beds are concretionary limestones, irregularly developed. Colour mostly red, or grey liable to become red. Thickness variable, from 100 to 10,000 feet.

This triple system becomes modified in the north of England, so as to constitute, in Derbyshire, a quadruple system, without any red sandstone, thus:—

Coal formation.

Millstone grit group.—A series of very pebbly quartzose and felspaothic gritstones, with other sandstones and shales, and some thin bad coal, several hundred feet.

Limestone shale.—A nearly uniform series of laminated shales or plates, mostly bituminous, with some ironstone and thin black limestones, but no coal — 1000 feet or more.

Mountain limestone formation.

(Old red sandstone almost wholly absent.)

Slight representatives of millstone grit and limestone shale may be seen at the gorge of the Avon, at Bristol, round the South Wales coal field, base of the Clee hills, &c.

Further north, viz. in the north-western parts of Yorkshire, the series is still more complicated and varied: as under:—

1. Coal formation.
2. Millstone grit.—A series of three mostly pebbly gritstones, separated by shales and several other flaggy, calliard and freestone grits; cherts; thin limestones; iron-stones; and several coal seams.— 1000 feet.
3. Yoredale rocks (equivalent of the lower part of limestone shale), a series of five or more limestones, with many freestones, flagstones, abundance of plates, some ironstone, chert, and several coal seams. —1000 feet.
4. Scar limestone, divided by partitions of grits and shales, and even some beds of coal — 800 feet.
5. Alternations of red sandstone, red clays, and limestone. 800 feet.
6. Red sandstone and conglomerate, very limited in their range; thickness variable. — 100 feet and upwards.

Pursuing the system to Northumberland, we find the scar limestone broken up into very many parts by interpositions of grits, shale, and abundance of coal; one of the grits being pebbly. Thus the whole *method of variation* of the system of carboniferous strata becomes known, and appears nearly as in the diagram (*fig.* 18. p. 59.).

We may here notice the remarkable section presented in the Island of Arran, where according to Murchison and Sedgwick, the new and old red formations are merely separated by a thin zone of limestone and coal, or, as from a careful examination we should be disposed to express it, where only small and diminished members of the mountain limestone formation (in one place yielding coal) appear buried in masses of red conglomerate, sandstone and shale, of very great thickness, there being no certain criterion for deciding that any of this series belongs to the new red sandstone. This section is, however, much in accordance with the views of Hoffman, who, in north-western Germany, finds the carboniferous limestone and coal buried in a great body of red sandstones; the lower ones being attributed to old red, the upper ones to new red.

The total thickness of coal existing in the English and Scottish coal fields, is generally about 50 or 60 feet: this is, in most districts, divided into 20 or more beds, of a thickness from 6 feet to a few inches, alternating with from 20 to 50 or 100 times as great a quantity of sandstones and shales. But in some districts (Cumnock in Ayrshire, Dudley and Bilston in Staffordshire) many beds of coal, deposited one upon another with but little intervening earthy matter, constitute one mass 30 or 40 feet in thickness, in which the different beds are easily traced, and possess different qualities, probably depending on the original differences of the component vegetables, and the manner of their accumulation.

In the Newcastle coal district, the coal beds are arranged in the following order by Mr. Westgarth Forster: —

	Yds.	Ft.	In.	Yds.	Ft.	In.
Brown post, or grindstone sill -	24	0	0			
Coal - - -				0	0	6
Rock measures - -	10	0	0			
Coal - - - -				0	0	8
Rock measures - - -	22	0	0			
Coal - - -				0	0	6
Rock measures - -	15	2	6			
Coal - - - -				0	1	0
Rock measures - -	11	1	0			
Coal - - - -				0	0	6
Rock measures -	7	1	0			
Coal - - -				0	0	8
Rock measures - - -	6	1	0			
Coal - - -				0	0	8
Rock measures - -	19	1	0			
Coal - -				0	1	0
Rock measures - - -	16	0	0			
Coal (High Main) - -				2	0	0
Rock measures - - -	11	0	0			
Coal (Metal Coal) - -				0	1	7
Rock measures - - -	10	1	2			
Coal (Stone Coal) - -				0	1	2
Rock measures - - -	19	0	7			
Coal (Yard Coal) -				1	0	0
Rock measures - -	7	1	3			
Coal - - -				0	0	6
Rock measures - - -	18	0	11			
Coal (Bensham) - -				1	0	3
Rock measures - - -	26	0	6			
Coal - - -				1	0	6
Rock measures - - -	9	1	10			
Coal - - -				1	0	2
Rock measures - - -	1	1	0			
Coal - - -				0	0	9
Rock measures - -	9	2	9			
Coal (Low Main) -				2	0	6
Rock measures - - -	27	0	0			
Coal - - -				0	1	6
Rock measures - - -	15	0	0			
Coal - - -				0	0	6
Rock measures - - -	6	0	0			
Coal - - -				0	0	2
Rock measures - - -	10	0	0			
Coal - - -				0	0	6
Rock measures - - -	4	0	0			
Coal - - -				0	0	6

	Yds.	Ft.	In.	Yds.	Ft.	In.
Rock measures - - -	12	0	0			
Coal (Whickham St.) -				2	0	0
Rock measures - - -	10	0	0			
Coal (Brockwell) - -				1	0	2
Various rock measures -	50	2	0			
Millstone grit						
	380	0	6	15	2	3

In Mr. Buddle's excellent sections, published in the "Transactions of the Natural History Society of Newcastle," the extent of the several alternations of coal, sandstone, shale, &c., in the upper parts of this series are clearly shown. There is very little ironstone in the coal tracts of the Tyne and Wear. In Yorkshire, the total thickness of the coal formation is from 1000 to 1500 yards. In Lancashire, perhaps a greater thickness must be ascribed to it. In South Staffordshire (Dudley), it does not exceed 1000 feet. The most variable parts, in all coal tracts, are the sandstones and shales; the most regular parts are the coal beds and ironstones.

Organic Remains. — The forms of life buried in the carboniferous system of strata are exceedingly numerous and varied, and, being generally in an excellent state of preservation, allow of a most strict comparison with existing types. They consist of very many races of plants, abundance of zoophyta, multitudes of mollusca, some crustacea, many fishes, but, as far as we yet know, neither reptiles, birds, nor mammalia. Many of the plants, indeed by far the greater number, are of terrestrial growth: all the zoophyta, and nearly all the mollusca, crustacea, and fishes, are marine. The excepted mollusca occur among the remains of plants swept down from the land: the excepted crustacea are those referred to by Dr. Hibbert, in his account of the Burdiehouse limestones, with which also a few fishes are found, which, by this author, are referred to a freshwater origin.

The plants are partly very similar to existing races, as the large group of ferns generally, and partly appear altogether unlike them, as the large-furrowed stems of sigillaria, the quincuncially ornamented stigmaria, &c. On making the most close comparison which the subject admits, we find that among the fossil ferns are arborescent species, to which we can only find parallels in warm or else Australian regions; that the same analogy to the productions of a warm climate is suggested by fossil equiseta, and confirmed by the lepidodendra, which seem related to existing lycopodiaceæ in structure, though enormously surpassing them in dimensions. Even the sigillariæ, when carefully studied, though they be not cacti nor euphorbiæ, nor arborescent ferns, are so much like those singular plants of hot climates, as to add considerably to the accumulating evidence in this direction.

The following is a brief summary of the plants: —

Cryptogamia vasculosa—	Equisetaceæ	about	20	species.
	Filices	above	100	
	Lycopodiaceæ	about	60	
Phanerogamia monocotyledoneæ	- - -	-	10	
	Coniferæ - -	-	10	
	Cacteaceæ - -	-	50	
	Indeterminate -	-	50	
			300	species.

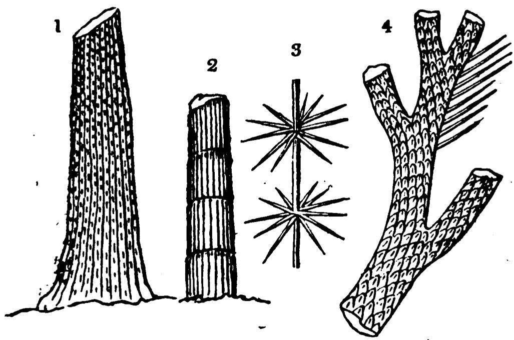


Fig. 1. Stem of sigillaria always denuded of leaves.
2. Stem of a large calamites.
3. Stem and leaves of asterophyllites.
4. Branch and leaves of lepidodendron.

Of the accumulated remains of these plants coal seams are really composed, and one cause of the differences amongst them is the different structural composition of the original plants. How far the above fossil flora is to be taken as exhibiting the true proportions of the tribes of plants living on the globe, at the time of the production of the rocks of the carboniferous system, is uncertain: since, when plants are swept down from the land into the sea, it depends on many unknown conditions *what sorts* of them shall escape the floods, or perish by maceration in the waters.

As a general rule, it may be said that the plants are confined to arenaceous and argillaceous deposits: they abound in the upper parts of the carboniferous system, where coal abounds: they also occur in the midst of the millstone grits, and in sandstones and shales among limestones, especially where coal beds also are found; but they are almost unknown in the midst of the undivided limestone, and are rare in the old red sandstone. It appears the most probable view that the plants forming coal were, with the arenaceous and argillaceous substances, swept into the sea by inundations from the land, and subsided into strata on the bed of the sea: forests or peat mosses submerged might be compressed into coal, and covered by inundated sediments; but this notion of De Luc requires in a coal district 50 or more elevations and subsidences of the same tract of land, a phenomenon too remarkable not to have left evidence of an independent character.

The plants appear, however, not to have been carried far into the deep sea, but rather (at least in the upper or true coal formation) to have been lodged in estuaries where shells of fluviatile genera might exist. Nothing offers a more striking similitude in modern nature to the processes whereby, as we suppose, an old coal formation was produced, than the accumulations of timber, and various sediments, at the mouth of the Mississippi. See (Lyell's Principles of Geology.)

The zoophyta of the carboniferous system are almost (perhaps wholly) absent from the coal formation: they are almost confined to the mountain limestone formation and to its calcareous portions, thus offering us most clear proof of the marine origin of that rock. When, to this, we add the absence of land reliquiæ from these limestones, it is evident that the materials of which these rocks are formed were not swept from the land like the substance of the arenaceous rocks, but elaborated from the salts of lime diffused in sea water. The zoophyta are partly of families almost extinct, as crinoidea; and partly of tribes yet abundant in the sea, as lamelliferous corals: the genera of corals often but not always (*e. g.* astræa, lithodendron) differ from those now living. The following summary is extracted from the "Geology of Yorkshire," vol. ii. p. 241.: —

Zoophyta —	Polyparia	41
	Crinoidea	40
	Echinida	3

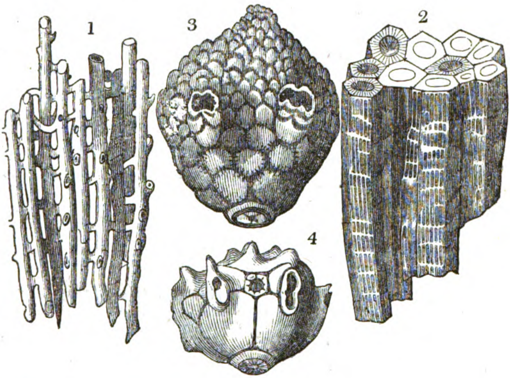


Fig. 1. Syringopora ramulosa. *Goldfuss.*
2. Cyathophyllum (or Lithostrotion) basaltiforme. *Phillips.*
3. Actinocrinus triaconta dactylus. *Miller.*
4. Platycrinus lævis. *? Miller.*

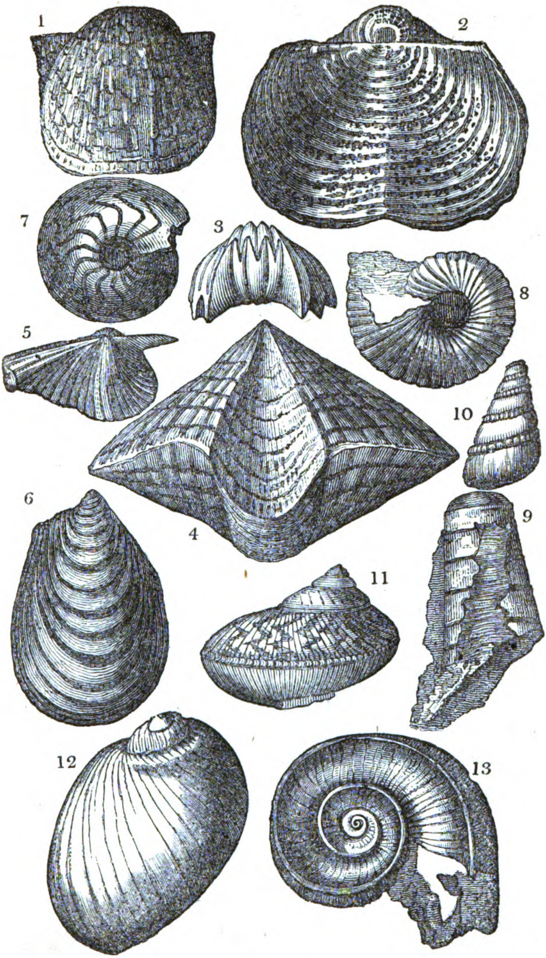
The molluscous reliquiæ are numerous; 326 species being described in the "Geology of Yorkshire," without noticing about a dozen others from the coal formation, which are included in the following general summary:—

Mollusca —	Conchifera	plagimyona	-	40
		mesomyona	-	28
		brachiopoda	-	100
	Gasteropoda		-	92
	Cephalopoda	monothalamia	-	10
		polythalamia	-	69
				339

Of these, only about 10 can by any means be considered as of freshwater, or even estuary origin: and these all belong to the coal formation (unio, anodon, &c.). Many of the genera are the same as those now existing (*e. g.* nucula, lingula, isocardia); but others are quite different, (as, pleurorhynchus, producta, euomphalus, goniatites, &c.) and seem to belong to another order of creation. About 60 per cent. of the species belong to extinct genera; and it is very remarkable, that brachiopodous bivalves, which, in existing nature, are perhaps to other shells as 10 in 1000, were in these ancient periods as 10 in 34. The goniatites are most

EXPLANATION OF FIGURES, p. 163.

1. Producta scabriculus. *Sowerby*. It occurs in mountain limestone generally, and in coal strata at Coalbrook Dale.
2. Producta punctata. *Sowerby*. Common in the carboniferous limestone.
3. Terebratula pleurodon. *Phillips*. Common in the carboniferous limestone.
4. Spirifera cuspidata. *Sowerby*. Not rare in the carboniferous limestone.
5. Pleurorhynchus minax. *Phillips*. From the carboniferous limestone of Ireland, Yorkshire, Derbyshire.
6. Inoceramus vetustus. *Sowerby*. From the limestones and shales of the north of England, the north of Ireland, &c.
7. Goniatites sphericus. *Sowerby*. A common shell in the limestone.
8. Bellerophon tangentialis. *Phillips*. From the limestone of Ireland, Yorkshire, &c.
9. Orthoceras cinctum. *Sowerby*. From the limestone of Ireland, north of England.
10. Melania constricta. *Sowerby*. From the limestone of Derbyshire, Yorkshire, &c.
11. Pleurotomaria flammigera. *Phillips*. From the limestone of Bolland.
12. Natica plicistria. *Phillips*. From Bolland in Yorkshire, Ireland, &c.
13. Euomphalus pentagonalis. *Sowerby*. Common in the limestone of Ireland, north of England, &c. Its internal cavity is divided into chambers by imperforate septa, as was first noticed by Mr. W. Gilbertson of Preston.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beautiful and characteristic features of this formation, being found in none of the more recent strata.

Crustacea existed during the accumulation of these rocks, but bore little resemblance to the present forms of the class: the trilobites of these rocks are, however, less numerous and varied than in the older Silurian rocks, where they are remarkably numerous.

The fishes of the carboniferous system (Caithness, Burdiehouse, Leeds, Bradford, Manchester) are mostly of the ganoid division of Agassiz: some of them are comparable to lepidosteus; and according to this able writer the larger sorts (megalichthys, holoptychus) had so much of a real analogy to reptiles (in the bones of the head, and character of covering,) as to justify the application to them of the title "Sauroid Fishes." From this general review, the reader will infer that most of the forms of plants and animals of the carboniferous system are very distinct from existing types, but yet comparable with them and intelligible by them; but that genera are mixed with them, which cannot be, or at least have not been, at all discriminated from recent; and among plants in particular, some fossil forms (ferns) have a resemblance to recent species, which is quite surprising.

Physical Geography.—Much of the most picturesque contracted scenery of England is situated among the deep-cleft valleys, and rock-breasted hills of the mountain limestone, which, in Cheddar cliffs, on the banks of the Wye, in Derbyshire, the Yorkshire dales, and parts of Cumberland, Westmoreland, Lancashire, Flintshire, and Glamorganshire, offers most attractive features to the artist. In Ireland, this rock is the source of very fine effects, about Sligo and Enniskillen. The Meuse flows from Namur to Huy, through a succession of precipices of limestone comparable to those of the Wye. There is not the same praise to be bestowed on the scenery of the old red sandstone, which, however, on the border of the Grampians, makes some interesting rock scenes (Braclyn Bridge), and in Breconshire and

Carmarthenshire rises into the Beacons and Vans. The coal formation is generally found in countries deficient of beauty of form and luxuriance of vegetation; yet the undulations of the large coal tracts of Yorkshire and South Wales, with the noble oak woods which fill some of the valleys, are worthy of notice.

The millstone grit and Yoredale rocks form in the north of England a peculiar order of scenery; for resting in detached masses upon broad, bare surfaces of scar limestone, their bold craggy tops and edges, and abrupt precipices, produce often a grand, though sometimes a formal effect, and their combinations are frequently fine. To this country belong also many beautiful waterfalls, originating in the decay of soft shales and grits below ledges of limestone, over which the stream flings itself, in a free and lofty leap. into a dark and precipitous glen. (Hardrow force, in Wensley Dale; Ashgill force, in Aldstone Moor.)

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Another thing worthy of notice in the scenery of the limestone districts in the north of England, especially Derbyshire, is the difference of herbage in the millstone grit, limestone shale, and limestone. On the latter (*l*), a fine green turf — on the shale (*s*), bluish green sedgy pastures — on the grit rocks (*m*), brown or purple heath, enable a geologist to mark out the leading features of districts with great facility, suggest to the botanist many interesting inquiries, and demonstrate to the agriculturist the dependence of the quality of soils on the rocks which they cover.

Geographical Extent.

The surface of country occupied by the rocks of the carboniferous system is proportionably much larger in the British islands than in other parts of the globe. In

Ireland, the greatest part of the plains and broadly undulated interior consists of the mountain limestone, in places covered by coal measures, and in other parts supported by the old red sandstone. In fact, excluding the parts previously described as gneiss, mica schist, clay slate, and grauwacke slate, and a large tract of later strata (red sandstone, green sand, chalk, &c. capped by basalt) extending from Lough Neagh to Lough Foyle, and to the sea-coast of Antrim, nearly all the rest of Ireland belongs to the carboniferous system. But the quantity of coal yielded by the coal fields about Lough Earn and Lough Allen, Monaghan, Dungannon, Newcastle, the counties of Clare, Kerry, and Limerick, about Cashel and Kilkenny, is not very considerable, nor is the coal of good quality. The Kilkenny coal is nearly pure carbon. The old red sandstone appears in Tyrone; about Omagh; near Enniskillen; on the south side of Donegal Bay; about Boyle and Longford: large tracts of the same appear N. W. of Lough Derg; about Killaloe and Roscrea; south of Tipperary; south of Clonmel; about Waterford and Thomas Town. But the greater part of the space between the primary tracts of Cork, Galway, Mayo, Donegal, Down, Cavan, Wicklow, Carlow, Wexford, is filled by mountain limestone. (Mr. Griffith's map.)

In Scotland the mountain limestone is, on the contrary, very slightly developed, in connection with the large coal field which stretches from St. Andrews to Ardrossan, and from Haddington to Ayr, filling large spaces in the valleys of the Forth, Clyde, Ayr, Irvine, &c. (M'Culloch's map.)

The old red sandstone ranges on the north-west coast of Scotland, in interrupted patches from near Cape Wrath to Loch Carron, Skye, and Rum: on the north-east side, it forms a large surface in Caithness, skirts the Dornoch and Moray Friths, passes up the great valley to Mealefavournie, and spreads by Nairn and Elgin to the vale of the Spey. A large belt of red conglomerates borders the Grampians, from Stonehaven to the islands in the lower part of Loch Lomond, and occupies much of the sea-coast to the Frith of Tay. Red sandstones border the northern flanks of the Lammermuir Hills, expand in the vale of the Tweed, and margin the slate tracts of Dumfries-shire and Kirkcudbright. Arran, Bute, Cantire, and the coast about Largs and Ardrossan, show the same formation.

In England, the carboniferous system of rocks is widely expanded. Old red sandstone appears in the parts adjacent to the Tweed, often associated with the lower beds of limestone into a transition group: it is seen along the line of the Penine chain about Dufton; and appears in the lake district at the base of Ulswater, in the valley of the Lune, and other parts. It is developed enormously in the counties of Hereford, Monmouth, Brecon, Carmarthen, and Pembroke; but is slightly exposed in connection with the limestone of Mendip, Bristol, and Wickwar.

The mountain limestone formation occupies an immense tract in Northumberland, Durham, and Yorkshire, from which country it runs out in a curve, to encircle on the north, and partially on the south, the group of Cumbrian slate mountains. It also appears in great force in Derbyshire; ranges through Flint and Denbigh, to St. Orme's Head and Anglesea; shows slightly round the Clee hills in Shropshire; and presents picturesque cliffs on the Wye, near Monmouth. There is a long belt of mountain limestone on the north and east sides of the coal fields of South Wales, from Narberth by Abergavenny to Caerphilly; and it is prolonged on the south side by Bridgend, Swansea, and Tenby, to Milford Haven. Detached masses of limestone appear about Bristol, and in the Mendip Hills, and, according to Messrs. Murchison's and Sedgwick's recent researches, the limestones of Barnstaple may be of the same age.

The carboniferous limestone is supposed to occur in a narrow band below the coal formation of the Clee hills, and this is probably the correct explanation of the phenomena visible under Knowle hill, at Orelton, &c.:

but we must call attention to the fact that the white (sometimes internally blue) *oolitic* limestone there occurring is associated not only with dark shales (clunch), and light marly beds, altogether of a considerable thickness, at least 100 feet, but is also overlaid by an important deposit of red, whitish, and greenish argillaceous strata, altogether of the same nature as the "old red formation" of the vicinity. The whole series of the south Clee hills may be thus expressed in general terms:—

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Jewstone basalt. Coal formation.—Two, three, or more beds of coal, some of it coked, some of it cannel coal; under it occur
g Conglomerates and other gritsones, some of them iron-specked and heavy. (Galena occurs in some beds.)
f Red and coloured clays.
e Bluish clunch beds.
d { Light yellow, marly and argillaceous beds. Calcareous layers, sandy or marly.
c Black clunch fossiliferous. (Crinoidea, spirifera, terebratula.)
b Limestone in solid beds, generally oolitic, much disturbed in the stratification, as in the sketch below (Ctenacanthus and other fossils.) It is worked for marble at Orelton.
a Thick red clays and sandstones.

Admitting the limestone and shale beds (*b, c, d, e*) to be the equivalent of the lower scar limestone (Derbyshire limestone) of the north of England, the quartzose conglomerate (*g*) may be ranked as millstone grit; and the red and white clays (*f*) must be considered as a recurring bed of the old red marl, interpolated among the carboniferous rocks, just as the red grits and clays of Orton and Ravenstone dale have been described as marking one form of a transition between the old red sandstone and the carboniferous formation, on the border of the primary districts of Westmoreland.

The millstone grit is an important deposit in the north of England, from the Coquet to the Tyne, and on the hills between the dales of Durham and Yorkshire, from the Tyne to the Aire and the Ribble. A large mass of these rocks occupies the higher parts of Bolland; and a far larger tract extends from the Yore at East Witton, nearly S. W. to Ormskirk in Lancashire, and spreads from this line to the east, under the magnesian limestone of Yorkshire, from Masham to Aberford, and under the coal of Yorkshire, by Leeds and Bradford, to Penistone. Near this place it divides into two branches, one of which separates the limestone of Derbyshire from the coal of Yorkshire, Nottinghamshire, and Derbyshire; the other in like manner divides that limestone from the coal of Manchester and Congleton. In the south of England the millstone grit is feebly represented by the "Farewell rock" of the Forest of Dean, South Wales, and Somersetshire; but in Ireland it appears in great force on Kulkeagh, Belmore, and other mountains about Enniskillen.

The coal formation of Northumberland and Durham extends from the Coquet across the Tyne, Derwent, and Wear, to Cockfield, where it suddenly breaks off, and ends against the valley of the Tees; and no more appears between the magnesian limestone and the millstone grit till the south side of Wharfdale. Here from Aberford to Bradford it runs out, in a counterpart of the Durham recession, and then returns by Halifax and Huddersfield to Sheffield, Dronfield, Chesterfield, Alfreton and Belper, and ends near Nottingham. On the western side of the Cumbrian mountains is a narrow belt of coal formation, about Workington and Whitehaven: a small field of coal lies at the foot of Ingleborough (corresponding to one at Hartley Burn, on the South Tyne). The coal deposits of Lancashire form a considerable breadth, ranging east and west, from Manchester by Prescot and Wigan to near Liverpool, and appear to be connected underground with the coal tract of Flintshire, and, perhaps, of Shrewsbury. The detached coal fields of Ashby de la Zouch, Coventry, Dudley, and Colebrook Dale, are very valuable: some smaller fields are known south of Shrewsbury, in the Clee Hills, and at Newent. The Forest of Dean is a rich though small tract, and the disunited patches of coal in Kingswood, and south of the Bath Avon, are valuable. Almost the largest coal field in Great Britain is the great oval elongated tract of South Wales, from Pontypool to St. Bride's Bay, which furnishes fuel to the great iron works of Merthyr, Tredegar, Neath, &c. It is thought by some geologists that the culm of Devonshire (Bideford, &c.) lies in a deposit of the same age as the culm of Swansea and other parts of South Wales, which is known to belong to the true coal formation.

When we recollect, that, in addition to this large expansion of rich coal tracts, in most of which 50 feet of coal (in many beds) exist, the millstone grit and mountain limestone tracts, north of Derbyshire, also yield *some* coal, it is easy to see that the popular opinion of the extraordinary abundance of coal in Great Britain is perfectly well founded. But does it follow that the supply of British coal is inexhaustible? will it last for one thousand or five hundred years, and during that period meet the hourly enlarging consumption at home, and the augmenting demands from abroad? This question has often been replied to, never answered. Nor have the replies been often dictated by a comprehensive view of the subject. If indeed the only data required were the superficial area of a coal tract, and the sum of the thickness of the several coal beds, nothing could be more easy than to convert this into a term of years, by assuming some fixed or regularly varying rate of annual consumption. But to this it must be objected, that *all the coal* in a given district cannot be worked, in consequence of *natural* impediments (thinness, bad quality, disturbed position, &c.), and of the wasteful and unscientific method of establishing coal works. It is not here meant to speak otherwise than with praise of the working of the collieries, in which much judgment and humanity are often to be noticed, but in the irregular and accidental manner (depending on distribution of property, private interests, &c.) in which the sites of collieries are chosen, and their field of work defined. Many portions of country are thus left full of unattainable coal; others untouched from dread of the water in long-abandoned works: beds of coal, of inferior quality or thickness, are abandoned till the future scarcity of fuel shall render it profitable to work them, under great disadvantages. Finally, as the thickness of the entire coal series often exceeds 1000 yards, and it is only in the Newcastle and Durham tract that pits descend even to 500, and then brave great dangers and difficulties, it is clear that, however long the coal of Great Britain may last, its price must gradually rise, because the cost of its production, relative to that of other articles of consumption, is necessarily on the increase. It is thus that coal will become scarce; and if the country be not yet sufficiently enlightened in this matter to prepare the way for some act of legislative wisdom, the time of trial may not be far remote.

It is a striking fact that no known coal district in the British islands (excepting, perhaps, a small part of Ayrshire) is unwrought: most of them are covered by manufactures; and ere long the geologist will be called upon to decide as to the propriety of sinking for coal in situations where it does not appear on the surface, yet is really spread beneath our feet in areas, perhaps, not less extensive than some of our largest coal fields. It *may* exist, for instance, beneath the plains of Cheshire, but who will have the boldness to penetrate the red sandstone, in search of that which may be placed by nature at an unattainable depth?

On the continent of Europe the carboniferous system is variously and locally developed in France, Belgium, Westphalia, Saxony, Bohemia, on the north of the Carpathians, &c. One of the most important deposits of coal and mountain limestone begins at Hardingen, near Boulogne, and, passing under the chalk and green sand, continues in an easterly direction by Valenciennes, Mons, Charleroi, and Namur, to Liege and Eschweiler, near Aix-la-Chapelle. On the right bank of the Rhine, the coal tract near Elberfeld may be viewed as a prolongation of this great Belgian deposit.

Some traces of millstone grit, and more of aluminous shales, divide the coal from the limestone, in the valley of the Meuse, and also in Westphalia, at Lintdorf, and between Werden and Velbert. These representatives of the millstone grit group (flötzleerer) sandstein acquire, farther east, a great development about Arnsberg, Meschede, and Warstein. No old red sandstone is known in Westphalia, but red conglomerates represent it on the Meuse. The Saarbruck coal field contains thick red sandstones in its upper part, resembling the South Lancashire section. The same, on a greater scale, appears in Lower Silesia, and there, as in Lancashire, the true bunter sandstein covers unconformedly the coal. In Upper Silesia the coal without either limestone or old red sandstone rests on grauwacke. (Von Dechen.) The coal of Saxony, about Zwickau and Dresden, rests on igneous rocks.

At Litry near Bayeux, and between Angers and Nantes, coal occurs under relations to the older rocks, which appear like those of the Devonshire culm. "In the centre and south of France are some limited coal deposits, lying in the valleys of the Loire, the Allier, the Creuse, and the Dordogne, the Aveyron, and the Ardêche, between ridges proceeding from the primary central group connected with the Cevennes." (These coal fields are devoid of mountain limestone.) Coal is mentioned as occurring in eight places in Catalonia, in three in Aragon, and one in New Castile. (Mr. Conybeare, in "Geology of England and Wales.")

In Russia (provinces of Tula and Kalouga), in Syria, in the basin of the Indus, at Batavia, and in China, in Van Diemen's Land and New South Wales, in Virginia, and at several points west of the Alleghany Mountains, are extensive coal fields.

Igneous Rocks.—A very considerable proportion of the trap rocks for which Scotland has long been celebrated is found amongst the strata of the carboniferous system. About Stonehaven, Bervie, Montrose, Arbroath, the Sidlay hills, south of Dunkeld, at Perth, Kinnoul, and Moncrieff, felspathic, basaltic, and amygdaloidal rocks (at Kinnoul yielding various agates) appear among the old red sandstones. The Ochill ranges from the mouth of the Frith of Tay to Stirling, continued in the Campsie hills to Dumbarton, and thence expanding to Greenock and Ardrossan, divide the red sandstone from the coal formation of the Forth and Clyde. From Greenock to Kilmarnock and the Haughshaw hills is a prodigious mass of trap: detached portions occur in Ayrshire; a long range extends from Tinto by the Pentlands to Edinburgh. North Berwick Law, Tantallan, and the Bass, are the extremities of a large body of trap in Haddingtonshire: these rocks abound between Linlithgow and Bothwell; and a great variety of igneous masses occur about Kinghorn, the Lomond hills, and between Cupar and Largo. A considerable proportion of all these extended igneous rocks is connected with the coal formation.

The variety of composition among these rocks is so great, as to defy description in any moderate compass. These rocks, felspathic (porphyry, claystone, clinkstone, &c.), felspatho-pyroxenic (greenstone, basalt, wackè), produce at many points remarkable changes on the adjacent sandstones and shales; hardening both to an extraordinary degree, so as to resemble jasper of different colours. (Salisbury Craig, Stirling Castle, hill of Kinnoul, &c.) At Cumnock, coal is converted to anthracite and plumbago. (See Bouè, p. 122. *et seq.*)

Perhaps the most remarkable variety of igneous rocks yet known in a small compass appears in the island of Arran, generally associated with the red sandstones, and conglomerates. Pitchstone, claystone, hornstone, trachytic porphyry, clay porphyry, basalt, and greenstone, appear in many dikes, and form interposed beds of great interest in the theory of the formation of such rocks. (Jameson, M'Culloch, &c.)

In the north of England, the porphyritic masses of the Cheviot hills, the range of greenstone and basalt in Northumberland from Belford, by Alnwick, Rothbury, Whelpington, and the Roman Wall to the South Tyne, and thence along the west front of the Penine chain, to Hilton, near Appleby, and down the Tees to Middleton, with dykes passing through the mountain limestone, coal and newer strata, are the principal masses of trap rock associated with the carboniferous system. Dykes of basalt are common in the coal fields of Northumberland and Durham, but totally unknown in those of Yorkshire, Derbyshire, Nottinghamshire, and Lancashire. In Derbyshire, the limestones are separated by an irregular mass of interposed amygdaloidal trap, called "toadstone;" (by some, more than one such bed is supposed to exist).

Mr. Murchison has described the trap rocks which penetrate the coal measures of the Titterstone and Clee hills, and cut and injure the coal: at Kinlet, Arley, and Shatterford the coal based on old red is divided by eruptive masses and dykes of trap. The trap rocks which rise in bosses within the coal fields of Colebrook Dale do not appear to have charred the coal: they never appear as dykes, or enter into the fissures of the rocks. (Mr. Prestwich.)

Basaltic hills adjoin coal and limestone at Rowley, near Dudley, and at Griffe, in the Warwickshire coal field: a dyke of basalt appears in Birchhill colliery, Walsall.

It is impossible in many cases to refer the igneous rocks, associated with the carboniferous system, to their true geological date. The bedded rocks of Northumberland, Teesdale, and Derbyshire, are certainly of the same age as the mountain limestone; but the dykes of Northumberland, Durham, and Walsall, and the other basaltic excrescences and ridges, are not easily determinable in age. This difficulty belongs to almost all cases of dykes, except when, as in the Quarrington dyke, in Durham, the igneous rock cutting through one formation (coal) is overlaid by another (magnesian limestone), which it does not divide. Even here the conclusion of the anteriority of the dyke to the overlying rock is somewhat insecure; because the extent of the dykes in the coal formation itself is very irregular and accidental.

Trap rocks are associated with the Irish mountain limestone between Limerick and Tipperary.

General View of the Circumstances under which the Carboniferous System was deposited.

If in the early part of the formation of the primary strata the ancient ocean was in a peculiar state, both as to temperature and extent, never since experienced, the effect of partial eruptions of igneous rocks, and perhaps of great displacements of the crust of the globe, was to vary the depths and localise the currents of the original ocean. But the effects of this change, apparent among the sedimentary deposits of the upper "transition" strata, were augmented to a vast degree, after the completion of the whole primary period, and the decided movements to which large parts of the globe were then subjected. The Northern Ocean, at the commencement of the carboniferous era, was certainly divided into basins, varied by islands, bounded by shores, supplied by inundations from extended land. The agitation on its shores is proved by conglomerates; the amount of inundations from the land is demonstrated by abundance of argillaceous and arenaceous sediments, plants, and beds of coal; while in the more tranquil laboratory of the deeper water limestone rocks were generated in great abundance.

The carboniferous formations are extensive, but, as compared with the older primary rocks, very limited in area, broken into many detached parts, and characterised by local conditions. Hence the red conglomerates of the Grampians, the Lammermuirs, and the Cumbrian valleys, hold fragments of the neighbouring and but lately uplifted rocks; hence the absence of old red sandstone in Derbyshire, its great predominance and complication on the south-east border of Wales; hence the unmingled oceanic character of the limestone of Derbyshire and Ingleborough, contrasted with the divided, sandy, shaly, carbonaceous littoral group of Northumberland. The small extent of coal in many countries is merely a fact indicative of the previous revolutions which affected the primary strata there; while the abundance of coal in Great Britain confirms to us the conclusion drawn from other considerations, that in this region of the globe, soon after the formation of primary strata, much land had been raised above the sea.

But there is yet to be explained the excessive abundance of the vegetation of that early land, which should be capable, even when swept down into estuaries and the sea, of collecting into so enormous a mass of coal. On this point, if we turn our eyes on existing nature, nothing appears so likely to aid our conception as the damp forests on the Oronoko, Maranon, or Mississippi, from whose mere waste the mighty rivers roll every year to the Atlantic an immeasurable mass of trees and herbs, with soil, sand, and clay, which are in process of time arranged on the bed of the ocean, as we find the coal and its accompanying sands and clays to be. The analogy is strengthened by the general consent of botanists, in regarding the plants of which coal was formed to be decidedly analogous (though differing much) to tropical vegetation, and especially to the vegetation of a tropical region contiguous to the sea, where palms, cacteaceæ, and lycopodiaceæ might abound, and yet varied with mauntain slopes on which tree ferns and pines might flourish. If further we suppose, with M. Brongniart, that the atmosphere of that early time might be loaded with an extra proportion of carbonic acid, against which no law of nature militates, (for we know not if this proportion of carbonic acid be now constant in the air, and must admit that a reconversion of all the coal to carbonic acid gas *would* give a very large addition of this gas to the atmosphere,) we shall understand how the vegetation of the carboniferous period might be *even more abundant than that now seen between the tropics*, and at the same time comprehend the *possibility of there being no land animal on the globe.* Within what limits of proportion of carbonic acid in the air plants and animals can live, we do not know; but in this respect they are reciprocally circumstanced,—plants require most, animals require least.

De Luc, Brongniart, and other writers, prefer to explain the origin of coal from somewhat like peat-bogs, or from the decay or overwhelming of forests *in sitû*: and this may possibly be found true of particular cases; but it is not to be admitted as a general explanation. In most coal districts are from 20 to 60 seams of coal, alternating with sandy and argillaceous strata, for each series of which (coal, sandstone, shale) the land must have been raised, decomposed to soil, covered by forests or peat, and then again submerged to receive sediments from the land or littoral agitation; and *these numerous risings and fallings of the bed of the sea have left no independent proof of their occurrence.* Undoubtedly there is a plausible argument furnished to De Luc's hypothesis, by the stems of sigillaria, supposed to be in attitude and place of growth; but until lepidodendra and coniferous trees, of which coal at least in part consists, shall have been similarly found, and in equal abundance, and until the reality of these stems being rooted shall be proved, we must not yield the general arguments to this exceptional and imperfectly ascertained phenomenon.* Inundations from the upraised land, littoral action of the sea, chemical decomposition of the oceanic waters, eruptive action

* What have been called the roots of these erect trees are not always really parts of the same kind of plant. We do not yet know *what were the roots of sigillaria.*

of subterranean heat, vital action on the land and in the water, — these are the causes to which the formation of the whole carboniferous system is clearly traceable; and by comparing the effects of all these causes in that ancient period, with what happen at this day, we shall find modern effects precisely comparable in *kind*, but altogether inferior in *magnitude*.

Where then was situated that ancient land, from which, according to our view, were swept the materials of the 1000 yards of sandstones and shales which inclose the coal deposits in most parts of England, and the continent of Europe? And recollecting that in the series of millstone grit and carboniferous limestone in the north of England occur other beds of coal, and several hundred yards in thickness of other sandstones and shales, again we ask from what land were the plants and earthy sediments drifted in such abundance over this limited area? In the discussion of this important question, which appears in my "Illustrations of the Geology of Yorkshire," I have found it necessary to analyse the phenomena, so as to be able to inquire separately into the local origin of the three substances of principal importance — limestone, sandstone, shale: the former is of oceanic origin, for it contains only marine exuviæ, and when in greatest thickness and purity, was evidently deposited by water in a state of great tranquillity, or slow decomposition. In the same south-eastern direction that the limestone grows thicker from a certain point in the district, the sandstones and shales grow thinner: in the opposite direction they thicken, but not equally; the sandstones thicken toward the north, the shales toward the west, and in this direction certain limestones and sandstones totally vanish. With these sandstones the coal beds also vanish; where the sandstones thicken and grow numerous toward the north, the coal beds also augment in number and thickness; and the limestones change gradually from an undivided mass to many distinct members, separated by sandstones, shales, coal, and ironstone.

Thus to any point A, in diagram No. 52., where a series of limestone, sandstone, shales, coal, ironstone, occurs,

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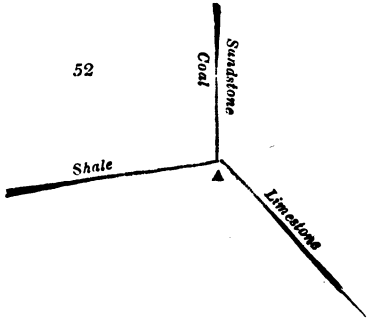

the limestone may be supposed to have been brought by diffusion in the ocean from an area situated to the south-east; the shale transported from the west, and the sandstone, plants, &c., drifted from the north. We may *imagine* two rivers, one flowing from the west, and bringing across the regions where now are Ireland, Lancashire, Derbyshire, and South Yorkshire, a vast body of argillaceous sediments, slightly charged with sand, and but little varied by floating trees and plants; the other rushing from the north, loaded with sandy matter, and bearing abundance of trees of different kinds, *but not many ferns or delicate herbaceous plants.* Alternately or contemporaneously, these rivers might fill the sea with deposits, such as we behold and in the manner that we see them, united with the proper calcareous deposit of the ocean.

This explanation of different sediments coming to the same part of the sea from various quarters, may probably be applied to every system of stratified rocks, containing, as constituent members, limestone, sandstone, and clay; but it is necessary previously to investigate the directions in which the agencies concerned in producing each sort of sediment, were most powerful; *i. e.* the points or lines of their greatest intensity.

In some cases it appears highly probable that one such irregular fluviatile action, modifying the continuous depositions from the sea, would sufficiently explain the phenomena of the association of sandstone, shale, and limestone; because, by such action, the shores would be margined by a sandy deposit, beyond which clay would predominate in the sediments, and at a greater distance calcareous matter would be nearly unmixed with the effects of littoral agitation.

In the diagram No. 53. S represents the sandy accumulation near the shore, passing by gradation to the

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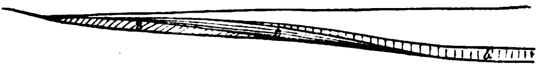


deposit of clay, *c*, which extends further, and is finally replaced by nearly pure carbonate of lime, *b*, which *grows thicker* farther from shore.

Still the question recurs, where was the land from which the materials were drifted? The slaty mountains of Cumberland, the Isle of Man, Cavan, &c., were perhaps above the water; but could they alone yield the materials for the argillaceous sediments, 1000 feet thick, of Enniskillen, Derbyshire, and Craven, even if we suppose them to have been much diminished by the operation? The Lammermuir mountains, to the north, seem not to be of such composition as would yield the coarse quartzose sandstones; we must therefore appeal to the Grampians or Scandinavian ranges, or finally close all further discussion, by admitting that tracts of land which supplied part of the sediments, mixed with the limestones of the carboniferous period, have disappeared from the Northern and Western Oceans.

The coal formation, lying above these limestones, appears in many cases (Yorkshire, Lancashire, &c.) to have been accumulated, or according to the other hypothesis, submerged, in estuaries or lakes: if so, the local origin of the materials must be sought around those lakes, and in one or more directions from those estuaries.

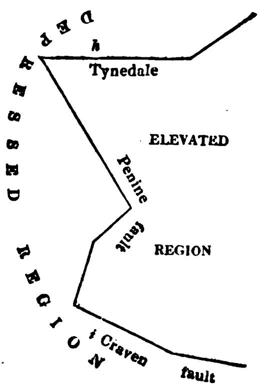
If, as seems probable, the coal fields of Yorkshire and Lancashire were once united, as those of Durham and Newcastle still are, the margins of the estuary in which they were formed are lost, except toward the mountains of Lancashire and Westmoreland. In like manner, no margin can be fixed for the estuary of the coal fields of Durham and Newcastle, except the Lammermuir range; and thus we are again conducted to the conclusion, that, unless those mountains be thought to have yielded all the sediments, great displacements of the crust of the globe have confused the ancient boundaries of the carboniferous sea, and reduced to mere conjecture the extent of the bordering land, and the circumstances of its drainage. This important though dark inquiry, will, however, again arrest our attention.

Extent of British Coal Fields under superior Strata.— Disturbances of the Carboniferous System.

To what extent the relative level of land and sea was disturbed *during* the period which elapsed in the production of the carboniferous rocks cannot be known: to judge from the universal conformity of all the strata which compose it, and the rarity of coarse conglomerates (except at the base of the system), it might appear that no considerable displacement of the crust of the globe happened any where near the British Islands, during the whole carboniferous period. Yet the occurrence of a marine conchiferous bed among the estuary or freshwater strata of the Yorkshire coal field, seems absolutely to require the admission of considerable disturbing movements at a distance.

After, however, the deposition of this whole system, and before, at least, any considerable part of the next (red sandstone system), was laid upon it, the scene was totally changed, and the carboniferous rocks of the British islands broken and contorted by subterranean movements of an extensive and complicated description.

Every coal field in these islands is remarkably dislocated by faults, often traversed by rock dykes, sometimes ridged or furrowed by anticlinal or synclinal dips, which cause great trouble and expense to the coalworker, and call forth all the resources of his art. Into the history of these disturbances we shall only enter, so far as to present a fair basis of comparison with physical theories. One of the most remarkable great faults or dislocations yet known in the world, belongs to this period; viz. that great and continuous fracture of the earth's crust, from Cullercoats, near Newcastle, westward along the valley of the South Tyne to Brampton; thence southward to Brough, Kirkby-Stephen, Dent, and Kirkby-Lonsdale; and afterwards eastward to near Grassington, in Wharfdale, a distance of 110 miles.* The whole of the somewhat rectangular tract of country, included between the northern (Tynedale), southern (Craven), and middle (Penine) portions of this fault, is elevated above the corresponding strata in the depressed surrounding regions, not less than from 1200 to 4000 feet; in consequence of which grauwacke rocks show themselves along the Penine and Craven portions, while small coalfields appear on the parts at *h* and *i*, thrown down 2000 feet below the summits of millstone grit!



On the south side of the Craven branch of this great fault are found many anticlinal ridges, severally ranging north-east and south-west, or nearly, and throwing

* See separate Memoirs by Sedgwick and Phillips in Geological Transactions; also "Geology of Yorkshire," vol. ii.

the whole Craven country into a series of parallel undulations. Through Derbyshire runs an axis, from which the rocks dip eastward and westward; and this ridge, continued northwards towards Colne, effects a complete disunion of the great coal field on the east (Yorkshire, Derbyshire, Nottinghamshire), from that on the west (Lancashire, Cheshire) which it appears most probable were once united on the bed of the sea. It is only by considering the effects of subterranean movements, that we can at all account for the disjointed and fragmentary condition of the central coal fields of England. Their disunion is sometimes real, but very frequently only apparent, since they often dip towards

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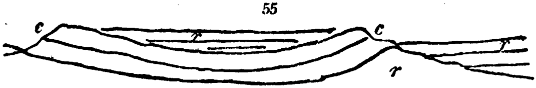

each other, as *c c*, and would perhaps be seen to unite but for the covering of red sandstone, which conceals the coal along the middle of the basin.

The great South Wales coalfield is a vast double trough, having an included anticlinal axis, ranging east and west; as Diag. 56.

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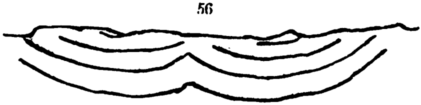


and if the Barnstaple and Bideford beds belong to this system, their principal dislocations range also east and west: this is, perhaps, the most general line of movement in the Somersetshire tracts, where dislocations are numerous and remarkable: it is renewed in the north of France and Belgium (at Mons and Namur), and about Elberfeld. Without now stopping to discuss the bearing of these results on M. de Beaumont's views, we shall observe, that a careful study of the phenomena in the north of England has left but slight doubt on our mind that the application of Mr. Hopkins's mechanical theory

(See Cambridge Transactions,) to the dislocations of the carboniferous system, will be successful. Mineral veins commonly range a little N. of E. and a little W. of N. on the carboniferous system of the north of England.

Saliferous System.

New Red Sandstone System of Authors; Poicilitic System. (*Conybeare.*)

Composition. — After examining the carboniferous rocks, the red sandstones and the associated strata present themselves with an air of novelty and freshness, not less striking to the geologist than a new country to the traveller. Instead of the black, blue, or grey limestone, full of crinoidal columns, productæ, &c., we have now yellow, sandy, or granular rocks, with few organic remains: the dark shales of the coal series are exchanged for red, green, and blue marls, and the micaceous yellow, ochraceous or brown grits, for red or white sandstones. One feature, indeed, the systems have in common; viz. red conglomerates at or near the bottom; and close examination points out several instances (Manchester and Salop) of *transition coal deposits,* in which red grits and clays inclose coal, with shales and limestones of a peculiar aspect.

The arenaceous deposits are a considerable part of the red sandstone system; they are generally red, and not micaceous. Some of them are coarse brecciated rocks (Kirkby-Stephen), containing limestone fragments; others conglomerates full of various pebbles (Nottingham castle); others holding a few pebbles (Runcorn). Many are coarse red grits (Penrith Beacon); or finer building stone (Meriden Hill, near Coventry), often white or greenish (Warwickshire). It is worthy of notice, that the grains of red sandstones near Manchester, were found by Dr. Dalton to be internally a clear quartz, the red oxide of iron being merely an external coating. In Germany are grits (keuper), somewhat resembling certain of the coal measure sandstones.

The argillaceous members are usually called "marl," though they contain little calcareous matter: they are often laminated; their colour is usually very red; but in the reddest cliffs occur distinct bands and spots of a bluish, greenish, or white colour; and in particular parts of these variegated marls lie nodules, and irregular beds and vertical plates of gypsum, very strangely ramified, or completely insulated in the mass of argillaceous matter.

The limestones of this system vary much. They are often loaded with magnesia, and in general called "magnesian limestone;" but there are many beds in which little or no foreign admixture deteriorates the carbonate of lime. The colours are white, grey, smoky, but more frequently yellow; and in some districts reddened, or even very red. In texture, a few limestones are compact, some oolitic, many cellular, the cells lined with crystallised carbonate of lime, a large proportion of a fine sandy grain, some quite powdery, with crystallised balls included; and in Nottinghamshire, considerable tracts yield granular crystallised limestones. Near Sunderland laminated rocks are really of sparry texture. Strings and plates of spar are very common, and render buildings of the magnesian limestone very irregular in their decay, from the unequal perishing of the stone between the ribs of spar.

The muschelkalk of Germany, not yet admitted as an English rock (the upper part of the magnesian limestone of the north of England is somewhat similar in mineral properties, but is apparently lower in the series), is usually a compact, hard limestone, of a grey or smoky tint; sometimes (Courcelles) it deviates to a whitish soft stone, more analogous to the magnesian type.

Rock salt occurs in the state of clear, white cubically crystallised masses, or reddened by the argillaceous sediment, among which it occurs; sometimes in Cheshire the red salt is fibrous. Brine springs, which issue from "rock salt," contain combinations of iodine and bromine, though in the rock itself that substance can hardly be detected; a circumstance depending on the extreme solubility of the iodic and bromic salts.

Gypsum, a very general product of the red argillaceous members of this system, and very commonly found in the vicinity of rock salt, is largely foliated (selenite) at Fairburn, near Ferrybridge, granular at Chelweston, near Derby, but generally fibrous, as at Pocklington, Nottingham, Aust Passage, &c.

Structures of Deposition. — Stratification is distinct in all these rocks; but in all of them some peculiarities appear in this respect. Among the argillaceous beds lamination prevails; but the gypseous interpolations produce great anomalies, and suggest what is probably true, that this mineral is often a segregation of later date. The sandstones are laminated or bedded, and the pebbly varieties commonly present most decided proofs of the agitation under which they were collected, in the abundance of oblique lamination ("false bedding" of authors), as in Nottingham Castle Hill.

The fine-grained upper limestones of Knottingley are thin-bedded: the granular rocks of Nottinghamshire are either thick-bedded or flag-like; it is sometimes difficult to trace the beds at all in the powdery magnesian rocks; and in certain sparry rocks near Sunderland, the bedded structure is almost overlooked in admiration of the coralloidal forms of the concretionary masses, which sometimes are enveloped in soft yellow powder (Building Hill).

Divisional Planes.—The fine-grained limestones of Knottingley are traversed by vertical divisions from top to bottom, which in some places are open to a foot in width, or filled with clay and rolled pebbles; in other cases they are merely thin cuts in the rock; always their regularity, parallelism, and polarity (if we may so term their direction to N. or N. N. W., and its rectangle E. or E. N. E.), are remarkable. In other thick-bedded limestones, the joints are less symmetrical, though always numerous: most of the rocks are traversed by small secret cracks, which, on being exposed by fracture, are found covered by dendritical markings of a dark colour. The joints are often coated by carbonate of lime, sometimes by carbonate of copper, or sulphuret of lead.

Succession and Thickness of Strata. — The most, or rather the only, complete series of the new red system in the British islands, is that of the north of England, where alone certain lower members are clearly exhibited. In Warwickshire, principally lie the grits (white, grey, and greenish), which are supposed to correspond to the keuper of Germany. The following synopsis is founded on the views of Professor Sedgwick. ("On Magnesian Limestone." *Geological Transactions.*)

Red sandstone formation, in places sunk into 600 ft.	*h.* Variegated marls. Red, with bluish, greenish, and whitish laminated clays or marls, holding gypsum generally, and rock salt partially (as in Cheshire); included in these marls are certain white and grey sandstones, supposed to represent the keuper grits of Germany.
	f. Variegated sandstones. Red sandstones, with some white and mottled portions; the lower parts in some districts (Nottinghamshire) pebbly.
Magnesian limestone formation, 200 or 300 ft. thick.	*e.* Laminated limestones of Knottingley, Doncaster, &c., with layers of coloured marls, 30 or 40 ft.
	d. Gypseous red, bluish, &c., marls.
	c. Magnesian limestone, yellow, white; of various texture and structure; some parts full of fragmentary masses.
	b. Marl slates; laminated, impure, calcareous rocks, of a soft argillaceous or sandy nature.
	a. Lower red sandstone, with red and purple marls and micaceous beds; sometimes the grits are white or yellow; and pebbly, or loose sand. Occasionally passes into coal measures, on which it rests.

In Somersetshire, and other parts of the south of England, the section consists almost wholly of gypseous red and variously coloured marls, with a few beds of red sandstone, having near the bottom a pebbly or brecciated rock called millstone, or magnesian conglomerate. The fragments imbedded are usually calcareous; but near older gritstone rocks conglomerates of the red marl are found to contain gritstone pebbles; magnesian conglomerates border the Staffordshire and Salopian coal fields, and have a lower red sandstone beneath them. At Manchester, the magnesian limestone is somewhat better defined; at Kirkby-Stephen, it is represented by a brecciated limestone rock; and at St. Bee's Head is a complicated formation of considerable thickness, in which the calcareous part is an important feature.

The principal difference between the complete German series and the English, lies in the addition to the former of the limestone called muschelkalk, above the variegated sandstones; the greater variety of substances corresponding to the variegated marls, and the far greater mass of the lower red sandstone. In the following table the complete French series is included:—

Germany.	England.	France.
Keuper marls and grits.	Variegated marls, and white and gray grits.	Marnes Iriseés.
Muschelkalk.		Muschelkalk.
Bunter sandstein.	Variegated sandstones.	Gres bigarré.
Stinkstein, rauchwacke, &c.	Upper limestone.	
Gypseous marls.	Gypseous marls.	
Zechstein.	Magnesian limestone.	
Kupfer schiefer.	Marl slate.	
Rothetodteliegende.	Lower red sandstone.	Gres de Vosges. Gres rouge.

It is evident that the limestones are the least extensive members of the series. Rock salt, which, in England, is found only in the variegated marls, lies in them both in France and Germany, but is even more common in the muschelkalk.

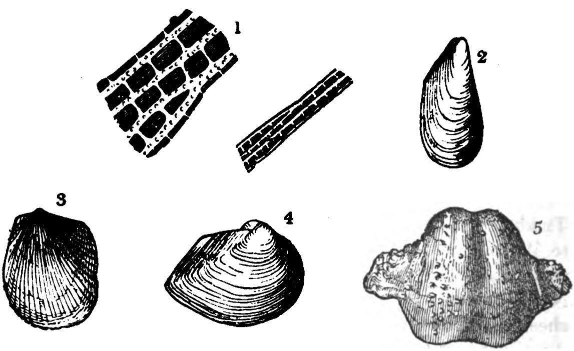
The Organic Remains of this system, though few in number, are exceedingly interesting to the naturalist and geologist, from the strong testimony they offer of the successive changes of the living creation, according to the new circumstances of the land and sea. The fossil plants, shells, fishes, and reptiles of this system appear to partake both of the character of those in the older carboniferous, and the newer oolitic, deposits. Calamites, like those of the coal formation, are mingled with cycadeæ, resembling closely those of the oolites. Productæ, so common in mountain limestone, occur in the zechstein with terebratulæ, like those of the lias and oolites. Fishes of the genus palæoniscus here occur for the last time, in ascending the series of strata; and here, perhaps, for the first time, we have remains of oviparous quadrupeds — the protorosaurus, phytosaurus. These interesting relations appear in the following table, which also contains the names of some fossils, which are found in only one of the three systems :—

<table>
<tr><td>Belemnites.
Ammonites.</td><td></td><td rowspan="4">Trigonia.</td><td rowspan="4">Stellerida.</td><td>OOLITIC FORMATION.</td><td></td><td></td><td rowspan="4">Pterophyllum.</td><td rowspan="4">Equisetum columnare.</td><td>Zamia.</td></tr>
<tr><td rowspan="6">Ceratites.</td><td rowspan="2">Photoosaurus.</td><td>Keuper.</td><td rowspan="7">Lepidodendron.</td><td rowspan="7">Calamites.</td><td rowspan="6">Voltzia.</td></tr>
<tr><td>Muschelkalk.</td></tr>
<tr><td></td><td>Red sandstone.</td></tr>
<tr><td rowspan="3">Palæoniscus.</td><td rowspan="4">Producta.</td><td rowspan="4">Cyathocrinus.</td><td>Zechstein.</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>Marl slate.</td></tr>
<tr><td>Rotheliegende.</td></tr>
<tr><td>Orthoceras.
Goniatites.</td><td></td><td>COAL FORMATION.</td><td>Sigillaria.</td></tr>
</table>

According to the organic remains, the lower half of this system might be ranked with the carboniferous, the upper with the oolitic rocks: but, by its own mineral characters, it is one great series of deposits which happened at the period when a decided change was taking place in the conditions which determine the forms of life upon the globe.

The following summary of the organic remains of the red sandstone and magnesian formations of England, includes some species in the possession of the author, which have not yet been figured : —

Plants —	marine.	Traces in the limestone, Durham.
	terrestrial.	Voltzia in the limestone, Durham. Dictyophyllum, &c., &c., in Cheshire, Worcestershire, &c.
Zoophyta —	polyparia.	Three species belonging to retepora, and a lamelliferous coral.
	crinoidea.	One species.
Conchifera —	plagimyona.	Ten or more species.
	mesomyona.	Three or more species.
	brachiopoda.	Ten or more species.
Mollusca —	gasteropoda.	Four or more species.
	cephalopoda.	(Nautilus.)
Crustacea.	? ———	
Fishes —	About 10 species, chiefly of the genus palæoniscus in limestone, Durham; in sandstone, Tyrone.	
Reptiles —	(thecodontosaurus — palæosaurus) in limestone, Bristol.	
	phytosaurus? in sandstone, Warwick.	



1. Retepora flustracea. *Phillips.*
2. Mytilus acuminatus. *Sowerby.*
3. Avicula gryphæoides. *Sedgwick.*
4. Axinus obscurus. *Sowerby.*
5. Producta horrida. *Sowerby.*

All these are from the magnesian limestone of Durham and Yorkshire.

Thus, about 50 species of fossils occur in these rocks in England, while 200 have been noticed in Germany and France. Every where, however, the *red* sandstones appear to have been accumulated under circumstances unfavourable to the occurrence of vegetable and animal exuviæ.

Geographical Extent.—Slight traces of new red sandstone occur on the western coasts and islands of Scotland: some considerable area is occupied by it in the country between Coleraine and Dungannon, about Belfast and on the coast of Antrim; but it is in England that the system takes its great development. The Solway Firth is in red marls and sandstones, and all the rivers which enter it from the Scottish frontier flow through the same (Dumfries, Lochmaben, Longtown); the plain of Carlisle, with nearly the whole course of the Eden, is on these strata, which also appear on the western coasts, from Whitehaven to Furness, and exist under the peat mosses of South Lancashire. The Vale of Clwydd is formed in the red formation. The river Tees, in Yorkshire and Durham, enters the sea in gypseous red marls and sandstones; so does the river Exe in Devonshire: and between these two points is an almost uninterrupted line of the same strata, ranging by Stockton, Northallerton, Boroughbridge, York, Snaith, Doncaster, Retford, Nottingham, Leicester, Warwick, Worcester, Tewkesbury, Newnham, Aust Passage, Wells, Taunton, and Honiton. From Hartlepool it is bounded on the west by magnesian limestone at Pierse Bridge, Catterick Bridge, Ripon, Knaresborough, Ferrybridge, Tickhill, Mansfield, to Nottingham: but from this point to Worcester, as a base line, it expands westwards across the whole island from Nottingham to Derby, Ashbourn, Newcastle-under-Line, Macclesfield, Stockport, Manchester, Newton, Liverpool; from Worcester to Kidderminster, Bridgenorth, Newport, Shrewsbury, Ellesmere, Wrexham, Runcorn, Liverpool—thus occupying an enormous area in the centre of England, partially broken by the upheaved coal measures of Leicestershire, Warwickshire, and Staffordshire. Small detached portions appear in Monmouthshire, Glamorganshire, and Devonshire.

On the continent of Europe, still larger spaces are covered by the saliferous system than in England. A small continuation of the Devonshire red rocks appears in Normandy, about St. Lo: a much larger area lies between the Ardennes and the Vosges, running westward from Luxemburg to Florenville, northward to Witlich and Vlanden, southward to Thionville, Pont-à-Chaussy, Château Salins, and Vic (where rock salt occurs), Mirecour, Jussy, and Villersexel; eastward to Treves, Wadern, Kaiserslautern, Neustadt, Weisspenbourg, Weshoffen, St. Diey, &c. In this large and intricate tract, the bunter sandstein, muschelkalk, and keuper, are fully developed: there are some magnesian bands in the keuper, but no zechstein below the red sandstone. The Vosges are almost wholly surrounded by these rocks.

In like manner the Black Forest is principally surrounded by saliferous deposits, continuously so on the eastern side, from which spreads to the north and east an enormous area of the red rocks, which represent the bed of a sea ramifying in several directions, among islands and promontories of older, and slopes of newer, rocks. The principal part of the mass lies to the east of a long line drawn nearly north from Waldshut on the Rhine, to Minden on the Weser, including the Odenwald, Spessart, and Habichtwald. Portions run out eastward towards Osnaburgh. From Waldshut, by Stutgard, to Dietfurt, nearly parallel to the Danube, is the south-eastern boundary: it thence turns northwards to the Maine, and returns to the Danube at Ratisbon, and fills the narrow space between the Franconian oolites and the primary igneous rocks of the Bohemian border and Thuringerwald. Round the end of these latter mountains it bends to the east, fills all the space between the Harz and the grauwacke border of the Erzgebirge, and passes the end of the Harz in a long tongue between Magdeburg and Brunswick. In this enormous area, the zechstein, or magnesian limestone, is exhibited along the Thuringerwald, in Hesse Cassel, on the southern and eastern sides of the Harz, between the Elster and the Saale, and about Waldeck. The muschelkalk occupies enormous areas, on a line from Waldshut to the Thuringerwald, and all around the Harz. Salt occurs in the keuper and muschelkalk especially. Considerable tracts of new red sandstone adjoin the Riesengebirge; and a line of these rocks, occasionally saliferous, borders the primary ranges of the Alps, from the vale of the Danube, by Rottenmann, Radstadt, to near Innspruck. On the south side of the Alps, the range is equally extensive, from Cilli, near the Save, by Villach to St. Lorenzen on the Eisach.

Physical Geography.— Spread over so immense a space in England, the saliferous system offers the remarkable fact of never rising to elevations much above 800 feet (Barr Beacon, in Staffordshire, is a gravel hill on a base of red rocks); a circumstance probably not explicable by the mere wasting of these soft rocks by floods of water, but due to some law of physical geology yet unexplained. We only can conjecture that it is connected with the repose of subterranean forces, which prevailed after the violent commotions of the coal strata, over nearly all Europe till the tertiary epoch. The red sandstone system, folding its level surfaces round the broken coal strata, seems to be like the large uplifted bed of a shallow sea, full of rocky islands, and bounded by bold promontories. The magnesian limestone range in the south of England constitutes a fine natural terrace of 100 to 500 or 600 feet in height above the sea; its escarpment being always to the west.

Igneous Rocks.—Almost the only cases known in England, are dykes of greenstone. One of these, the great Cockfield dyke, extends from Middleton, in Teesdale, to near Robin Hood's Bay, and passes through mountain limestone, coal, magnesian limestone, red sandstone, red marl, the lias, and oolites. Another passes from the Breiddin hills across the plain of Shrewsbury, and dislocates and alters red sandstone at Acton Reynolds. In the Isle of Arran, dykes of pitchstone, claystone, trap porphyry, &c., divide red and white sandstones, supposed to be of this era.

Origin and Aggregation of the Materials of the Saliferous System.

Peculiar in their mineral composition, rocky structure, and the nature and distribution of their imbedded organic remains, the constituent members of the red sandstone and magnesian limestone sometimes offer many points of inquiry to the inductive geologist, and much that seizes on the imagination of those who venture freely into the unsafe regions of speculation. What has caused in the sandstones, clays, and marls of these formations, such various tints of the oxides of iron? If the greenish and bluish tints of the clays and gritstones be due to protoxide of iron, what have been the circumstances which determined in these small portions that particular state, while all around, above, and below them, the masses are tinged, and the particles enveloped by the peroxide?

In particular cases blue centres to yellow rocks occur (oolite, calcareous sandstones), and may be thought to be the *residuary primary* tint, the outward parts having been decolorised. But this does not apply to the red marls and sandstones, among which (except at the weathered surfaces and in the soil), yellow tints are rare; the prevalent tint of red appears rather to be the original, and the rarer and detached tints of white, green, and blue, to be the decolorised portions of the mass. We may imagine chemical processes of change from protoxide to peroxide, but it is very difficult to find data for applying them to the cases before us.

The general extension of these tints appears to imply a very general cause. This can hardly be understood as a mere process of common oxidation; for this gives greater variety of tints, and cannot be supposed so uniform or extensive in its action. May we venture to offer as a question deserving attention, the possibility of explaining the red colour of these rocks by a general influence of volcanic eruptions on the sediments of the ocean?

In the same manner the limestones offer curious topics of remark. Where they degenerate to a sandy state (near Nottingham), they assume a decided red tint; nor is this tinge any where entirely absent from large tracts of magnesian limestone. It is complicated with purple (Doncaster), yellow (Sunderland), or is totally replaced by a pure or creamy whiteness. The various modes and degrees of consolidation already noticed among these limestones, imply, of course, different modes of aggregation: for the shelly rocks of Hawthorndean and Humbleton (Durham), we may, with some confidence, claim a corallaginous origin: the globular concretions of Sunderland remind us of the pisolite of Carlsbad, and, according to an unpublished suggestion of Dr. Forchhammer, may be really due to ancient submarine springs of great force, yielding mingled carbonates of lime and magnesia, which were afterwards consolidated together, or separately deposited. The dusty portions of rock seem to be really decomposed; and it is worthy of remark, that the tufaceous deposits from these rocks, as well as the crystallised spars in geodes, consist of carbonate of lime.

There appears no reason whatever to apply to these magnesian rocks either the speculation of Von Buch concerning Alpine dolomites, that they are common limestones impregnated with carbonate of magnesia by heat, or the notion of their mechanical origin from disintegrated magnesian beds of the carboniferous limestone.

Origin of Rock Salt and Gypsum.

In the present state of nature salt (chloride of sodium) appears in solution at the surface, under the following circumstances:—

1. In the sea, every where, but in variable quantities.
2. In springs arising from salt rocks, known or presumed to exist.
3. In springs arising in volcanic regions.
4. In small quantity in all springs whatever.

It is only by considering these existing sources of salt in combination with the phenomena accompanying ancient salt deposits, that we can expect to gain light toward the solution of the problem of the formation of rock salt.

This general investigation would here be out of place;

but we shall present a short view of some of the principal conditions ascertained to accompany these deposits.

First, as to the Rocks which inclose Salt.—The great abundance of this valuable substance in the red sandstone and red marl of England, as well as in the contemporaneous rocks of Germany, naturally produced a general impression that salt was peculiarly the product of that geological era; and it was sometimes assumed without evidence that all the well-known salt works of Switzerland, Poland, Spain, &c., drew their supplies from the new red sandstone formation. The inference was extended not only to the salt lakes and springs of European, but also of Asiatic, Russia, to the sands of Persia and salt-houses of Ormuz, and the saltworks of India, between the Indus and the Chellum. Even the American salt deposits were thought to belong to the red sandstone formation of Europe.

The progress of information has corrected this over-extension of a well-grounded inference: salt springs rise in Durham and Northumberland, and Leicestershire, from the coal system; some of the saltworks of the Alps are supplied from the oolitic system: the famous mines of Cardona and Wieliczka have been referred, the former to green sand, the latter to tertiary rocks; and, to complete the series, salt springs abound in the volcanic regions of Sicily and Auvergne.

It appears then that salt is derived by the action of water from almost every stratum, formerly left by the sea, and from many volcanic and other products, and that large beds of salt occur at several stages of the series of marine formations, but that in Europe they are remarkable and frequent in the new red sandstone system. This may, therefore, without impropriety, be called the saliferous system.

Hence we may securely infer that although salt was more or less diffused through all the marine deposits the enormous accumulation of this substance in certain places can only have happened in consequence of local peculiarities several times recurring, but at least, in

Europe, more frequent in a particular period of the earth's lamellar incrustation.

It is very important to remark that the salt lies always in small narrow patches; therefore, most evidently it was not produced by a *general* extrication from the marine water, and most probably is to be referred to *local heat*, or some other cause at great depths, or else to evaporation from a limited area, filled at intervals by the sea.

In order to discover the nature of these local peculiarities, we must compare the different salt deposits, with reference to their *situation, accompanying minerals, and other leading circumstances.*

So little relation appears between the actual form of the ocean and the boundaries of the ancient seas in which the strata were formed, that it will probably be of little use to notice the geographical situation of the beds of rocksalt as compared to the present distribution of land and water. The salt mines of England are in very low ground: those of Wieliczka lie at the foot of the Carpathian mountains on the north, and those of Cardona beneath the Pyrenees on the south: many mines in Wurtemburg and central Germany are in the midst of rather elevated plains; and at Bex salt lies in an ancient valley, some distance above the Lake of Geneva, itself 1000 feet above the sea. With respect to the present ocean, the mines of England and Cardona are near to it, but the others far distant.

It does not seem possible to extract from such a discordant assemblage of facts any general character of situation depending on the present distribution of land and water, nor perhaps has it ever been attempted; but because in the instance of the Cheshire salt district, the local circumstances are such as to have given occasion for Dr. Holland's hypothesis, that the salt there was derived from the neighbouring sea, it will be worth while to discuss the formation of that salt basin separately.

The Cheshire deposits of salt lie along the line of the valley of the river Weaver, in small patches, about

Northwich. There are two beds of rock salt, lying beneath 40 yards of coloured marls, in which no traces of animal or vegetable fossils occur. The upper bed of salt is 25 yards thick: it is separated from the lower one by 10½ yards of coloured marls, similar to the general cover; and the lower bed of salt is above 35 yards thick, but has nowhere been perforated. Whether any other beds lie below these two is at present unknown. They lie horizontal, or nearly so, and both beds of salt are below the level of the sea. They extend into an irregularly oval area, in length one mile and a half, in breadth about 1300 yards, ranging from N. E. to S. W. Gypsum, so abundant in many other salt mines, and generally plentiful in the tracts of red marl, is found in most of the clays associated with the Cheshire salt.

The physical features of the country about Northwich are not very peculiar, yet sufficiently favourable to Dr. Holland's hypothesis. The valley of the Weaver is separated from that of the Dee by the sandstone ranges of Delamere forest, and the Peckforton hills, and from the course of the Mersey by an extension of the elevated ridge, called Alderley Edge. Below Northwich these bordering hills come very close together, and naturally suggest the idea that in ancient times there might at this place have been accidental bars formed, which while they lasted, would exclude the inroads of the sea. If by such an event the sea lake flowing up the valley of the Weaver was converted into an inland sea, and if the supply of fresh-water streams from the neighbouring country was very scanty, the natural progress of evaporation would certainly tend to dissipate the water, to concentrate the solution of salt, and finally to cause in it a partial precipitation. At first, gypsum or any other of the less soluble salts would be formed, and perhaps mixed with the earthy sediments mechanically deposited in the lake, and afterwards the salt be accumulated in the deepest parts of the water, in quantity proportioned to the evaporation of the liquid. If, at a subsequent time, the sea should again burst the barrier and inundate the valley, a new deposit of gypseous marls, and a bed of salt would naturally be occasioned, upon any renewed blocking up of the entrance.

The entire absence of marine exuviæ from these strata is no objection to the hypothesis; because this is the case with almost the whole extent of the red sandstone formation in England.

Upon the whole, it seems evident that this hypothesis is well adapted to the circumstances of the case for which it was framed, and is in itself very simple and plausible, but is liable to the serious objection that it employs data drawn from the *present relations* of land and sea to elucidate the phenomena of a period long gone by, and when, from unquestionable evidence, it is certain that their relations were *generally* very different. It is, however, not impossible that the district in question may have been undisturbed by any subsequent convulsion, and only altered in its physical features by the general elevation which our island appears to have undergone, by the rapid transition of diluvial currents, and the erosive action of rains and rivers. This is perfectly supposable, and may be true; for, as far as yet known, the circumstances of the case do not appear to contradict it; but before adopting this explanation, we must examine other salt deposits, and see whether a similar mode of origin can be reasonably ascribed to them.

Oolitic System.

Composition.—The change of deposits from the saliferous to the oolitic system is in all respects great, and, from the contrast of colours in the rocks generally, very obvious. Instead of red, green, or white marls, we have blue clays: the red and white sandstones are exchanged for calcareous grits, tinted yellow, or ochraceous, by iron in a different state of oxidation: instead of powdery magnesian limestones, we have compact or oolitic rocks. Nothing can be a clearer truth than that this great difference of chemical and mechanical deposits requires the supposition of some great physical revolution in the relations of land and sea. If we suppose that, in consequence of a subterranean movement *somewhere*, the oceanic basins were filled by sediments from other lands, or other lines of wasting coasts, the *change* from coloured sandstones to oolitic deposits in the same basin would be intelligible, though we might never know the local position of such tracts of land or lines of coast.

Most frequently, the arenaceous deposits associated with the oolitic system are easily and obviously distinguishable from those of earlier date: they are not micaceous, and seldom felspathic, as many of the carboniferous grits are; they are never of the same red, and seldom so white as those of the saliferous period. A yellow tint prevails among them, which sometimes deepens into ferruginous stains; the grain is generally fine; quartz pebbles seldom occur; their substance is mixed with carbonate of lime. But from this description, which applies to the south of England, great variations occur in particular districts, as in Yorkshire, Sutherland, and Westphalia, in the wealden districts of Kent and Sussex. The first three tracts may be sufficiently illustrated by the Yorkshire type, which is eminently distinguished from the rest of England, by having, in the lower parts of the group, enormous masses of sandstone and shale, greatly analogous to the sedimentary rocks of the carboniferous system, interpolated among the reduced and deteriorated strata of oolitic limestone. What renders the resemblance of these to the older grits and shales the more striking, is the circumstance that thin beds of coal, with fossil plants, occur among them, and that some beds of ironstone, and abundance of diffused oxide of iron, augment the analogy. There can be no doubt that these great and numerous points of similitude between the oolitic and carboniferous systems, in the north of England, point to a similarity of causes, extensively acting in the earlier, but reduced to limited effects in the later periods.

In the wealden tracts of Sussex and Kent, an almost similar series of sandstones (quartzose, coarse or fine-grained) and clays, with impure, but not oolitic limestones, occur, with ironstone beds and diffused oxide of iron, traces of coal and fossil plants. Were the beds of this local deposit placed by the side of others of the old carboniferous era, it would be difficult to distinguish them by any mineral characters capable of being expressed in language; we may therefore admit for this district, and some small tracts related to it, a renewal for a short period of the actions by which the carboniferous rocks were formed; and this is easily intelligible upon the principle of changes in the direction and depositions of oceanic currents, occasioned by subterranean movements.

The clays of the oolitic system are mostly of a decided blue colour (near the surface changing to yellow), often laminated, especially in the lias formation, but more frequently appearing like a nearly uniform mass of argillaceous sediment obscurely divided by a few laminæ of shelly limestone, or lines of septaria: pyrites and jet lie in many of them. The gradation from these clays to the limestones and sandstones is usually very gentle.

The limestones of this system are various: those associated with a great abundance of blue clays (as the lias limestones) are mostly of a compact texture, and of white, yellow, grey, blue, or blackish colour. Frequently, nodular masses collected by molecular attraction round organic bodies constitute the whole mass of the lias limestones. Those which appear in considerable thickness, as the Bath oolite, Portland oolite, Oxford oolite, are generally of the oolitic texture in the middle, though below and above this may be exchanged for compact or shelly beds. Thin detached limestones, like the forest marble, are sometimes very coarsely oolitic: calcareous layers in sand are usually charged with siliceous matter and often cleaveable to slate or flags (Stonesfield). The grains of oolite vary much in size; the smallest are perfectly spherical, the largest irregular; they generally cohere; the interstices are sometimes filled by calcareous spar: the centres of the large grains of oolite are commonly occupied by small shells or portions of shells, corals, grains of sand, &c., which served as the points of attraction for the calcareous matter, while it was in a soft condition.

Structure.—In the whole series, not a mass occurs which can be viewed otherwise than as an original deposition, or a subsequent concretion of aqueous sediment. The sandstones are always stratified: sometimes the coarse-grained sorts (Whitby, Tilgate forest) exhibit oblique laminations, the finer sorts often split into flags or slate: shells and plates of oxide or carbonate of iron appear as the result of molecular arrangement round particular masses, as centres of attraction. The clays, as above stated, are either laminated, or appear as vast uniform masses of sediment; bedded they can hardly ever be said to be, unless where interposed between beds of sandstone, or limestone. The ironstones, septaria, and "cone-in-cone" masses occur in the clays, in surfaces always parallel to the planes of stratification, and thus appear to mark periodical changes in the nature of the sediments; but this accumulation is generally the result of molecular attraction round organic bodies. Jet, another frequent substance in the clays, (especially in lias,) lies in laminæ parallel to the stratification, being nothing less than chemically altered coniferous wood.

Thin limestones associated with thick clays, as the lias limestones, are usually laminated or thinly bedded, and interstratified with the clays: thicker rocks, as the Bath oolite, are formed in regular beds of two to four feet in thickness; thin layers of clay often occur between the beds. Oblique lamination belongs to many of the coarse shelly oolites: spongoid bodies, enveloped in siliceous matter, lie in the oolitic rocks of Portland and Oxford, but not so regularly as flints do in chalk: there is very little pyrites, and, except in the lower Bath oolite, little oxide or carbonate of iron in the calcareous rocks, above the lias.

Divisional planes.—All these rocks are traversed by divisional planes, but very unequally, for the massive clays show few of them; in the calcareous rocks they are both numerous and regular; in the coarse and irregular bedded grits of Yorkshire and Sussex, the joints are also irregular; but in the slaty beds of Collyweston, Stonesfield, &c., the contrary is true. The joints are most open in the thick oolites, where they are frequently lined by stalagmitic incrustations, and filled with clay from above, and sometimes terminate in caverns, which, in Yorkshire and Franconia, contain bones of quadrupeds introduced at much later dates.

In certain districts these joints contribute, by weakening the rocks in certain lines, to produce the phenomenon of sliding ground; this is especially the case in the Hambleton hills, Yorkshire, from which, at different historical times, even as late as 1790, great landslips have occurred by the sliding of the clays below the calcareous grit, and the separation of masses of that grit and the superincumbent oolite along the planes of great vertical joints. The main line of these joints is about N. by W., and parallel to the immense natural escarpment of the Hambleton hills.

Series of Strata.—On the continent of Europe, the oolitic system, as characteristically exhibited in the Jura mountains, shows less distinctly than in England the minor groups, which furnished to Dr. William Smith the first proofs that England was regularly divided into strata, following one another for great distances on the surface, and sinking in the same direction beneath it. The divisions of the oolitic system, recognised by that distinguished observer, near Bath, are found however to apply with sufficient general accuracy to all European countries; and there is reason to think, the European type will be found applicable even to the flanks of the Himalaya.

Of the five formations which compose the oolitic system in England, the upper or wealden formation is the most local—the lower or lias formation the most extensive: the three intermediate or properly oolitic formations are easily distinguishable in the south of England and the north of France; but in the south of France, and generally in the Jura mountains, from Geneva to Bayreuth, this discrimination is a work of difficulty. Even in England, the three oolitic formations are not coextensive, at least their calcareous portions: the upper or Portland limestone is the most limited and interrupted; the lower or Bath rocks are the most extensive and connected, but at the same time, perhaps, the most variable. These and other results will appear in the following comparative table, suited to the north and south of England.

Peculiar to the North.	Common to both.	Peculiar to the South.
		Wealden clay. Hastings sand. Purbeck beds.
	Kimmeridge clay.	Portland oolite. Sands.
	Upper calcareous grit. Coralline oolite. Lower calcareous grit. Oxford clay. Kelloways rock.	
Carbonaceous gritstones and shales.	Cornbrash and clays.	Hinton sandstones and sands. Forest marble and clay.
Carbonaceous gritstone, shale, and coal.	Great oolite. Inferior oolite and sand.	Fullers' earth rocks.
	Upper lias shale. Marlstone beds. Middle lias shale. Lias limestone. Lower lias shale.	

If, comparing Britain with Europe, we view the oolitic system in gross, we shall find as the most general result, three considerable groups of rocks, viz.:—

Upper group, consisting of arenaceous (wealden) formation;

Middle group, consisting of the calcareous (oolitic) formations;

Lower group, consisting of the argillaceous (lias) formation;

and may consequently view the whole as a succession of argillaceous sediments widely disseminated in the sea, followed by calcareous accumulations from the oceanic waters, and closed by a local rush from some parts of the land. But analysis of these groups shows the effects of many alternations of oceanic rest and littoral movement, prevailing in the same parts of the sea, and producing at one time limestone with quietly imbedded shells and attached corals; at another, sandstones; at a third, clays. If we admit — what is perhaps impossible to be denied — that the production of each sort of rock spread from some centre, and that these centres were not coincident for different rocks, it becomes a very curious problem to determine what are *the lines of contemporaneity* in the oolitic system.

For let A be a point from whence a deposition of carbonate of lime spreads slowly through the ocean, but not reaching to B, a point from which depositions of sand happen, not reaching to A — the general basis *r, r, r,* being red marl and sandstone. The surfaces of strati-

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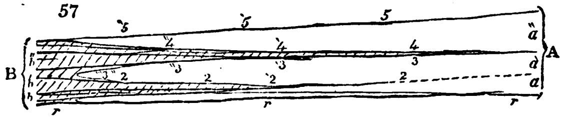

fication *r, r, r,* — 1, 1, 1, — 2, 2, 2, &c., are usually spoken of in geological works as marking distinct periods in the deposition of the beds, and the matter at any point on one of the three surfaces is usually supposed to have been *contemporaneously* deposited. In the diagram referred to, five lines of contemporaneity thus appear to be designated, but this inference is by no means perfectly correct. If the calcareous and arenaceous deposits were supposed to happen in alternate periods, those parts of the former which were furthest from A, on the planes 1, 1, 1, 3, 3, 3, and 5, 5, 5, would be of somewhat later date than the others, though exactly similar in substance, organic contents, &c.; and the like reasoning with reference to the point B, applies to the arenaceous deposits on the planes 2, 2, 2, and 4, 4, 4. Yet the beds *a, a', a'',* and *b*, *b'*, *b''*, would be correctly described as the deposits of a certain *period.*

But if the deposits from A and B were continuously and contemporaneously spreading, the lines 1 and 2, 3 and 4, would completely coalesce towards A,—and the lines *r* and 1, 2, and 3, and 4 and 5 toward B The sandstones would vanish indefinitely towards A, and the limestones towards B: a certain portion of sand would be diffused through the calcareous bed toward A, and some portion of calcareous matter through the sand towards B: the lines of contemporaneity would intersect obliquely the surface of the beds, as in the Diag. (No. 58.)

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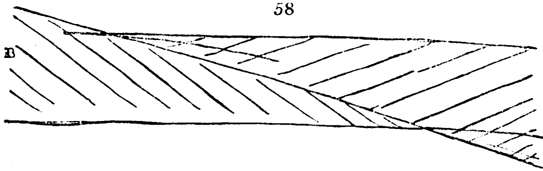

If the rate of deposition were *uniform* from each point, there would be only one calcareous and one arenaceous mass, (*fig.* 59.); but if from either of these points the

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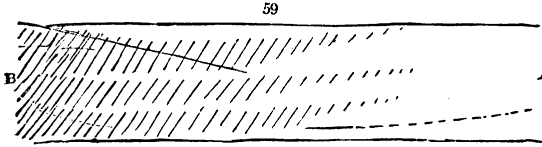


depositions were subject to periodical changes of intensity, this would occasion alternations of calcareous and arenaceous beds more or less distinct, according to the variations of intensity.

From this it may be concluded that the alternations of beds of different nature, proves either cessations or varying intensities of deposition, in one of the deposits; that, consequently, such a system as the oolites must have taken *a long time* for its accumulation and could not possibly have been generated with that rapidity which has been ascribed to the deposition of formations, from considerations founded merely on the state of conservation of organic remains.

Organic Remains.—The numerous remains of plants, zoophyta, mollusca, articulosa, and vertebral animals, belonging to the oolitic system, have long been celebrated and represented in many works of merit in England and Germany. Some general considerations arise from a contemplation of them, which deserve attention. The following estimate of the numbers of specific forms in the whole system (exclusive of the wealden formations), drawn up by the author, is at this time undoubtedly below the truth. (Encycl. Metrop. p. 653.)

Plants	marine	4	In limestone chiefly.
	terrestrial cryptogamous	39	In sandstones and shales chiefly.
	monocotyledonous	33	
	gymnospermous, uncertain	4	
Polyparia	fibrous	75	Chiefly in limestones, but rarely in the lias.
	corticiferous and celluliferous	44	
	lamelliferous	59	
Radiaria	crinoidea	31	
	stellerida	17	
	echinida	47	Chiefly in limestone, rarely in lias.
Conchifera	plagimyona	189	
	mesomyona	134	
	brachiopoda	61	
Mollusca	gasteropoda	114	
	cephalopoda	273	
	annulosa	55	
	crustacea	22	Chiefly astacidæ.
	insects	20	Solenhofen and Stonesfield.
	fishes	40	
	reptiles	40	
	mammalia	2 or 3	Only in the lower oolite formation at Stonesfield.

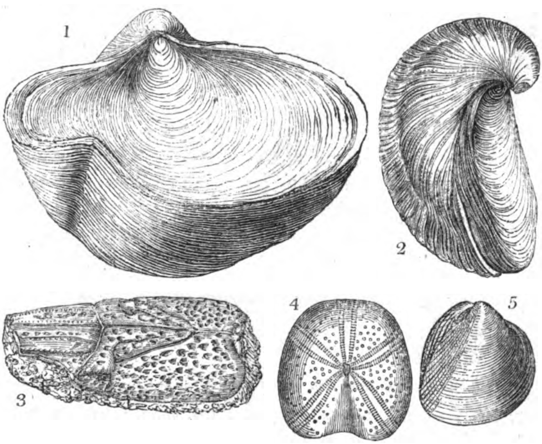
In the wealden formation, are no zoophyta, no cephalopoda—various land plants—some fresh-water bivalves and univalves—a few estuary shells—cyprides, lepidotus, and other fishes—iguanodon, hylæosaurus plesiosaurus, &c., with various chelonida, both of fresh and salt water.

The most characteristic of the plants are the group of cycadeæ, of which stems in the isle of Portland, and leaves and fruits in Yorkshire, show considerable analogy to the existing forms of the tribe, at the Cape of Good Hope, and in India and Australia. Compared with existing races, the polyparia present some general resemblance, with constant and obvious lesser differences. The sponges are seldom so large as those of the South Seas, and appear most to resemble those of New Holland. It would be difficult to doubt that the radiaria of this system are altogether more like the existing pentacrinus, stellerida, and echinida, than are those of earlier date. The beautiful genus cidaris, in particular, exhibits in many ways a decided analogy to recent tropical species. The mesomyona and brachiopoda, taken together, still predominate over the plagimyona; and cephalopoda are more numerous than any other group of mollusca; thus offering a broad distinction between the system of oolitic and modern life in the sea. The fishes belong mostly to the ganoid division of Agassiz, and are remarkable for the beauty of their preservation in the lias of Dorsetshire, Leicestershire, and Yorkshire. Among the saurians, those which frequented the water predominate in number, but the largest forms were terrestrial (iguanodon, megalosaurus). The natural order of turtles was exceedingly developed in this period. Hugi has found in the Jura formation, about Soleure alone, more than twenty species of emys (fresh water). We are not to imagine the few mammalia, insects, and plants, yet published from these formations, a fair specimen of these races, as they existed on the land during the oolitic period. Doubtless we may believe that the buprestidæ of Stonesfield were not the only beetles that fed its pterodactyle and didelphides: of these latter the few jaws yet found convey only partial information; but it is interesting to know that the earliest mammalia, of which we have yet any trace, were of the marsupial division, now almost characteristic of Australia, the country where yet remain the trigonia, cerithium, isocardia, zamia, tree fern, and other forms of life so analogous to those of the oolitic periods.

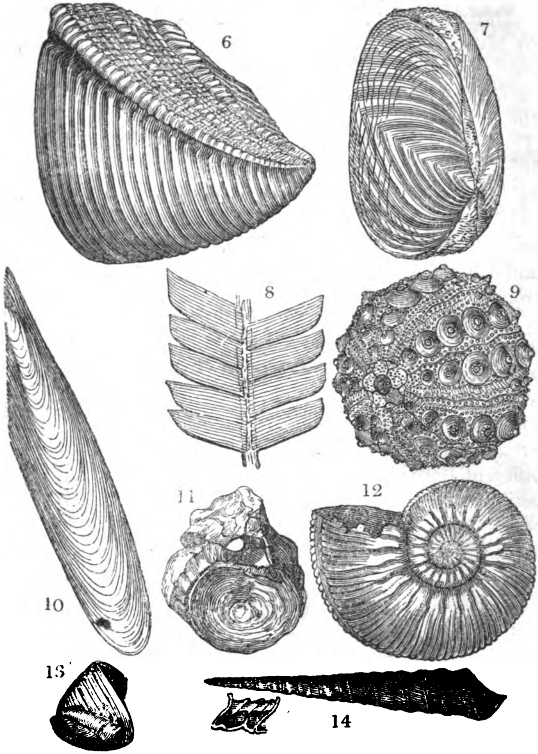
The following table will show somewhat of the distribution of remarkable families and genera in the oolitic system, which appears cut off from the cretaceous rocks above by a more decided line than the older formations.

Hamites Turrilites.	Plesiosaurus. Ichthyosaurus. Ammonites. Belemnites. Trigonia. Stellerida. Cidaris.	CRETACEOUS SYSTEM.	Spirifera.	
Megalosaurus.		Wealden Formation.		Clypeus. Apiocrinus.
		Upper Oolite Formation.		
		Middle OoliteFormation.		
		Lower Oolite Formation.		
		Lias Formation.		

OLDER SYSTEMS OF STRATA.



1. Gryphæa dilatata. *Sowerby.* From the Kelloway rock and Oxford clay.
2. Gryphæa incurva. *Sowerby.* (G. arcuata, *Schlotheim.*) From the lias.
3. Astacus rostratus. *Phillips.* From the lias, lower oolite, and middle oolite formations.
4. Clypeus clunicularis. *Llwyd.* From the lower and middle oolite formations.
5. Cardium truncatum. *Sowerby.* From the marlstone beds in the lias formation.



6. Trigonia costata. *Sowerby*. From the lower and middle oolite formations.
7. Mya V-scripta. *Sowerby*. From the lias, lower and middle oolite formations.
8. Pterophyllum comptum. *Phillips*. From the carboniferous shales of the lower oolite series near Scarborough.
9. Cidaris intermedia. *Fleming*. From the middle oolite formation.
10. Gervillia acuta. *Sowerby*. From the lower oolite formation. (Goldfuss thinks it a different species.)
11. Vertebra of plesiosaurus. From the lias.
12. Ammonites calloviensis. *Sowerby*. From the Kelloway rock and Oxford clay.
13. Terebratula acuta. *Sowerby*. From the marlstone beds in the lias, &c.
14. Nerinea cingenda. *Voltz*. From the lower oolite formation.

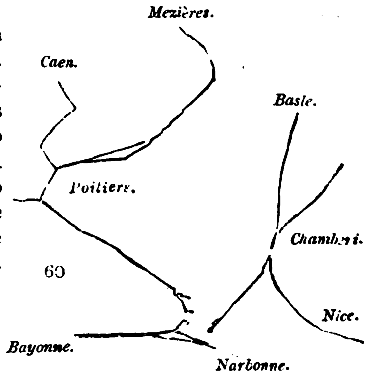
During the oolitic period the arctic land was covered by plants like those of hot regions, whose vegetable ruins have locally generated coal beds—adorned by coleopterous, neuropterous, and other insects—among which the flying lizard (pterodactylus) spread his filmy wings. The rivers and shores were watched by saurians more or less amphibious (megalosaurus, iguanodon), or tenanted by reptiles, which by imaginative men have been thought to be the originals of our gavials and crocodiles; while the sea was full of forms of zoophyta, mollusca, articulosa, and fishes. Undoubtedly, the general impression, gathered from a survey of all those monuments of earlier creations, is that they lived in a warm climate; and we might wonder that the result of all inquiry has shown no trace of man or his works, did we not clearly perceive the oolitic fossils to be all very distinct from existing types, and combined in such different proportions, as to prove that circumstances then prevailed on the globe, materially different from what we now see, and probably incompatible with the existence of those plants and animals, which belong to the creation whereof man is the appointed head.

Geographical Extent.—The oolitic system occupies a considerable surface in England, but is very slightly represented in Scotland (at Brora in Sutherland, in Skye, and other Western Islands), Ireland (about Ballycastle), and in Wales (Aberthaw, Glamorganshire). The lias formation has its western edge continuous, or nearly so, on the surface from the sea-coast near Redcar in Yorkshire to the rival cliffs of Lyme Regis in Dorsetshire. In this long course it passes by Northallerton, Easingwold, and Market Weighton to the confluence of the Trent and Humber; thence due south to Newark; afterwards in a generally south-west course by Belvoir, Leicester, Lutterworth, and Southam to Evesham. From Pershore a long projection of lias runs out northward to Hanbury, but the principal range returns by Tewkesbury, Gloucester, Berkeley, and Sodbury to the Avon at Keynsham. From the Avon to the Mendip Hills the distribution of the lias is intricate; south of that chain of limestone, the lias runs out westward between the rivers, and even extends beyond Watchet; from Langport and near Taunton it turns south and (resting on red marl) it passes under the over-extended strata of green sand and chalk. An extraordinary patch of lias occurs in the red marl between Whitchurch and Wem.

Within this long range the lower or Bath oolitic formation is equally continuous, except where unconformably covered by the chalk between the Yorkshire Derwent and the Humber, and in Dorsetshire; and its course may be described as parallel to, and lying on, the eastern side of the lias. Guisborough, Coxwold, Whitwell, South Cave, Lincoln, Grantham, Uppingham, Northampton, Banbury, Stow, Cheltenham, Stroud, Marshfield, Frome, Yeovil, Ilchester, and Bridport, are situated near its western boundary. Parallel to this, and more to the east, is the less continuous range of the coralline oolites, which passes from Scarborough due west to Hambleton, then turns south-east to Malton, beyond which it is concealed beneath the chalk. The argillaceous part of this group (Oxford clay) reappears in Lincolnshire, near Brigg, and passes by Sleaford, Peterborough and Bedford, to Ottmoor near Oxford. From this point the oolitic rocks are added to the series, and the formation fills the vale of Isis to Cricklade, turns south to Chippenham, Calne, and Melksham, and, with some interruption in the oolites, continues by Wincaunton and Sturminster toward Ilminster, where it is covered by the Dorsetshire chalk, but reappears on the south side of it about Weymouth. The Portland oolite formation, represented only by the Kimmeridge clay, fills the vale of Pickering in Yorkshire, borders the chalk and lower green sand of Lincolnshire, from the Humber at Ferraby to Spilsby; underlays a large part of the Fens, and with the Portland oolite fills a considerable breadth in the vale of Aylesbury. Irregularly capped by the same oolite, and sands, the Kimmeridge clay passes by Shotover, Cumner Hurst, Faringdon, and Swindon, to Wotton Basset; turns south to Seend and Westbury; appears about Wincaunton and Sturminster, passes under the Dorsetshire chalk, and reappears near Weymouth and in the isle of Portland.

The minute flexures, irregularities, and breaks in the ranges of these formations, can only be understood by consulting a good geological map; but the preceding notices will suffice to show how remarkable is the effect, in the geology of England, of their parallel courses from sea to sea—from Yorkshire to Dorsetshire. In this respect their ranges are of great importance, offering to the inquiring mind a proof of the long succession of quiet processes by which the bed of the sea was gradually filled with a regular series of varying deposits—alternations of chemical and mechanical products—and afterwards, it is almost certain, gradually lifted so as to change with a certain regularity the ancient boundary of the sea. The Wealden formation, in this, as in all else, contrasts very strongly with the truly marine deposits. It makes no part of this parallel series, but lies principally in Kent and Sussex, occupying all the drainage of the Medway above Yalding, the upper branches of the Mole, Wey, Arun, and Adur, and the Ouse. From near Beachy Head to near Hythe and Ashford, the whole breadth of the Weald of Kent and Sussex is formed on these rocks, which are therefore happily named. Detached portions occur in the isle of Purbeck and in the vale of Wardour in Wiltshire, and analogous accumulations near Boulogne and Beauvais.

On the continent of Europe the oolitic rocks appear connected by direction in Normandy with those of England, and the series there is extremely similar and not less fully developed. The figure of the geographical area occupied by these rocks in France and Germany is so singularly ramified as almost to defy description. One portion surrounds the basin of Paris in a course from Caen by Mortagne near Angers, Saumur, Poitiers, Chatelherault, Bourges, Auxerre, Bar le Duc, Mezières, spreading to Luxemburg, Metz, Nancy, and Dijon,



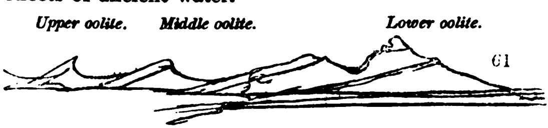
and running south to near Lyons. From near Poitiers branches pass off westward to La Rochelle, and south-eastward to the Cevennes. The north flank of the Pyrenees has a belt of oolitic rocks. Another range passes from near Narbonne due N. E. to Savoy, where it bifurcates; one branch forming the French and Swiss Jura, which, crossing the Rhine above Basle, continues north of the Danube to Ratisbon, and thence turns north to the Mayne at Banz. The other branch keeps the south side of the Rhone, to the Vallais, and thence forward to Vienna forms part of the great chain of the Alps, but is so altered in aspect from ordinary "Jura kalk" as to have been for a long time considered as quite of a different age. The limestone, north of the Carpathians about Krakow, may be looked upon as of the same age.

The south side of the Alps is in like manner bordered by a similar range of the Jura kalk, from the Lago Maggiore, by Lago di Guarda, Belluno, and Laybach, where it expands greatly, and sends off ridges through Illyria, Dalmatia, Albania, and Greece.

Throughout the greater part of this range, except in France, the minute distinctions of the English formations vanish. In the Swiss and German Jura, and the Alpine borders, the oolitic rocks, though connected with the strata of Normandy, vary greatly from that type, so that in some districts hardly any member but the lias can be perfectly discriminated from the general oolitic mass. This renders very singular the perfect exactness with which the argillaceous rocks in the south slope of the Himalaya represent the English lias,—an agreement which, perhaps, by further researches, may be found not less complete than that presented by the lias of Wurtemburg and Franconia, which can hardly be said even to differ from the argillaceous rocks of the Yorkshire coast. (See Geol. Proceedings, for Mr. Murchison's notices of the Banz Series, and Voltz on Belemnites for proof of the identity of the Wurtemburg and Whitby lias.)

Spain, the Balearic Islands, and the Apennines, contain the oolitic system, which also appears in the range of the Atlas.

Physical Geography.—The oolitic tracts of England present a broad band of dry limestone surface, rising westward to elevations of 800 and 1100 feet (in Yorkshire 1485 feet), with escarpments commanding very extensive prospects over the undulating plains of lias and red marl. Even where the valleys are abrupt, as about Stroud and Bath, the scenery, though pleasing, appears tame to one acquainted with the older strata. This arises from the comparative softness and easy destructibility of the rocks; for in some parts of the Swiss Jura the harder limestones appear in mighty precipices. The facility of waste has permitted, on the western border of the districts in England, the production of frequent outlines of the limestones on the clays; as Bredon Hill, which stands up in the vale of Gloucester to attest the powerful effects of ancient water.



The whole tortuous line of oolitic escarpment from the Humber to the Avon may be regarded as the wasting effect of water on the subjacent red marls and lias clays; but what that water, when and how applied, is a problem of general geology, on which we may enlarge hereafter.

Each oolitic rock forms an escarpment over the subjacent clays, so that several longitudinal hollows and ridges undulate the area occupied by the oolitic system.

Igneous Rocks.—In Scotland, the Ord of Caithness offers a case of granitic rocks uplifted in a solid form among the oolitic strata, which are in consequence much fractured and displaced. In Yorkshire, the great Whin-dyke of Cockfield fell crosses the lias and lower oolites, and affects the argillaceous and arenaceous beds considerably, both by induration and debitumenisation.

General Review. — *Oolitic System.*

Perhaps nothing more clearly demonstrates the frequent dependence of geological phenomena upon causes acting at a distance, than the total dissimilitude of the rocks of the oolitic and saliferous periods; for not the slightest unconformity of dip or direction appears at their line of junction, to mark any local disturbance. The repetition of clay sandstone and oolitic limestone observed at least four times in this system, shows the persistence of the new conditions impressed upon the land and sea, while the very local interpolation of grits, shales, and coal, like those of older periods, may be viewed as the result of a temporary restoration of communication from some particular tracts of land to the oolitiferous sea. If, as appears probable from the thickening of the interpolations towards the north, we suppose that the same land yielded the sandstones, shales, and vegetable basis of coal in the carboniferous and oolitic periods, the change of the land plants in the interval from lepidodendra to cycadites is very remarkable, especially when we take into account the exceptional case stated by Dr. Beaumont, of plants of the true carboniferous era occurring above and below beds containing fossils of the true lias at the Col du Chardonet in Dauphiné.

The Wealden formation suggests inquiries of the same order as to the situation and character of the ancient land, from which it has been assumed that a great river flowed into the estuary, through forests of large endogenous plants, tenanted by the iguanodon, hylæosaurus, and other large land reptiles. The limited range of the Wealden deposits, their quick termination toward the north-west and south-west, and their expansions, though feeble, to Beauvais and Boulogne, seem to render the supposition of a single river flowing from the west less probable than the concurrence of partial streams from the south and east, with a great current from the north. May we venture to suppose that the primary tracts of the Scandinavian peninsula and Scotland, with other land now sunk beneath the German Ocean, has been the source of most of the arenaceous and argillaceous deposits of the carboniferous, oolitic, and Wealden formations of England? In this point of view, the local strata of Brora, the thick coal series of Bornholm, the oolitic coal tracts of Yorkshire and Westphalia, the Wealden of Boulogne, Beauvais, Sussex, Dorset, Wilts, are all partial and local deposits due to a similar succession of causes, and arising from the same or neighbouring physical regions, as the materials of some of the older coal strata. In Bornholm, coal occurs with marine beds of all geological ages from the transition era to the cretaceous group; and the dependence of its deposits on the waste of the Scandinavian mountains is decided. The dependence of the other deposits on the waste of land in the north is a probable inference; and if we imagine, what is probably true, that the Scottish and Scandinavian coasts were once united, the whole of the phenomena are intelligible as varied deposits on the shores of one limited sea.

The distinction of quantity between the few oolitic and wealden plants, and the vast heaps of vegetable reliquiæ preserved in the older coal strata, is important, and might be explained as an effect of the diminution of the quantity of carbonic acid gas in the atmosphere, did not the uncertainty of our knowledge of the position of the ancient land, and the too local occurrence of the phenomenon, prohibit the application of such general views. It is supposed to be certainly proved (Buckland's Bridgwater Treatise), that the dirt bed in the island of Portland contains the remains of trees which really grew on the very spot, and were, by a general and quiet subsidence, overspread by oceanic sediments: the character of the cycadioideæ here buried demands our belief that the climate of the northern lands was then warm. It would be altogether unreasonable to doubt that the same explanation is required by the numerous and varied forms of reptile life, which, with the oolitic era, sprung into such wondrous magnitude: nothing can be more clear than the dependence of the geographical distribution of reptiles upon the feeble power of generating heat in their own bodies, in consequence of the nature of their respiration; for this renders their existence impossible without a certain amount of heat communicated from without. Hence the magnitude, and variety, and activity of reptile life under the tropics; hence the smallness, feebleness, summer life, and winter sleep, of the very few species which occur in the northern regions.

Perhaps we may properly appeal to the fossil corals of the oolitic rocks in support of this conclusion; but it would be ridiculous to quote mollusca or crustacea for such a purpose; and, with regard to fishes, we must wait for the deliberate decision of M. Agassiz. It is remarkable that something like a gradation of deposits connects the red marls and lias marls of England; sandstones which might be referred either to keuper or to lias occur in Luxemburg and on the Rhine; while in the Alps of Savoy we see the oolites intercalated with green sands, and in Yorkshire and at Havre the Kimmeridge clay appears to join itself with the golt. These transitions are merely examples of the general harmony which connects together the whole system of stratified deposits into one varied and locally disturbed series of phenomena.

Cretaceous System.

Composition.—As in all the older great assemblages of strata, calcareous, argillaceous, and arenaceous rocks combine to form the Cretaceous System ; but all of these have peculiarities by which they may, *upon a great scale*, be distinguished from the aqueous products of other periods. The arenaceous rocks are often found in the state of unindurated or even loose sand, the clays are generally soft and marly, the limestones soft and earthy. Peculiar colours also belong to these different members of the group: the sands are often green, sometimes very ochraceous, the clays of a pale greenish blue, the limestones white or red. Variations, however, occur in particular districts. The sands and limestones are usually rather coarsely grained, composed of clear worn quartz grains and pebbles, mixed with some calcareous matter, and coloured by disseminated ochraceous oxide of iron to yellow or brown tints (Woburn, Ryegate), or rendered green by interspersed large or small grains of a peculiar mineral (silicate of iron). This granular mineral is, indeed, eminently characteristic of the lower portions of the cretaceous system, being found commonly in two great groups of "green sands," in an intermediate clay, and in the superincumbent chalk. Nor is its diffusion confined to Europe: it is so abundant in the cretaceous rocks of the New World, as to be used for manure in New Jersey. Fuller's earth and good ochre lie in the lowest arenaceous sands (Woburn, Nutfield, Shotover). Layers of chert nodules occur in the sand, and sometimes beds of chert. In Kent, beds of whitish limestone, of considerable thickness, interlaminate the lower green sands; harder limestone lies in them in Lincolnshire. The clay is usually of a marly or even chalky type, and of a light blue tint (golt of Cambridge), but also of a full blue colour (Folkstone) and somewhat laminar texture; generally it holds small balls and irregular masses of clay indurated by oxide of iron, or crusted over by pyrites. In the Wealden district are some red layers. Green grains are commonly found in it: analysis generally shows it to contain much calcareous matter.

But the most peculiar characters belong to the calcareous rocks, which are, of all the limestones known (excepting some in the tertiary deposits), the softest and most earthy. Not that the whole mass is correctly described by the term chalk, as technically applied by geologists; but yet a large proportion of the rock would be so termed even by ordinary observers, from the whiteness and comparative softness of it. In the lower parts, green grains are common; at the base in Lincolnshire and Yorkshire, a red band of from 6 to 12 feet in thickness is traced. Throughout the lower and indeed the greatest part of the chalk in Yorkshire, flint nodules occur in layers; but in the south of England they are nearly confined to the "upper chalk," in which they form layers 4 to 6 feet apart. At Sudbury, flint laminæ occur in the planes of stratification, as at Meudon near Paris.

Stratification.—The clearest possible evidence of regular deposition from water is found in all the rocks of this system, but in few instances are either beds or laminæ traceable so clearly or for such distances as among the older formations. In the green sands, beds are seldom clearly traceable, except where, as in the Isle of Wight and at Folkstone, argillaceous beds occur below and above, and are interpolated among the sands, or where, as at Maidstone, Hythe, and in Lincolnshire, bedded limestones necessarily introduce this structure among the sands. In other cases the layers of chert nodules, or thin chert beds, mark the successive stages of deposition: where none of these causes exist, oblique lamination, and concretionary geodes and other arrangements of oxide of iron, render it almost vain to look for stratification.

The golt clays are sometimes laminated (Speeton, Folkstone), and often, by the courses of small nodules, or by interposed beds of sand, show proofs of successive deposition.

The chalk is only partially bedded, and not at all laminated: its slow, and quiet, and intermitting accumulation is, however, perfectly proved by the regular arrangement of the flint nodules, which are so common in its upper part. No layers of sand (or clay ?) occur in any part of its thickness. Joints are not, in general, either numerous or regular in these formations, nor, excepting geodes and shells of oxides of iron, and the nodules of flint and chert, are concretionary structures common among them

Succession of Strata.—The basin of Europe offers generally the same succession of cretaceous deposits, as in the British islands; but there are local variations of importance. Two formations constitute this system in England and Ireland, which may be thus analysed and described: —

Chalk formation, 600 ft. thick.	g Upper chalk, usually a soft white calcareous mass, with chert nodules at regular intervals: the upper part in the Isle of Wight is of a marly nature.
	f Middle chalk, not very clearly definable; of intermediate character as well as place between the upper and lower chalk.
	e Lower chalk, harder and less white than the upper, sometimes varied by green grains, generally with fewer flints (red in the North of England).
	d Chalk marl; a soft argillaceous form of chalk.
Green sand formation, 600 ft.	c Upper green sand (firestone, malm rock, &c.); a mass of sands, occasionally indurated to chalky or cherty sandstone, of green, gray, or white colour; with nodules or laminæ of chert.
	b Golt (Tetsworth clay, Folkstone clay, &c.); soft bluish marly clay, with green grains.
	a Lower green sand (iron sand, Shanklin sand); a considerable mass of green, or ferruginous sands, with layers of chert, local beds of golt, rocks of chalky or cherty limestone, and deposits of ochre and fullers' earth.

In the north of England the upper green sand is totally deficient; nor is it so distinct from the chalk formation in Kent and Sussex as in Berkshire and Wiltshire. In Yorkshire there is no lower green sand, but in Lincolnshire it is greatly developed, and contains useful calcareous beds. In the north of Ireland the series of cretaceous rocks corresponds nearly to the English type, the green sand being called mulatto, but the chalk is generally harder. Round the basin of Paris the series is also similar, as may be seen by consulting the classification of Cuvier and Brongniart. — About Aix-la-Chapelle, the same formations and groups appear; and the general features, at least, are retained through Westphalia (Essen, Paderborn) and along the plains of northern Germany. On the Elbe, about Dresden and Pirna, the lower green sand is called quadersandstein, the representative of the chalk planerkalk. In the Carpathians is no chalk, the green sand being greatly developed. In the Alps is no chalk, and beds of green sand are intercalated among the upper Jurassic oolites (Salève). But the most remarkable case is the addition of another limestone rock, above the upper chalk, very coarse and sandy in texture, but containing layers of flints, in St. Peter's Mountain, near Maestricht. This rock seems, by its composition and organic contents, to offer an imperfect transition from chalk to the calcaire grossier, one of the next incumbent tertiary strata (Fitton). Murchison and Sedgwick suppose the shelly marls of Gosau to present a somewhat different case of transition from the cretaceous system of the Styrian Alps to the tertiary rocks. The whole cretaceous system of America may be taken together into two great masses, — a chalky, or at least calcareous, mass above, and a green sand mass below. These very general analogies appear at very distant points, and the most constant of the formations is the sedimentary or green sand group. (Rogers, in Rep. to Brit. Assoc.)

Organic Remains. — The fossils of the cretaceous system are eminently marine: nearly all the plants which it contains (they are few) are of marine types; and the sponges, stellerida, mollusca, crustacea, fishes, and reptiles, all appear to have been inhabitants of the ocean. Mammalia are not known in the cretaceous rocks. It appears that (excluding the Maestricht and Gosau beds) nearly the same large proportion of extinct genera, and the same differences of proportionate development of molluscous groups, is traced in the cretaceous as in the oolitic system; so that both the oolitic and cretaceous fossils are reliques of a condition of land

and sea very different from what we now witness. The fossils of the two systems are, however, very materially different, even in the same natural groups, as sponges, crinoidea, stellerida, echinida, cephalopoda, crustacea, fishes, and reptiles, in most of which groups the chalk and green sands contain genera never found in any rocks more ancient or more modern; while oolitic and tertiary genera are not found in the cretaceous rocks. There appears no sufficient evidence in the fossils of this system to justify any positive inference as to the character of the climate then prevailing in the northern zones; but we may be sure that the sea was very little disturbed by inundations from the land, otherwise ferns and other land plants, and not fuci, would have been found in the sandy strata.

The condition in which the zoophyta especially are preserved in the chalk and green sands deserves notice. Sponges are silicified in both deposits — possibly from some peculiar affinity which those organic bodies, even in a recent state, appear to possess for silica; but in the same flint nodules which envelope silicified sponges, the crusts of echinodermata and stellerida are found converted to crystallised carbonate of lime, and lamellar shells of the genus gryphæa, and radiated sheaths of belemnites, are not at all changed in texture, and very slightly altered in chemical composition. It is a very common fact that iron pyrites collects around sponges and other organic bodies in the chalk, and, when decomposed, leaves an ochraceous oxide of iron.

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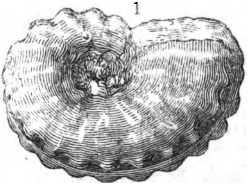

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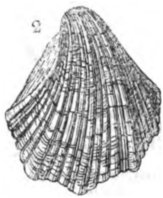
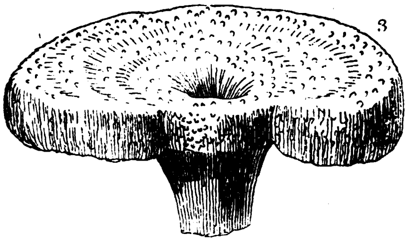
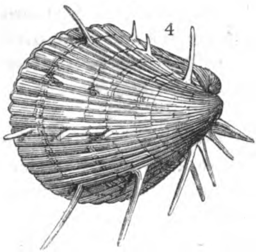
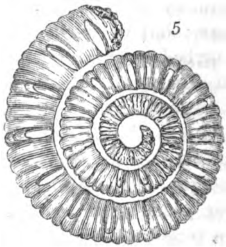
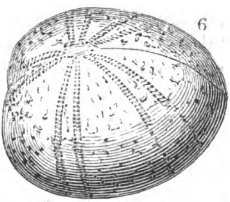


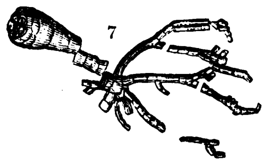
1. Ammonites varians. *Sowerby*. From the lower chalk, chiefly.
2. Pecten quinquecostatus. *Sowerby*. From the upper green sand, chiefly.



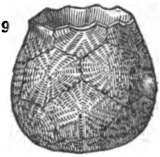
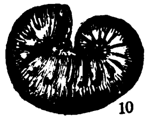








3. Spongia plana. *Phillips.* From the chalk.
4. Plagiostoma spinosum. *Sowerby.* From the chalk.
5. Hamites intermedius. *Phillips.* From the Gault. (It belongs to the new genus Crioceratites.)
6. Spatangus hemisphæricus. *Phillips.* From the chalk.
7. Apiocrinus ellipticus. *Miller.* From the chalk.
8. Belemnites mucronatus. *Brongniart.* From the upper chalk. Several other species occur in the English and European chalk.

9   10

9. Marsupites ornatus. *Miller.* From the chalk.
10. Scaphites equalis. *Sowerby.* From the chalk.

Geographical Extent. — In a general sense, the cretaceous system ranges parallel to the oolitic formations from Yorkshire to Dorsetshire, and sends branches from the plains of Hampshire which border on the north and the south the Wealden formation of Kent and Sussex. The green sand formation is, in all parts of England, so closely connected with the chalk (except in Yorkshire, where it is almost deficient, and in Blackdown, Devon), that it appears unnecessary to notice more than the characteristic range of the chalk. This distinguishing feature of English geology overlooks the German Ocean at Flamborough Head, and sweeps in a large curve inland by Birdsall and Pocklington to the Humber, at Hessle; thence it pursues a south-eastward course to Candlesby in Lincolnshire; and, after the interruption of the "Wash," reappears in the cliffs at Hunstanton. Hence to Stoke Ferry its course is south; but it turns S.W., parallel to the oolities, by Cambridge, Baldock, Wendover, Wallingford, to above Wantage and Devizes. Hence it returns east to the sources of the Kennet, and gives origin to a great ridge (the North Downs) dipping north, and passing by Kingsclere, Guildford, Reigate, Wrotham, and Maidstone to Dover; which corresponds to another great ridge (the South Downs) dipping south, and passing from Beachy Head by Lewes, Steyning, Petersfield, and Alton, to join the North Downs at Farnham. From the sources of the Kennet to Salisbury, and from Farnham to Bishop Waltham, the chalk expands over a vast space in Hampshire; but its proper outcrop is the western boundary of Salisbury Plain, by Lavington, Westbury, and Maiden Bradley. The Vale of Wardour is another deep indentation reaching almost to Wilton, from which the chalk returns to Shaftesbury, and then sweeps in a concave arch by Cerne Abbas to Beaminster, and suddenly retires in a narrow eastward course by Abbotsbury and Upway to Corfe Castle. This remarkable ridge of chalk (nearly vertical), reappears in the Isle of Wight at the Needles, and ends at the Culver Cliffs. Detached portions of chalk lie on the green sands of Blackdown; Portsdown and Thanet are detached ridges.

In Ireland, a large detached tract of chalk lies under the basalt of Antrim. About Ballycastle, Glenarm Bay, and Larne, and at Belfast, the superposition of the basalt on the chalk is very plainly seen. There is no chalk in Scotland or Wales.

On the continent of Europe, the cretaceous rocks are no where more perfectly developed than in France, where a complete series of the chalk and green sand formations encircles with a broad ring the tertiary basin of Paris; filling large tracts in Artois, Picardy, Normandy, Touraine, and Champagne; bordering the Channel from Boulogne to the mouth of the Seine, and resting every where on an oolitic basis, except on the Belgian frontier about Avesnes and Mons. Here it touches the slaty rocks of the Ardennes, and covers their parallel bands of coal and limestone. It continues north of the Meuse to Maestricht and Aix-la-Chapelle, and reappears beyond the Rhine in a narrow range and argillaceous condition, north of the Westphalian continuation of the Ardennes from Essen to beyond Paderborn. Detached portions occur about Hanover and Brunswick*; and from the appearance of it at Grodno, Prentzlow, Luneburg, the isle of Rugen, and many parts in Jutland, Zealand, and Scania, there can be little doubt that chalk

* The upper part, or slaty, marly limestone, rather than chalk, is called planerkalk; the lower or sandy rock is called quadersandstein: distinctions still clearer in the large area within the Bohemian mountains, where on the course of the Elbe the rocks of this system are widely spread.

lies very extensively under the plains of northern Germany. (Heiligoland is formed of wasting green sand.)

The green sand formation is more extensively spread than the chalk, for it is chiefly in this form that we recognise the cretaceous system about Dresden, in the Alps, in the Carpathians, and even the Pyrenees. On the Italian side of the Alps, the chalk is supposed to be represented by the scaglia of Genoa and Lombardy.

In North America, according to Dr. Morton and Professor Rogers, the cretaceous system is largely developed on the Atlantic coast in New Jersey, whence it may be traced locally through Delaware, Maryland, Virginia, North and South Carolina, Georgia, Florida, Alabama, Mississippi, Tenessee, Louisiana, Arkansas, and Missouri. In the northern parts of this extensive range, yellow ferruginous and green sands, and some argillaceous beds, constitute the greater part of the system, as in the Carpathians, and are excessively rich in the green silicate of iron; they are covered by friable limestones and calcareous sandstones. Such green sands occur more rarely in the south-western tracts, and are there associated with, and finally superseded by, very thick cretaceous and compact shelly limestones, apparently superior in position, which rise into bold hills. It is curious that, for a great part of this range, the green sands are separated from the primary strata more inland by a narrow belt of tertiary and alluvial deposits. "By specimens brought from time to time from the interior of the continent, it would appear to occur abundantly on the Missouri, far across towards the Rocky Mountains."*

Physical Geography.— In England, the range of the chalk is one of the most conspicuous features of the eastern and southern counties, in which it forms a noble chain of hills, still partially left (as, perhaps, they all should have been) open for sheep-pasture. These

* Rogers, in Report to Brit. Association.

"wolds" or "downs" are covered with a sweet short herbage, generally bare of trees, and singularly dry, even in the valleys, which for miles wind and receive complicated branches, all descending in a regular slope, yet are frequently entirely dry, and, what is most singular, contain no channel, and but little other circumstantial proof of the action of water, by which certainly they were excavated. Both the dry valleys and the bare hills have characteristically smooth and flowing outlines (represented with excellent taste by Fielding), very different from the tabular hills of oolite, and the rugged chains of older rocks. The same characters accompany the chalk in France. The green sand ranges are less characteristic, though in Leith Hill and Hazlemere Forest they rise to nearly 1000 feet in height, and thus rival the chalk, which generally swells to 800 feet, but no where, except at Inkpen Beacon, equals 1011. Copious springs flow from the chalk, over the subjacent golt; or issue on the dip side at low levels: wells sunk in the chalk to some hundred feet yield water, *at different levels according to the impediments in the subterranean currents.* Where tertiary clays cover the chalk, as in the basin of London, the boring rod no sooner pierces them than strong streams arise, with a temperature much superior to that of the surface, over which they sometimes flow in a constant stream.

Igneous Rocks.—In no part of England is there the smallest trace of igneous rocks associated with the chalk. In Ireland, a very large tract of basaltic rocks occupies the greater part of the drainage of Lough Neagh, and the river which issues from it to Coleraine. If a line be drawn from the mouth of Lough Foyle to Lurgan on Lough Neagh, nearly all the country to the east of it is trap, here and there in the interior, and generally on the coast, exposing chalk, and more locally mulatto, lias, new red sandstone or coal measures. The thickness is in places (Knockhead) supposed to be little short of 1000 feet, and the superficial area 800 miles! What a magnificent volcanic eruption is here pictured in its submarine lava currents! For it undoubtedly was a mass or series of expansions of liquid lava poured on the bed of the sea after the deposition of the chalk. It is a series of basaltic and ochraceous beds,—some of the former being eminently columnar. Near the Giant's Causeway, the following succession is given by Dr. Richardson:—

1. Basalt rudely columnar	60 ft.
2. Red ochre or bole	9
3. Basalt rudely prismatic	60
4. Basalt columnar	7
5. Intermediate between bole and basalt	8
6. Basalt coarsely columnar	10
7. Basalt columnar; the upper range of pillars at Bengore Head	54
8. Basalt irregularly prismatic; inclosing the wacke and wood coal of Port Noffer	54
9. Basalt columnar forming the Causeway	44
10. Bole or red ochre	22
11, 12, 13. Basalt, tabular, divided by the layers of bole	80
14, 15, 16. Basalt, tabular, with zeolite	80

The stratified rocks on which the basaltic masses rest, are variously altered by the effect of their former heat. Lias is changed, at Portrush, into a hard rock like flinty slate: by the side of basaltic dykes at Fairhead, the coal shales are similarly hardened: red sandstone is indurated at the foot of Lurgethan; and in Rathlin, at Glenarm, &c. the chalk is changed by dykes into a largely crystalline marble.

The quadersandstein (?) of Weinbohla (on the Danube) is overlaid by a syenitic rock.

In the Pyrenees, cretaceous strata are in contact with granitic and serpentinous rocks, and mineral veins are in consequence introduced among them. (M. Dufrenoy.)

Close of the Secondary Period.—Ensuing Disturbances of the Crust of the Globe.

With the cretaceous system ends the long series of deposits which are, by general consent, ranked as strata of the secondary periods of geology. In reviewing the successive secondary formations, from the red sandstones to the green sand, and from the mountain limestone to the chalk, it is impossible not to recognise, on a great scale, the gradual change of the physical conditions of the globe which took place during this period. Mineralogically, the rocks successively deposited deviate more and more from the types of the primary strata; considered as to their zoological and botanical relations, it is evident that the circumstances influencing organic life were undergoing gradual but great changes; and a careful study of the geographical areas over which the secondary strata spread, demonstrates that an equal amount of variation occurred in the relations of land and sea. It may, indeed, be objected, that these conclusions, however true, are almost limited to Europe, North America, and India, since elsewhere the secondary rocks are but imperfectly known; but if the data for reasoning are satisfactory, the geographical area of their application is ample.

Several distinct mineral types appear predominant in the secondary rocks of Europe, constituting various groups of strata, which may not always be found to combine into exactly the five systems adopted in these pages. The really oceanic types of limestone are three, viz. —

Chalk.
Oolite.
Mountain limestone.

To each of these belong similiar concretionary masses of flint or chert, often aggregated round organic bodies, and sometimes extended into thin interrupted layers.

The really littoral types of sandstone are various: —

Green or ferruginous sands.
Pale coloured calcareous grits.
Red and white sandstone.
Red conglomerates.
Felspathic sandstones.
Quartzose grits.

Of argillaceous beds are three principal types :—

Blue clays, often inclosing nodules and beds of compact limestone.
Red, white, and blue clays, with gypsum.
Blue or black shales.

Not one of all these rocks can be considered as universally coextensive with the secondary series: but it appears from examination, that, in most districts, the conditions under which these various deposits happened, were contemporaneous, or at least succeeded one another in the same order. A very general view of the mineral relations of the rocks would allow us to consider the whole secondary series in two parts, — the lower one characterised by red sandstones and red clays, the upper by blue clays and light coloured sandstones; while in each of these divisions occur carboniferous deposits breaking the uniformity of the series. This arrangement is seen below: —

Cretaceous group. Oolitic group.	Including the coal deposits of the Wealden, Yorkshire, and Bornholm.
New red sandstone group. Old red sandstone group.	Including the principal coal deposits of Europe.

Nor would such a classification be inapplicable to the calcareous portions of the series, though, as might be expected, these admit of other combinations. Whenever the causes of these successive mineral characters in the secondary rocks shall be known, a great advance will have been made toward a general theory of the stratified crust of the globe.

Turning to the organic remains of the several secondary systems, it is apparent that, within the period of time which elapsed between the deposition of the primary and tertiary strata, two very distinct assemblages of terrestrial plants had flourished and become extinct. The ancient and abundant flora of the carboniferous era, with its lepidodendra, sigillariæ, and calamites, had been replaced by new races of zamiæ and cycadeæ, which, in their turn, vanished from the northern zones of the globe before the completion of the cretaceous system. The marine zoophyta were changed, though not to the same extent, both as regards the polyparia and crinoidea. One total change had come over the crustacea, — not a single trilobite being known in the strata more recent than coal: the brachiopodous conchifera, the gasteròpodous and cephalopodous mollusca, were equally altered. Two large assemblages of fishes had vanished before the deposition of the chalk; and both on the land and in the sea, gigantic reptile forms had come into being — reproduced themselves to a marvellous extent — and then all perished with the close of the secondary period.

How, then, can they, by whom the magnificent truths of elapsed time and successive creations have been put in clear and strong evidence, how can they be expected to yield to false notions of philosophy, and narrow views of religion, the secure conviction that, in the formation of the crust of the earth, Almighty wisdom was glorified, the permitted laws of nature were in beneficent operation, and thousands of beautiful and active things enjoyed their appointed life, long before man was formed of the dust of the ancient earth, and endowed with a divine power of comprehending the wonders of its construction? It is something worse than philosophical prejudice, to close the eyes of reason on the evidence which the earth offers to the eyes of sense; it is a dangerous theological error to put in unequal conflict a few ill-understood words of the Pentateuch, and the thousands of facts which the finger of God has plainly written in the book of Nature; folly, past all excuse, to suppose that the moral evidence of an eternity of the future shall be weakened by admitting the physical evidence for an immensity of the past.

Since the close of the secondary period, the earth's surface has been greatly altered and the boundaries of the ocean entirely changed in the northern zones, on the Mediterranean shores, and on the coasts of India and America. It is difficult to collect very certain evidence of the occurrence of general subterranean movements immediately after the completion of the chalk, though the great extent of sands, and pebbles, and lignitic beds which cover it, and the deep wasting on its surface, as seen beneath those sands and pebbles, leaves no doubt that what had been deep sea was converted to shallow water, and subject to inundations from the land. In many cases, these pebbles appear to be nothing else than broken and rolled flints, derived from the chalk itself; some of the white sands which form part of the tertiary series, when magnified, appear to be fragmentary particles of flint, very slightly worn by attrition; but, upon the whole, the great mass of tertiary deposits in every country can only be understood as derived from the older strata, and, in some cases, transported from considerable distances.

Clear proof of local disturbance of the chalk and older strata, before the production of any tertiary strata, can no where be given in England or Ireland, unless the pebble beds of the former country, and the basaltic eruption of the latter, be admitted in evidence. In the south-east of France De Beaumont ascribes to a late epoch in the cretaceous period the system of dislocations ranging from N. N. W. to S. S. E., which traverses Mont Viso, the French Alps, and the south-west extremity of the Jura. After the cretaceous period occurred the great disruptions of the Pyrenees and Apennines; but there is yet too little known of the geology of the Ghauts and the Alleghanies, to allow us to determine whether these ranges, which are rudely parallel to the same great circle as the Pyrenees and the Apennines, were (as De Beaumont supposes, and his speculation on the relation of age and direction among mountain chains requires) uplifted at the same geological epoch.

To determine exactly the geological date of a disruption of the crust of the globe is not easy, even when the case is so simple as that of a common "fault;" when it is to apply to a whole chain of mountains no more difficult problem can be proposed to geological observers. In the present case it is rendered still more perplexing by the change of mineral and organic characters which, on the flanks of the Pyrenees, almost destroys the distinction of secondary and tertiary deposits, and leaves little relation between the Apennine limestone and the chalk of Northern Europe, except what the scaglia of Lombardy has afforded.

As far as regards the British islands, a gradual or interrupted rising of the whole bed of the sea would much better suit the phenomena than one mighty convulsion; and Mr. Lyell's views of the gradual rising of the Weald *, though, perhaps, not entirely satisfactory in that particular instance, contain an important illustration of the consequences of such an hypothesis.

TERTIARY SYSTEM OF STRATA.

Supracretaceous Deposits. — *Terrain Tertiaire.* — *Tertiärgebilde.*

Offering a most decided contrast with the secondary and older strata in most of their essential characters, the tertiary strata form a division of the series which may be considered as of more elevated rank than the term "system," in our mode of using it (which is now become common) denotes. But, on the other hand, so many analogies appear among these strata of all ages, that, though with great propriety distinguishable into "formations," they must, for the present at least, be ranked in one general system.

* Principles of Geology, vol. iii. 1st edit.

Composition.—Arenaceous deposits predominate in most parts of the tertiary system; argillaceous types, however, abound in particular districts; calcareous rocks, marine or of freshwater origin, pure, sandy, shelly, or siliceous, lie in many basins; marls and gypsum are locally accumulated. Marine, freshwater, and terrestrial exuviæ occur in strata of all these descriptions; and so much information is now accumulated concerning them, and so many comparisons have been made between tertiary and modern products, that it is probable the origin of no part of the series of strata is so well understood. The sea, sudden land floods, river currents, lakes, springs, have all contributed to the accumulation of the supracretaceous strata, and left characteristic marks of their action. But confining our views, at this time, to the composition of the masses, those distinctions of the origin of the deposits vanish, for it is not directly by the mineral nature of the strata that their freshwater or marine origin could be known.

The arenaceous rocks are either in the form of conglomerates, holding fragments, pebbles, and enormous boulders of the neighbouring mountains, as the molasse of the northern slope of the Alps; or appear as sand (rarely indurated to sandstone), tinted of many varying hues, as at Alum Bay, in the Isle of Wight, where the effect of the many colours imparted by oxide of iron is of a magical description; left white and colourless, as in the Dorsetshire heaths and forests, and at Fontainbleau; or dyed of a general green, as near Paris, at Reading, Sudbury, &c., by silicate of iron. Beds of rolled pebbles (flints from the chalk) and layers of lignite appear not unfrequently among them, and are generally accompanied by sulphuret of iron and clay (Isle of Wight). Mica occurs, but is not plentiful, in these tertiary sands, which convey the impression of much and long abrasion in water, and various exposure to oxygenating processes.

The argillaceous sediments of the tertiary system offer also a considerable variety. The principal mass in the vicinity of London is of a dull bluish or brownish tint, not unlike a clay of the oolitic era. The subapennine "marls" are more sandy. Light greenish and bluish marls occur, with prismatised beds of gypsum, at Montmartre, and accompany the limestones of Headon Hill in the Isle of Wight. But the most singular clays are those which accompany the coloured sands of Alum Bay and the neighbourhood of Paris; for these are almost black, or brown, or mottled in the richest manner with red or white, or almost entirely red, so that the same causes of diversity of colour appear to have affected nearly all the deposits of that particular tertiary period.

The tertiary limestones might, perhaps, generally be discriminated from all those of older date by their very inferior degree of induration, though to this certain freshwater limestones (as near Weimar) offer exceptions. The marine calcaire grossier of Paris is a coarse sandy or chalky limestone; the leithakalk of Austria is a coralline rock, somewhat like the English crag; the freshwater limestones of Headon Hill are soft, marly, and full of shells; that of Oeningen marly and laminated; near Weimar are very hard and compact beds, which inclose nodules of flint, like some in Cantal, described by Mr. Lyell; a peculiar siliceous limestone occurs in the basin of Paris.

From all these variations of composition, it is evident that the accumulation of tertiary strata is the fruit of a great diversity of causes, or else a great amount of local influences has modified the effects of the general agencies. It is not merely that some are of marine, and others of fluviatile, or of lacustrine origin: these are, indeed, the leading considerations to guide our inquiries, but *local peculiarities* of *physical geography* are also clearly indicated as important conditions in determining the nature of tertiary strata.

Structure.—Stratification.—The whole of the tertiary accumulations are plainly stratiform deposits; and they exhibit the different kinds of lamination and bedding which have been so often noticed before, while speaking of older rocks. The molasse of Switzerland, sandstone of Fontainbleau, and sands of the Isle of Wight, are stratified; sometimes, also, parted by oblique or parallel laminæ: the London clay and Headon marls are partially, the Montmartre marl perfectly, laminated: the marine calcaire grossier, and most of the freshwater limestones, are regularly bedded, and the latter very frequently laminated: gypsum occurs at Montmartre, and elsewhere in France, in a bedded mass.

Divisional Planes.—Agreeably to a very general law, which connects the divisional structures with the age of the rocks, and expresses their relative abundance and regularity in terms of their antiquity, we find them less remarkable in the tertiary sands, clays, and marly or chalky limestones, than in any of the older rocks. Joints do certainly exist in them, and especially in the lamellated limestones; and it is probable, from general considerations of the agency of heat in developing these structures, that, near large masses of igneous rocks, as in the Alps, they may be found more numerous. Nor does it appear that many cases of re-arrangement among the particles occur: some oolitic beds occur in the leithakalk; menilite is concentrated in certain marl beds near Paris; flint is collected in nodules in some freshwater limestones; sulphuret of iron gathers round and in the substance of lignite.

Succession and Thickness of the Strata.—Difficulties unfelt with regard to the older systems embarrass the history, or rather the classification, of the tertiary strata. The lower boundary of this system is in general very clearly marked by the peculiar mineral character and remarkable organic remains of the cretaceous rocks; but the upper boundary, the line of distinction between the "tertiary" deposits and those which we may agree to call "modern," is not at all clear. This difficulty arises in various ways: the mineral character and circumstances of aggregation of the tertiary rocks are extremely various according to locality; and in this respect so closely resemble formations now in progress, that were the bed of the Adriatic raised to our view, it would, according to the observations of Donati, most closely resemble the subapennine tertiaries; the German Ocean would disclose shelly sand-banks, comparable, perhaps, to the Norfolk crag; and the coral reefs of Bermudas may be thought to resemble the leithakalk of Transylvania. The analogy of tertiary and modern shells and vertebral reliquiæ is also very great,—so great, indeed, that nothing but very refined knowledge can establish differences between them.

When, in addition to these facts, we are further embarrassed by the intermixture of lacustrine, estuary, and marine deposits, which belong naturally to as many distinct *series* of operations, and certain organic exuviæ which may have unequal *degrees* of relation to existing types, what wonder if it be sometimes impossible to distinguish tertiary from modern accumulations? The progress of research has, indeed, shown us the necessity of separating from the tertiary class a considerable quantity and variety of superficial accumulations, more or less evidently related in their position to the present features of physical geography; but it has also placed the distinction on its true ground, viz. the difference of organic life in the modern and tertiary periods. This difference, however, is probably of a positive character only in the classes of vertebrated animals, which are chiefly met with in lacustrine sediments; and is with difficulty applied to marine races, which constitute by far the largest portion of tertiary fossils, and are the principal means of linking the history of supracretaceous deposits to those of the older periods, which contain almost no traces of mammalia or birds, and only a very limited number of fluviatile reptilia or lacustrine fishes.

It is hardly to be doubted, that hereafter the mode of studying supracretaceous deposits will be so far changed, that the whole series of marine accumulations of every age, from the cretaceous period to the present day, will be grouped together, but distinguished from another equally extended series of lacustrine and fluviatile sediments; the principle of investigation in each case being founded on a rigorous study of the characters of mineral structure, and the organic exuviæ, which are characteristic of the sea, the streams, and the land.

At present, however, not to deviate too far from the method now familiar to geologists, we shall assume that, in spite of the difficulties above noticed, the tertiary strata and modern deposits can be distinguished in particular cases, though not in conformity with any general definition. If the account of the modern deposits be in like manner arranged with reference to the same really influential conditions, — their marine or freshwater origin, — no confusion will, under any circumstances, be caused.

The English series of marine tertiaries is principally exhibited in the basin of Hampshire and the Isle of Wight, in the basin of London, and on the eastern coast, from the mouth of the Thames to that of the Yare; and each of these districts exhibits peculiarities of the component terms. The section of the Isle of Wight, at Alum Bay, one of the most remarkable known in the world, exhibits a great and varied mass of sands and clays, whose planes of stratification, originally horizontal, are now vertical. The whole may be considered as one formation; for, in the lower part, which is principally sandy, argillaceous beds occur, with fossils the same or very similar to those in the upper part. The following is a synopsis of these vertical beds: —

Freshwater Formations above.

Upper group, or London clay.	Yellow and white sands. Dark clay with green earth and septaria, rich in fossil shells. 250 feet thick.

Lower or plastic clay group	Upper part	Layers of black flint pebbles in yellow sand - - Pipeclays and sands of many colours, enclosing several beds of lignite - -	543
		Coloured sands of many tints	321
	Middle part	Dark blue clay, with green earth and shelly nodules	200
	Lower part	Green, red, and yellow sand	60

In the basin of London, the series is very similar; but the London clay is of double or triple the thickness, and the plastic clays and sands are much thinner. The situation of the Bagshot sand at Hampstead and Bagshot Heath appears to be above the London clay, from which it may perhaps be proper to distinguish it as a superior group.

Upper group or London clay	Bagshot sands. London clay of a dull gray, or blue, or brown, sometimes red; often full of green grains. Septaria abound in certain parts: the rocks of Bognor and Selsea are supposed to belong to the lower part of it. 700 feet.
Lower group of plastic clay and sands	Sand of various colours, with occasional beds of lignite or plants. Sand and layers of clay, with or without shells. Sand, green and ferruginous, accompanied by flint pebbles, oyster shells, &c.

In Essex, Suffolk, and Norfolk, the plastic clay group is chiefly represented by the lower green sandy portions, which appear seldom deficient (being found in the Isle of Wight, at Reading, Woolwich, Sudbury, &c.). The London clay is seen at Harwich; and a superior marine deposit, the "Crag," unknown elsewhere in England, appears at Ramsholt, Orford, &c.

Crag formation.
- Upper or red crag; resembles a raised sea-beach, being composed of layers of sand and pebbles, mixed with marine shells and polypifers, worn fish teeth and bones, quadrupeds' bones, &c., the whole generally ochraceous.
- Lower or coralline crag, less ochraceous, almost without pebbles; containing abundance of shells not at all worn, at Ramsholt, and abundance of corals not of European forms at Orford where it is used as a limestone. (Mr. Charlesworth.)

London clay of Harwich, &c.
Green sands over the chalk at Sudbury.

A deposit of tertiary shells in green and irony sands, and in blue clay, occurs at Bridlington in Yorkshire; it is perhaps of the age of the crag, but certainly contains only a few species known to occur in that formation. The most general view of the English marine tertiaries shows sands to be more extensively diffused than clays; the latter are almost limited to the southern basins; the former are no where wholly deficient, and their lower green portions very characteristic. The calcareous crag is merely a local product.

Turning now to the district where first the genius of Cuvier awakened the philosophical study of the tertiary strata,—the basin of Paris,—we obtain highly interesting results for comparison with the English series and those of the south of France, Italy, and the Danube.

The Parisian series is quintuple, but only two of the terms are marine; two are decidedly of freshwater origin as to the materials (one certainly even lacustrine); the fifth (and lowest) is rather to be viewed as a troubled estuary or river deposit, and may be united with the lower marine formation. The whole stands thus in general terms; but we must observe that the several groups are partially mingled with one another by intercalation: there are, in fact, many marine and many freshwater strata.

Upper term.	*Epilimnic or upper freshwater formation* — the uppermost of all the stratified deposits near Paris; consisting chiefly of *siliceous limestone*, or burrstone, marl, and marly sands.
	Upper marine formation — consisting of sandstone, generally white, or partially reddened or ochraceous, and but slightly aggregated, except at Fontainbleau.
Lower term.	*Palæotherian freshwater formation* — characterised near Paris by its ossiferous *gypsum* and marls, siliceous limestones, &c.
	Lower marine formation — consisting principally of limestone (*calcaire grossier*) of various degrees of coarseness, with laminated flint, marls both calcareous and argillaceous, green sands.
	Plastic clay group — an irregular mass of deposits varying with locality, in places yielding *plastic clay* and sands; in other situations, lignites or pebble beds.

There is no trace in the basin of Paris of the shelly and gravelly deposits (falun coquillier) of Touraine, which M. J. Desnoyers compares to the English crag, and considers to be more recent than the epilimnic group of the Parisian basin.

It is obvious that the agreement between the Parisian and English tertiaries is merely in the great features of succession: the lower marine formation in England is principally clay—in France, limestone: gypsum abounds in the palæotherian freshwater beds of France, but not in England. Yet the basin of the Seine, and that of Hampshire, were connected with the same sea, and subject to very similar successions of marine and fluviatile agencies. The difference of deposits is due to the different materials transported in the currents of the sea.

In the south of France the tertiary deposits of the large basin of the Garonne, contain shells like those of Touraine; the beds of Narbonne and Montpellier more resemble the Parisian series. In M. Dufrenoy's recent memoir, he arranges the tertiaries of the south of France in a series of three terms, the upper one of which does not exist at all in the basin of Paris; while, on the other hand, the lower one, well developed near Paris, is only locally seen in the south.

Upper term	Composed principally of beds of pebbles, sands, and coarse sandy clays, which appear all to be eminently detrital formations, so that Elie de Beaumont formerly called them 'Terrain de transport ancien.' Perpignan offers the best type of these beds.
Middle term	Comprising a great variety of deposits, partly freshwater and partly marine; freshwater deposits of limestone on hills (Agenois, Provence); sands and pebbles (faluns) on the plains (Landes); sands and marls (molasse) in low hills in Languedoc; conglomerates at Pau; gypsum and lignites at Aix, and in Provence; concretionary limestones (calcaire moellon) at Montpellier. It contains locally sulphur, and generally iron ore. These variations are the result of local circumstances influencing the borders of an oceanic basin.
Lower term	Chiefly consists of calcaire grossier, and this is almost confined to the 'Landes' between the Adour and Garonne. The beds of limestone alternate with marls and clays, and rest on the cretaceous rocks. — They are full of miliolites.

The middle term of this series corresponds to the upper term of Paris: it expands greatly in Spain and Switzerland.

In Spain abundance of freshwater deposits occur; in Switzerland the sandy and conglomerate beds (molasse) expand into a vast thickness, include beds of limestone and layers of lignite yielding bones, and extend along the north front of the oolites of the Alps towards Vienna. Here in the basin of Lower Styria, Murchison and Sedgwick give us the following general section of the tertiary series.

Upper group.	Calcareous sands and pebble beds, calcareous grits and oolitic limestone—in the low ground of Hungary full of shells, as in the highest beds of the basin of Vienna. White and blue marl, calcareous grit, white marlstone, and concretionary white limestone: shelly.
Middle group.	Coralline limestone and marl, of a yellowish white colour, very thick and shelly (Leitha-kalk of Vienna.)
Lower group.	Conglomerate, with micaceo-calcareous sand and millstone conglomerate: thick. Blue marly shale, sand, &c., full of shells compared to those of London clay and calcaire grossier. Shale and sandstone, with coal or lignite, containing bones of anthracotheria, gyrogonites, &c. Micaceous sandstones, grits, and conglomerates, made up of the detritus of the primary slaty rocks, on which they rest at high angles of inclination.

The authors consider the lower group to correspond with the calcaire grossier and Palæotherian deposits; the middle to the English crag, and middle subapennines. According to M. Dufrenoy, the former would rather appear to belong to the middle tertiary period.

The sections of Transylvania, Hungary, and Moravia may be reduced to the above general type; the lower beds being more argillaceous.

The Italian tertiaries constitute a triple series, but the lower and upper terms appear only at particular points.

Sicilian or upper tertiaries, best seen in the Val di Noto (and Calabria), consist of thick limestone (700 or 800 feet) rising in the hill of Castrogiovanni to 3000 feet elevation; shells nearly all of existing species; white calcareous sand, sandy limestone, and conglomerates.

Subapennine or middle tertiaries, of very great thickness, consisting of innumerable laminæ of marls, calcareous and argillaceous, blue or brownish, like the mud now gathered on the bed of the Adriatic: some sandstones, limestones, and gypsum are locally traceable: 40 per cent. of the shells belong to existing species.

Superga or lower tertiaries, consisting of fine green sand and marl, resting on conglomerate, full of boulders of primary rocks; unconformed beneath the subapennine marls, and containing only a small proportion of recent shells.

Geographical Extent, and Physical Geography. — The tertiary system of strata is the most recent of all the regular marine series of deposits: its relation to the existing oceans is therefore a highly interesting subject of inquiry; the more so, as, from the phenomena of alternating marine and freshwater deposits, conclusions have long since been presented by distinguished writers that particular tracts were alternately raised above and sunk below the sea. Cuvier and Brongniart proposed this hypothesis to explain the freshwater interpolations among the marine strata of Paris; and the notion has gradually become a popular part of geological speculation. The geographical relations of tertiary strata must be understood before venturing to adopt or to reject the hypothesis.

Before the deposition of the tertiary system, Europe had acquired many of its marking features: the Pyrenees, Brittany, parts of Wales and Scotland, Scandinavia, the Carpathians, Apennines, the mountains of Bohemia, the Vosges, Auvergne, and other tracts, were uplifted above the sea. But these appear to have stood up like unconnected islands, round which the ocean currents passed variously into wide basins like those of the Danube, Paris, &c.; or poured into insulated bays, like what may be termed the Gulf of Bohemia. The direction, force, and materials mixed with these currents, would be materially influenced by the submarine slopes from these insulated ridges, and by other undulations in the bed of the sea; the nature and abundance of the tertiary sediments, and the organic forms which are buried in them, would be greatly dependent on the force and origin of the currents; and thus we see a reason why tertiary strata should be so distinctly related to the present configuration of the surface of the earth, and so various both as to mineral character and organic contents, though the basins, as we term them, in which they now appear, were parts of one general ocean. In a few instances, however, the tertiary deposits were almost totally formed in vast lakes or inland seas, as in the valley of the Rhine, from Basle to Bingen.

The relation of tertiary deposits to existing seas will appear from the following classification of the European deposits.

1. Connected by gradual inclinations with the North Sea.

The basin of London, Norfolk, Yorkshire.
The north-east of France, Belgium, Westphalia, Holstein, Jutland.

2. Between the Baltic and the Black Sea.

The extensive sandy deposits of Prussia, Poland, Volhynia, Wallachia.

3. Dependent on the English Channel.

The basin of Hampshire.
The basin of Paris.

4. Bordering the Atlantic.

The basin of the Garonne.

5. Bordering the Mediterranean.

Tertiaries of Catalonia.
——— of the south coast of France, and the valley of the Rhone.
——— of the northern sub-apennine regions and Sicily.
——— of the northern parts of Africa.

Besides these are the following secluded tracts:—

The valley of the Rhine from Basle to Bingen.
The interior basin of Bohemia.
The great hollow of the northern Swiss lakes, and the vale of the Danube, with the Moravian, Hungarian, and Transylvanian strata.

These latter may be viewed as seas wholly drained; the former as merely the raised margins and bays of the actual seas. But this view is imperfect: *since* the date or during the progress of the tertiary deposits, the partial as well as general uprising of the bed of the sea has materially changed their geographical relations, by separating parts once united, and giving to the detached parts a delusive character of basin-shaped insulated accumulation, which further researches will not justify. For instance, the uprising of the chalk and Wealden tracts between London and Portsmouth has divided the basins of the Solent and the Thames; on a far grander scale, the Alps, raised, at least in part, since all the tertiaries were formed, have given a more complete geographical opposition than originally existed between the tertiaries of the Danube and the Po. It may indeed be supposed, in conformity with Mr. Lyell's views, that the insulation thus attributed to the *subsequent* rising of mountains, may have been begun by their *contemporaneous* rising,— a mode of explanation well suited to the case of the difference in the Hampshire and London basins.

Before the production of the earliest tertiaries, inundations from several uplifted ranges of country (as the Pyrenees, Brittany, Auvergne, the Ardennes, and parts of the Jura, sent detritus into the sea of Paris: the London tertiaries are supposed by Mr. Lyell to have been derived from the waste of the previously raised or then rising Weald: oceanic currents would plough the sloping parts of the submarine land; and thus we have a clear explanation of the mixture of marine and fluviatile sediments, as well as the local diversity of their nature, which so remarkably characterises the tertiary strata. The purely lacustrine deposits, with their embedded mammalia, tell a different history. The tertiary land was raised where they occur at the time of the existence of these mammalia; and thus it is often possible to prove that considerable movements of the bed of the sea occurred during the tertiary period. With regard to the age of lacustrine and fluviatile deposits, it is to be observed, that when a series of such beds lies inclosed in marine sediments, as the gypsum of Montmartre, the lignites of the Isle of Wight, Zurich, and Styria, they must of course be ranked according to the marine strata with which they are associated; but when, as at Headen Hill in the Isle of Wight, on most of the *plateaux* round Paris, at Œningin, at Georges Gmünd, the freshwater deposits are uncovered by any but superficial accumulations, how can their true geological age, on the scale of marine formations, be known? No method but one is likely to be at all satisfactory, — the study of their embedded organic exuviæ; which therefore is the method now generally adopted. Mr. Conrad and Professor Rogers have thus classed the tertiaries of North America. How far this mode can be safely trusted will be considered in the next section.

Organic Remains. — In general, no contrast can be greater than that offered by comparison of the tertiary with secondary and primary plants, shells, and vertebral reliquiæ — no analogy more striking than between the tertiary and living forms of life. Plants, shells, insects, and even quadrupeds, of the same genera, sometimes even of the same species (as far as naturalists can decide so nice a point), often so similar as to be only distinguishable by minute circumstances, render it doubtful to the inexperienced, whether they are not rather looking upon the buried remains of the present creation, than upon the work of one of those systems which passed away before the birth of man. The number of the species of tertiary fossils is very great, as compared with that of even the rich and well-explored oolites; among them are far more freshwater tribes, and far more terrestrial forms, than among all the older strata taken together; a conclusion which harmonises perfectly with the leading fact of the history of their formation, viz. that before the period of their formation, the great sea of Europe was broken into basins between ranges of mountains and masses of land, which in various ways influenced the deposits and supplied some of their organic contents. Yet, upon the whole, the number of terrestrial and freshwater remains is small compared to the marine; a circumstance which, as far as relates to the products of fresh water, is analogous to the present condition of nature. With regard to plants on the land, it has been already shown, (page 70.) that, however numerous these might be, only a few of them would reach the sea, except under particular circumstances of physical geography. The number of land animals already found in tertiary lacustrine, fluviatile, and marine deposits, ought perhaps to strike us by its magnitude, rather than by its inferiority to the catalogue of the living quadrupeds.

Referred to the groups of the basin of Paris, M. Adolphe Brongniart presented, in 1829, the following synopsis of the tertiary plants:—

In the group of plastic clay and lignites —	
Marine plants, none	
Land and freshwater plants, chiefly coniferæ, palms, and amentaceæ - -	30 or 40
In calcaire grossier and Monte Bolca beds—	
Marine plants - - -	16
Land and freshwater plants - -	16
In the palæotherian and epilimnic freshwater beds —	
Marine plants, none	
Land and freshwater plants - -	21

From the laborious and successful researches of M. Deshayes concerning tertiary mollusca (see Lyell's Geology, vol. iii. first edition), we shall extract some of the leading results.

The recent species examined by this eminent conchologist amounted to - -	4780
The fossil species of the tertiary system alone -	3036
Together - - - -	7816

Of which were found both recent and fossil 426, leaving for the total number of species examined -			7390
The ratio of the species which are both recent and fossil, to the whole number is -			5·7 to 100·0
The 4780 living species consisted of -	univalves 3616	or per cent.	75·6
	bivalves 1164		24·4
The 3036 tertiary species	univalves 2098	———	60·1
	bivalves 938		30·9

Among the shells examined were included 1465 recent, and 259 fossil.

Shells of the land and freshwater, viz.

Freshwater species, living	bivalves	118	fossil 30
	univalves	151	fossil 151
Land species,	living univalves	1196	fossil 78

As before observed, the ratio of the number of species, both recent and fossil, to the total number of recent and fossil observed, is -	426 to 7390, or, 5.7 to 100
The ratio of the same to the number of recent species, 4780, is - -	8·9 ——
And to the number of fossil species, 3036, is -	14·0 ——

But this last general average of the number of tertiary species now living, is composed of many very different ratios, by the study of which M. Deshayes has been led to class the tertiary formations upon a new principle. He assumes, as a general truth, that those tertiary deposits which contain the greatest proportion of existing species are of the most recent date; and on the contrary, that those in which the ratio of existing species is smallest are the oldest. Applying this principle to the most important localities of tertiary strata, and grouping together those which have the greatest agreements in ratio of living species, he arrives at the following series of three terms for the whole mass of tertiary strata.

Localities.

Upper or most recent group.	Sicily; the subapennine beds; the crag. (Perpignan and the Morea agree in their fossils with the subapennine beds.)

Middle group.	Bordeaux; Dax; Touraine; Turin; Baden; Vienna; Angers; Ronca. The Viennese and Baden fossils are a general type for Moravia, Hungary, Cracovia, Volhynia, Podolia, and Transylvania.
Lower group.	Paris, London, Hants, Valognes, Belgium. (The fossils of Castel, Gomberto and Pauliac are the same nearly as those of the basin of Paris.

From each of these localities, the ratio of the species now living has been determined by M. Deshayes as under: —

Upper group. — General proportion of living species, 49 per cent.
(Allowance being made for occurrence at more than one locality.)

Sicily has yielded	226 species, of which	216, or	95·0	per cent. are living.
Subapennine	569	238	41·8	
Crag	111*	45	40·1	

Middle group. — General proportion of living species, 18 per cent.

Vienna has yielded	124 species, of which	35, or	28·2	per cent. are living.
Baden	99	26	26·2	
Bordeaux and Dax	594	136	22·9	
Touraine	298	68	22·7	
Turin	97	17	17·5	
Angers	166	25	15·0	

Lower group. — General proportion of living species, 3½ per cent.

Ronca† has yielded	40 species, of which	3, or,	7·5	per cent. are living.
London	239	12	5·0	
Paris	1122	38	3·4	

Mr. Lyell, by independent researches, was induced to class the Sicilian deposits as a separate formation from the rest of the upper group of Deshayes; but in other respects his scheme of nomenclature subjoined is perfectly in accordance with Deshayes' results.

Newer pleiocene of Lyell	— Sicilian deposits, with 95 per cent. recent species.
Elder pleiocene	— Italian and crag deposits, with 41.
Meiocene	— Vienna, Bordeaux, Turin, &c. 18.
Eocene	— Paris, London, Belgium, 3½.

The terms are derived from the Greek καινος, recent, combined with ἠως, the dawn, μειῶν, less, and πλειῶν, more.

* There are above 450 species of fossils in the crag, and on the relation of its shells to recent types, Dr. Beck of Copenhagen holds a different opinion from M. Deshayes. See also Mr. Charlesworth on the crag formation, in Phil. Mag. and Annals, 1836.

† Placed by Deshayes in the middle group, but with hesitation.

I have elsewhere tested the results of M. Deshayes' researches in a peculiar manner, and shown that, tried by the relations existing among one another, the classification which he has proposed is well founded: there may be doubts as to the exact discrimination of the species, and the precise proportions of recent forms included among the fossils; but as the whole have been examined by an eminent naturalist, it is probable that, even if the species supposed to be identical were not so, the conclusion of the order of antiquity of the several deposits would be correct. The only thing remaining to be examined, before adopting these conclusions, is, *the general principle upon which they all depend.* (p. 250.)

This principle is not collected, as an inference, from many observations on the order of tertiary strata, and determinations of the proportion of living species in each, according to its known position in the series; nor is it to be considered in the same light as a mathematical principle, assumed as the basis of certain deductions, which, being compared with phenomena, may serve to test the truth of the assumption; but, in the absence of proof, it is to be admitted or denied upon the following statement of the reasons. In all the series of stratified rocks, the systems of organic nature are found to be different, according to the period: these differences are sometimes gradually, and sometimes abruptly, produced between system and system: in any one clearly defined system, the strata differ as to their organic contents, according to their order of superposition, and the nature of the rock; and, upon the great scale, are characteristic both of geological period and local conditions. Below the tertiary system are no recent species: at the base of that system the lower strata, determined to be such by observation of their position, undoubtedly contain only a very small proportion of recent forms (basin of Paris): in the middle of that system, determined as before, the strata contain about 20 per cent. of recent forms (Bordeaux): in the highest of the system (in only one locality, Sicily), the strata contain 95 per cent. of existing forms.

Supposing these statements (which might be fortified by other equally important but more refined results) are thought sufficient to establish the principle, that the affinity of fossils to recent forms, commencing with the geological date of the chalk, has gone on increasing gradually to the close of the tertiary period, and that, therefore, the relative age of tertiary strata is to be judged of by the proportion of recent forms in them, let us inquire what difficulties lie in the way of the practical application of the doctrine.

There is a real difficulty in determining upon what basis to make the required comparison between fossil and recent forms: whether the fossils of a particular region, as, for example, the subapennine countries, should be compared with the *whole* series of known testacea, or with the shells of the adjoining Mediterranean, to whose products they are extremely similar, and from whose waters they may be thought to have been raised.

In certain cases it appears probable that the strictness of the rule must be relaxed to avoid important errors. For example, the long basin of the Danube, the valley of the Rhine, the basin of Paris, contain a great variety of organic forms, which must have been peculiar to those arms and gulfs of the sea, as we find at this day peculiar shells in almost every partially insulated bay of the sea. But these tertiary tracts having been wholly raised to dry land, all their *peculiar* shells have perished; and the analogy of the fossil to recent types appears less than would be the case with strata like the subapennine beds, which are yet margined by the sea, out of which they were uplifted.

Peculiar shells live in the German Ocean and English Channel: the crag formation is supposed to contain many now living in these waters; but, had the whole of these seas been obliterated by the rising of their bed, the extensive shelly sand thus brought to the surface would have presented but slight analogies with the general catalogue of recent shells from which the peculiar forms were excluded.

These remarks are by no means brought forward to discredit the highly important results of M. Deshayes and Mr. Lyell, but to draw attention to the basis on which they rest, and to induce geologists to follow steadily a plan of observation, which may place the principle assumed on such a foundation as to authorise its being used as the origin of deductions, which may have undoubted influence both in theoretical and positive geology.

Professor Rogers, in his Report on the Tertiary and Secondary Rocks of North America, has adopted the nomenclature of Mr. Lyell, and ranked the deposits on the eastern coast chiefly according to their proportionate numbers of recent forms, as eocene, meiocene, and pleiocene. Both the recent and fossil species of America are, however, almost wholly different from those of Europe: of 210 'eocene' species in America, only 6 belong to Europe; of 195 meiocene and pleiocene shells, only 6 belong to Europe; not more than 32 recent testacea and shelly annulosa are stated by Mr. Conrad to be common to the two sides of the Atlantic.

The number of species of other invertebral animals buried in tertiary sediments, is very much too small to justify any general inferences; but we may attend to what M. Agassiz has stated concerning the subject of his successful studies.

"The fishes of the tertiary strata are so nearly related to existing forms, that it is often difficult, considering the enormous number (above 8000) of living species, and the imperfect state of preservation of the fossils, to determine exactly their specific relations. In general, I may say that I have not yet found a single species which was perfectly identical with any marine existing fish, except the little species which is found in nodules of clay, of unknown geological age, in Greenland. The species of the Norfolk crag, of the upper subapennine formation, and of the molasse, are mostly referable to genera common in tropical regions; such as platax, cartharias, myliobates, &c. In the lower tertiaries of London, the basin of Paris, and Monte Bolca, at least a third of the species belong to genera which are now extinct."

In the chalk, two thirds of the species belong to extinct genera; and in the oolitic system, not a single species can be referred to a living genus!

The same conclusion as to the great general analogy and real specific differences between the fossils of the tertiary series and living races comes with equal force from a consideration of the families of reptiles. Among chelonida, occur freshwater trionyces and emydes, as well as marine cheloniæ and terrestrial testudines: among saurians we have no more the geosaurus, mastodonsaurus, streptospondylus, megalosaurus, ichthyosaurus, plesiosaurus, nor iguanodon; but instead of these extraordinary creatures of the oolitic and saliferous epochs, genuine crocodiles, very nearly agreeing with existing types, appear for the first time, and in considerable variety: decided batrachia show themselves in the freshwater beds of Œningen and the brown coal of the Rhine, and in this latter deposit are accompanied by snakes.

Without stopping to notice the few remains of birds which lie (exclusively?) in tertiary formations, we shall pass to consider the very interesting question of the relation of the quadrupeds of the tertiary periods to the present free and domesticated tribes.

In general it is to be remarked, that, concerning the date of some of the fossil animals, especially when they occur in lacustrine deposits not interstratified with marine formations, there is danger of confounding tertiary with diluvial species; but this difficulty applies only to some particular cases, and will be better discussed when we come to speak of the diluvial deposits, to which we shall defer the reasonings we have to offer on fossil mammalia in general.

In the following catalogue of remains of mammalia in tertiary strata, chiefly taken from Meyer's Palæologica, extinct genera are marked by an asterisk.

Section A.—*In Marine Deposits.*

Carnivora.

Gulo antediluvianus	In sand. Eppelsheim on the Rhine.
Canis	In Volhynia, with marine shells.
Felis aphanistes	Eppelsheim.
ogygia	Eppelsheim.
prisca	Eppelsheim.
Phoca	Hungary.

Rodentia.

Castor	Crag of Essex.
Palæomys castoroides	Eppelsheim.
Hare	Faluns of Touraine.
Aulacodon (chelodus) typhus	Eppelsheim.
Chalicomys Jageri	Eppelsheim.
Myoxus primigenius	Eppelsheim.
Spermophilus superciliosus	Eppelsheim.
Cricetus vulgaris	Eppelsheim.
Chloromys	Volhynia. (Also in freshwater deposits.)

Pachydermata.

Maotodon angustidens	In subapennine formation. In the faluns of Touraine. Eppelsheim.
arvernensis	Eppelsheim.
Hippopotamus major	In faluns of Touraine.
minutus	In faluns of Touraine.
undetermined	In molasse, Galicia, and Switzerland.
Rhinoceros Schleiermacheri	In sand. Eppelsheim.
incisivus	Eppelsheim.
leptodon	Wiesbaden.
Elephas primigenius	In sandstone, 456 ft. Warsaw. In sandstone at Wieliczka. In molasse, near Estavayer, Switzerland.

* Dichobune -	In calcaire grossier near Nanterre.
* Dinotherium Bavaricum	- France, Bavaria, Eppelsheim.
giganteum	- Eppelsheim.
Equus caballus primigenius	In the faluns of Touraine. In sand. Eppelsheim.
mulus primigenius	- Eppelsheim.
asinus primigenius	- Eppelsheim.
Sus antiquus -	- Eppelsheim.
palæochærus -	- Eppelsheim.
—— -	- In molasse. Estavayer.
* Palæotherium -	Under calcaire grossier in the department of Gironde; at Provins; in Touraine; at Zurich.
* Lophiodon - -	Under calcaire grossier at Provins. Eppelsheim.
Tapirus priscus -	- Eppelsheim.

Ruminantia.

Cervus anocerus -	- Eppelsheim.
brachycerus	- Eppelsheim.
trigonocerus	- Eppelsheim.
dicranocerus	- Eppelsheim.
curtocerus -	- Eppelsheim.
Deer -	- In the faluns of Touraine.
Antelope -	- In molasse. Estavayer.
Moschus antiquus -	- Eppelsheim.

Cetacea.

Manatus fossilis - -	Calcaire grossier. East coast of Maryland.
Balæna fossilis - -	Virginia, Wurtemburg, Dauphiné, Berne, Montpellier.

SECT. B.—*In Lacustrine and Lignitic Deposits of known Geological Era.*

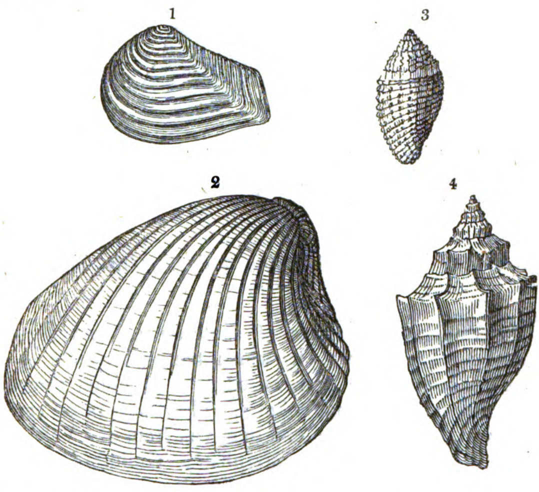
Vespertilio Parisiensis	- Gypsum of Montmartre.
murinus fossilis	- Œningen.
Nasua - -	- Gypsum of Montmartre.
Viverra Parisiensis .	- Gypsum of Montmartre.
Hyæna Parisiensis, *Clift*	- Styrian brown coal.
Vulpes vulgaris, *Mantell*	- Œningen (Murchison).

Canis -	- Gypsum of Montmartre.
Didelphis Cuvierii -	- Gypsum of Montmartre.
Castor -	- Brown coal near Zurich.
* Anœma Œningensis	- Œningen.
Mus musculus -	- Œningen.
Myoxus -	- Œningen; Montmartre.
Sciurus -	- Montmartre.
Lagomys - -	- Œningen.
* Mastodon tapiroides	- Montabusard, near Orleans.
turicense	- In brown coal near Zurich.
* Adapis Parisiensis	- Gypsum of Montmartre.
Chœropotamus Meisneri	- Brown coal near Zurich.
* Anthracotherium magnum	Brown coal of Cadibona; marl of Limagne.
minus	- Cadibona.
minimum	- Lot et Garonne.
Alsaticum	- Lobsan.
Velaunum 1 and 2	- Puy en Velay.
undetermined -	Brown coal of Scheineck in Styria.
* Anoplotherium commune	- Montmartre; Isle of Wight.
secundarium	Montmartre.
* Xiphodon gracile	- Montmartre.
* Dichobune leporina	- Montmartre.
murina	- Montmartre.
obliqua	- Montmartre.
* Cainotherium 2 species, *Bravard*	Puy de Dôme.
* Palæotherium magnum	- Montmartre.
medium	- Montmartre.
crassum	- Montmartre.
latum	- Montmartre.
curtum	- Montmartre.
minus	- Montmartre.
minimum	- Montmartre.
Aurelianense	Orleans; Argenton.
Isselanum	- Issel.
Velaunum	- Puy en Velay.
* Lophiodon tapirotherium	- Issel.
occitanicum	- Issel.
Isselense	- Issel; Argenton; Soissons.
medium	- Argenton.
minimum	- Argenton.
tapiroides	- Buchsweiler.
buxovillanum	- Buchsweiler.
giganteum	- Montabusard.

* Lophiodon Monspessulanum	Montpellier.
sibericum -	In limestone. Government of Orenburg.
other species -	Laonnois; Argenton; Paris; Frankfort.
Cervus capreolus Aurelianensis	Montabusard.

Sect. C.—*In Lacustrine Deposits of Doubtful Era.*

Ursus spelæus - -	Georges Gmünd.
Vulpes - -	Georges Gmünd.
Hyæna, ***Hehl*** - -	Gypsum of Unterturkheim.
Mustela - -	Georges Gmünd.
Chœropotamus Soemmeringii	Georges Gmünd.
*** Palæotherium Aurelianense**	Georges Gmünd.
*** Anoplotherium commune ?** -	Georges Gmünd.
*** Mastodon minutum** -	Georges Gmünd.
Rhinoceros pygmæus -	Georges Gmünd.
Hippopotamus, Bos, } *Clift* -	Georges Gmünd.



1. Crassatella sulcata. *Sowerby*.
2. Venericardia planicostata. *Sowerby*.
3. Conus scabriculus. *Sowerby*.
4. Voluta dubia. *Brander*.

} Chiefly found in the London clay.

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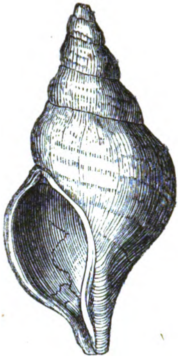

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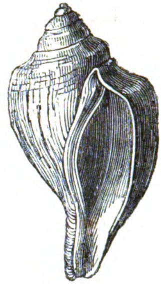

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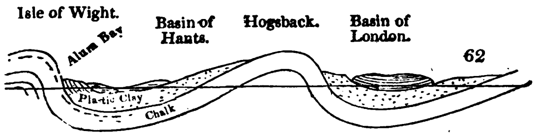
5. Fusus contrarius. *Sowerby.* From the crag of Suffolk.
6. Fusus bulbiformis. *Sowerby.*
7. Dentalium striatum. *Sowerby.*
8. Paludina lenta. *Sowerby.*

} Chiefly found in the London clay.

Disturbing Movements during and after the Tertiary Period.

In England, two lines of subterranean movement have long been known, by which the tertiary and secondary strata have been raised into anticlinal ridges and sunk into synclinal hollows. They both range east and west, or nearly so; one line, viz. from the Vale of Pewsey by Kingsclere, Farnham, Guildford, and through the Weald of Sussex to Boulogne, is somewhat parallel to the vale of the Thames; the other, from Weymouth by the isle of Purbeck through the Isle of

Wight, is nearly parallel to the south coast of England. Thus the lines would converge toward the east somewhere about Boulogne; and diverge westwards, so that, *if continuous (which they are not)*, the northern one would nearly coincide with the south side of the South Wales coal field, and the southern one pass across the southern part of Devonshire. Each of these two lines of dislocation has caused the strata to dip with great steepness to the north (in the Isle of Wight, the beds on this dip are vertical), but the southward dip is in each case moderate. A cross section gives the following appearance:—



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To disturbances during the tertiary periods, M. de Beaumont ascribes the elevation on a north and south line of the ridges of high land in Corsica and Sardinia: the Western Alps (from the Mediterranean to Mont Blanc) are considered to have been raised after the deposition of the Swiss molasse, in a direction N.N.E. and S.S.W.; and the principal chain of the Alps, from the Valais into Austria, E. ¼ N.E., to be of so recent a date as to have succeeded all the true tertiary deposits, and to have coincided with the dispersion of the great blocks and masses of diluvium on both slopes of the Alps.

Igneous rocks are no where in England associated with the tertiary strata; but in many parts of Europe, as in Central France, the north and south of Italy, Sicily, on the Rhine and in Hungary, volcanic phenomena are even specially abundant among lacustrine tertiaries.

From the activity of Etna and Vesuvius, we pass by an easy gradation to the phenomena which mark the former violence of the now silent fires of Auvergne, the Euganean Hills, and Hungary. The relation of these to the basaltic streams of Ireland and Scotland is clear enough as far as relates to the general agency; but the determination of the period when these igneous rocks were formed is difficult. Etna may have begun to burn as soon or even sooner than the now decaying lavas were poured from the craters of Auvergne, the Eifel, and Hungary; and the mere fact of igneous rocks being associated with particular strata, is no criterion of their antiquity. We must therefore endeavour to combine the history of the tertiary volcanic products with those of later and earlier date, in a general discussion of the effects of subterranean heat, which we propose to place after the description of the superficial aqueous deposits, which are intimately related to the tertiary products.

Post-tertiary and Modern Deposits.

(*Syn. "Diluvium," and "Alluvium."—"Superficial Deposits."*)

Since the tertiary formations were completed in most parts of Europe and America, the energies of nature have gone on to accumulate over them and earlier deposits a great quantity of additional matter, under many varied circumstances. It is often extremely difficult to say, whether certain aggregations of sand, gravel, and shells, are of tertiary date, or the productions of later times: enormous heaps of pebbles and bones lie in particular situations, and are evidently of great antiquity; but whether of the tertiary era or not, requires much care in determining. Certain lacustrine deposits, full of shells, marls, peat, and bones of stags, cannot, by a hasty glance, be known from tertiary strata collected from ancient lakes. But, upon farther and closer scrutiny, geologists have generally agreed to think that a whole series of deposits, partly marine, partly terrestrial, lacustrine, and fluviatile, has been formed since the date of the truly tertiary strata.

The evidence for this opinion is absolutely conclusive, as to the great body of tertiary strata: it is past a doubt, that, since the age of the palæotheria in the formations of Paris, the same physical regions have been tenanted by wholly different races of animals. The same conclusion is equally and easily proved for the basins of London and Hampshire, and for many other tracts in Europe; and, if we did not inquire very scrupulously, these partial truths might be thought to justify a general inference that the tertiary strata could always be clearly separated from the overlying diluvial and alluvial sediments. But we must not disguise the real difficulty which occurs to the candid inquirer, who wishes to find out laws of phenomena as a basis for theory, rather than to rest satisfied with a conventional system.

By what rule of practice, or deduction from theory, does the geologist discriminate between the Sicilian tertiaries, with 95 per cent. of existing species of shells, and the conchiferous gravels and sands of Holderness and Lancashire, in which, among twenty species of shells now living in the German Ocean, *one* occurs which is not yet known? If the Lancashire shells are, like those of Speeton, Uddevalla, and the coasts of Devon and Calvados, raised beaches, and to be classed in the modern epoch, why are the Sicilian deposits ranked as tertiary? At what place in the scale of *percentage* of species is the line of division to be drawn, and how is this division to be justified?

The gravel which is spread over great surfaces in England, is called diluvial, and supposed to be the product of great but transient disturbances in the level of land and sea: for another example, the dispersion of blocks and gravel from the High Alps might be quoted as an effect of this kind, according to the view of M. Elie de Beaumont; but, if such be the effect of elevation of mountain ranges, may we not expect somewhere to find traces of a "diluvium" of tertiary, secondary, or even primary date?

Lacustrine deposits formed in and since the tertiary era, are not so clearly distinct even by position, as to allow us, in all cases, to be well satisfied about their date; witness the ossiferous beds of Weighton in Yorkshire, the Val d'Arno, Œningen, Gmünd, and many other localities.

Yet, notwithstanding these objections, geologists have for a long time recognised the classifications which are based on the principle that, since the tertiary era, marine, fluviatile, and lacustrine deposits have happened on the land in various parts of, at least, the northern zones of the globe; and though impartial researches have led us to doubt the practicability and advantage of this broad distinction, we shall now endeavour to develope the history of the "post-tertiary," or diluvial, alluvial, and modern aqueous deposits; reserving for the section on organic remains what general reasoning we are disposed to advance.

In one point of view, these deposits of post-tertiary periods are of the highest possible importance: they form the connecting links between the great phenomena of long past time, whose causes we are to seek, and the less obvious effects occasioned in modern nature by causes which are known. The post-tertiary accumulations consist of detrital deposits, reminding us of ancient conglomerates, lignitic beds like ancient coal strata, calcareous, arenaceous, and argillaceous layers, which are specially comparable with tertiary, and through them with secondary strata. On the other hand, almost every thing that we see among these deposits is clearly intelligible by study of analogous diurnal operations in nature; and thus it is desirable to include in one section the consideration of post-tertiary and modern aqueous products, and to reason on the agencies concerned, as if the whole were one connected series of events still in continuation.

To preserve clear ideas on the subject of these superficial deposits, it is requisite to classify them, not according to a scale of time, which is seldom applicable, but in relation to the predominant agency concerned in their production. Thus we shall have the several principal groups further subdivided as under: —

1. Detrital deposits.	*a.* Erratic block group. *b.* Ossiferous gravel, pebbly clay, sand, &c. *c.* Ossiferous caves and breccia.
2. Marine deposits.	*a.* Raised from the sea, or, *b.* Yet in progress.
3. Fluviatile deposits.	*a.* Terraces on the valley side. *b.* Deposits in the valley. *c.* Deposits at the mouth of the river.
4. Lacustrine deposits.	*a.* Completed in former times. *b.* Yet in progress.

"*Detrital Deposits.*" — "*Drift.*" — "*Diluvium.*" — "*Boulder Formation.*"

Since the date of the 'reliquiæ diluvianæ' and 'ossemens fossiles,' many geologists have been accustomed to refer to a particular era and a violent agency the destruction of many land animals which lived with elephants and mastodons on the surface of Europe: the era was supposed to be the termination of a long post-tertiary period in which these animals lived; — the agency something of the nature of a cataclysm, and very extensive, if not universal. Their opinions were founded principally on the superficiality of situation, confused aggregation, and similarity of organic contents, in the gravel, sands, and clays which constituted the deposits, and in many instances appeared to have been moved enormous distances across valleys and seas or over elevated ranges of ground. These deposits were supposed to have happened on the dried and elevated land, because of the occasional abundance of bones of land animals in them; yet they appeared to be due to the action of large bodies of water: and the notion commonly entertained was, that the sea had been, by some violence of nature, thrown over the land, so as to destroy, at one definite epoch, over large tracts of the globe, wh[illegible] traces of the existing mammalia, and greatly modify the physical aspect of our planet.

Fresh discoveries showed, that the diluvial accumulations contained a great variety of deposits accumulated under different circumstances, by water moving in different directions and with various degrees of force: the remains of elephants, mastodons, &c., were found, though rarely, in really tertiary strata, both marine and fresh-water; it was further observed, that the diluvial masses were totally absent from some districts, and in others appeared to have gone in various directions from a particular group or range of mountains. Influenced by these considerations and the growing importance of the study of modern causes in action, some of the most eminent geologists of England dissented totally from the views of Dr. Buckland, and declared, from the chair of the Geological Society, their conviction that the diluvial deposits did not belong to the effects of one general flood, and were not really distinguishable in origin, on the one hand, from the tertiary; and, on the other, from the modern effects of the sea, the rivers, and the land.

Perhaps we may be allowed to regret both that the "diluvial" theory, as it was termed, was at first so confidently embraced, and extended to so many phenomena, and that afterwards it was formally abandoned, without that full and patient discussion of the reasons which should ever precede the rejection as well as the adoption of generalisations in science. In one point of view, the sudden rise and decline in popularity of this doctrine may be very advantageous to geology, since many persons who were so inconsiderate as to attach much importance to the seeming conformity of the "diluvial catastrophe" with the Scriptural deluge, may learn from this example the danger of confounding the really independent bases of religious and natural truth; the former resting on moral evidence and the nature of man, the latter on physical facts and the sure laws of nature. Both are true and cannot disagree, but we must know them both well before we attempt the serious task of determining the manner of their union.

a.—Erratic Block Group.

In the British islands, very considerable tracts of country have been traversed since the land had its present general aspect of hill and dale, and was inhabited by large quadrupeds, by currents of water due to some unknown cause, which transported rock masses with so great a degree of force, to points so elevated, in such directions, and at such distances, that we cannot avoid feeling extreme astonishment, and look around in disappointment on the physical processes now at work on the earth, for any thing similar. But it is only in particular tracts that the magnitude of the transported rocks is such as to deserve the title of erratic blocks; and, among several examples, we know of none which more strikingly exemplify the phenomena, as the dispersion of granite, slate, porphyry, &c. from the vicinity of the English lakes, because the nature of the rocks and the limited extent of that region render the observations and inferences more precise than when reference is made to the Grampians, Lammermuirs, or mountains of Wales.

Many, perhaps most, of the Cumbrian mountains have yielded detritus to the diluvial currents (a term we here employ for its convenience, without wishing to convey any hypothetical notion beyond that of the force of their movement); but certain of them contain rocks so remarkable, that wherever fragments of these are seen in the gravelly deposits of the neighbouring regions, an experienced eye may at once refer the pebbles to their parent site. Such are the granites of Ravenglass and Devock lake: in a still higher degree the porphyritic granite of Shap fell, the sienitic and hypersthenic rocks of Carrock fell, the amygdaloidal slaty rocks of Borrowdale, some kinds of slaty rocks full of fragments about Grasmere, certain felspathic rocks at the base of Helvellyn. It appears to be certain that, in the dispersion of boulders of these rocks, the present physical configuration of the neighbouring regions had great influence: they are found to descend from the Cumbrian mountains northward in the Vale of Eden to Carlisle, eastward to the foot of the Penine chain, southward by the Lune and the Kent to the narrow tract between Bolland Forest and the bay of Morecambe; and from the vicinity of Lancaster they are traced at intervals through the comparatively low country of Preston and Manchester, lying between the sea and the Yorkshire and Derbyshire hills, to the valley of the Trent, the plains of Cheshire and Staffordshire, and the vale of the Severn, where they occur of great magnitude. It thus appears, that the Penine chain, ranging north and south, acted as a great natural dam, limiting the eastward distribution of the blocks; but at Stainmoor, directly east of Shap fells, a comparatively low part of the chain (1400 feet above the sea), granite from Shap fell, which is about 1500 feet, as well as sienitic rocks from Carrock fell, which is 2200 feet, and red conglomeritic masses from Kirby Stephen, only 500 feet above the sea, have been drifted over the ridge.

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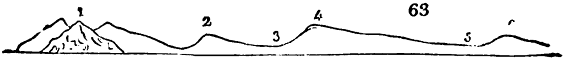

1. Shap fells, whence the granite blocks have been drifted to
2. Orton Scar, a range of limestone hills, and from these have passed
3. The Vale of Eden, in new red sandstone.
4. Stainmoor Forest, across which, in the lowest part of the range of the Penine chain of hills, the boulders have gone to
5. The Vale of York, &c.
6. The Oolitic moorlands.

This great barrier passed, the blocks are scattered from Stainmoor, as from a new centre, to Darlington, Redcar, Stokesley, Osmotherly, Thirsk, and the whole front of the Hambleton hills; they have gone down the whole length of the vale of York, and by the base of the chalk wolds to the Humber. But the barrier of oolite and chalk has been in places surmounted, and the

Shap fell granite lies on the moors near Lastingham, and near Scarborough, and on the wolds near Flamborough, Middleton, &c.

The Penine chain ends abruptly on the north against Brampton, Hartley Burn, Hexham, &c.; and a great depression is formed on the line of the 90 fathom dyke and the vale of the Tyne. *Along this depression,* and far down to the mouth of the Tyne, the Cumbrian detritus is found, though no streams now flowing there have any connection with the mountains from which the materials came.

The large quantity of detritus from the Cumbrian mountains, which has been drifted to the south, on the western side of the high mountain border of Yorkshire and Derbyshire, has gone across the drainage of the Lune (Lancaster), Wyre, (Garstang), Ribble (Preston), Mersey (Manchester), Weaver (Northwich), into and beyond the drainage of the Trent, the Dee, and the Severn (Bridgnorth). Not in any instance have they overstepped to the east the mountain barrier previously noticed; but they lie up against it in enormous quantity, and in the most inextricable confusion, not to be explained by any thing like the action of the sea on its coasts, even during the most violent storms.

In and under Barr Beacon, is a mighty mass of drifted quartz gravel, and sand, with fragments of limestone, trap, and coal sandstone rocks from Dudley, Rowley, &c.; but I found no distinct proofs of Cumbrian rocks,—not a bit of granite, and no bones. This seems to be analogous to the great drifted mass of gravel, coal, and sand at Durham, which has followed the drainage of the Wear.

The distribution of pebbles of quartz rock from Bromsgrove Lickey to the north and east, even to the valley of the Thames, and along the hills which border it, is well known from Dr. Buckland's description, and certainly it is one of the most striking examples of the effect of ancient currents; but it appears totally independent of the "drift" from Cumberland.

Let us then return to the Cumbrian mountains, and mark the nature of the forces indicated by the superficial area and the geographical features of the region covered by the erratic detritus. It is remarkable, in the first place, that the detritus in question has been transported chiefly to the south and east, slightly to the north, and hardly at all to the west. The same thing is true for the greater part of the diluvial accumulations in England. In the southward direction, the moving forces were sufficient to conquer such obstacles as the bay of Morecambe, and all the undulated and hilly region between the mountain border of Yorkshire and Derbyshire, and the Irish Sea, but not to pass that mountain boundary; and of such continuity, as to be recognised as far at least as Bridgnorth, 130 miles and more from their origin. In an eastward direction, the boulders have crossed the bold limestone ridges of Orton and the deep and broad vale of the Eden; from this they have been raised over the Penine chain of mountainous land, *but only at one and that the easiest pass*, which, however, is 900 feet above the Eden. Could we venture to assume, in this case, that one long slope of surface *formerly* continued from Shap fells, and Carrock fell, to Stainmoor, the arrival of the blocks on the latter point might be explained: but the hypothesis is wholly gratuitous; for the rocks of the Penine chain, of which Stainmoor is a part, must have been elevated above the strata of what is now the vale of Eden, even at so ancient a period as the deposition of the new red sandstone; since the Penine fault, to which that elevation is due, was anterior to all, or nearly all, the red sandstone formation; and there is no proof, nor reason to imagine, that any strata were superimposed on that red sandstone, so as to fill up in any degree the ancient vale of the Eden.

Whatever hypothesis be proposed for the transit of the blocks from Shap to Stainmoor, must include the consideration of this original difference of level on the line of the movement. Once on the summit of the pass of Stainmoor, the natural course of the vales of Tees and Greta may account for the directions at first taken by the boulders to Darlington; and the plains of Cleveland, and the vales of Mowbray and York, easily conduct us to the Humber. But still the same kind of difficulty as that presented by Stainmoor meets us at the foot of the Hambleton hills and the wolds of Yorkshire, over which high and continuous ranges, the boulders have been lifted from the vale of York, which spreads wide and far, several hundred feet below, and drifted onward till they reach the sea, 100 and more miles from their parent rocks.

On the line of these hills there is no great dislocation of strata: their elevation was probably effected by a general upward movement of the whole area of the eastern side of England, affecting equally the chalk wolds, oolitic hills, and red sandstone vale. As, therefore, it by no means follows in this case that such distinctions of level were aboriginal (as in the instance of Stainmoor and the vale of Eden), it may be *imagined,* that from the Penine ridge to the German Ocean, one long slope permitted descending streams to transport the detritus; and that to the same or subsequent watery force we must ascribe the production of the inequalities which render the transport of the boulders, in the directions they once took, impossible now, without extraordinary dynamical means.

But, granting this, we shall still advance but little in the explanation of the phenomena. For if it be admitted that currents flowing from the Penine ridge toward the east could remove all the mass of materials, thus *imagined* to rest on the carboniferous rocks, why have they left on the summits of the hills, and on the lower ground of this very region, plenty of the blocks of granite, which, by the hypothesis, should have been swept away over the unwasted surface? Dismissing, then, for the present, the notion that drainage waters, under any possible condition of levels of the dry land, could disperse these erratic boulders, let us inquire under what circumstances they might be moved by the waters of the ocean.

Either we may suppose the waters to be thrown in a body over the land, so as to conquer by their violence and volume certain inequalities of the surface, and to cause particular local currents depending on the resistance offered by the physical configuration of different districts; or we may imagine alterations in the relative level of land and water, in the whole region where the detritus is spread, of sufficient amount to permit the transfer of heavy bodies by oceanic currents over surfaces which subsequently (at once or in succession) became dry land. This latter supposition admits of many gentle or many violent upward movements of the land round a vertical axis; and in this instance the axis may be imagined to pass parallel to the extreme points whereto the detritus has reached, viz. Bridgnorth and the mouth of the Humber, or north-east and south-west; and the movement to be upwards in all the region between this and the Cumbrian mountains. The consequence might be, dispersion of gravel, &c. from the primary mountains, in various directions within the semicircle from N.E. to S.W.; and it is entirely within this range that *all the* Cumbrian detritus is really located. To determine whether the upward movements assumed were gentle or violent, we must look to the deposits of boulders and gravel which have resulted; and as the leading facts which they exhibit are undoubtedly the heterogeneous admixture of substances of different magnitude and density, the absence of parallel and continuous stratification, and the frequency of contorted and inexplicably jumbled masses, we cannot hesitate to pronounce in favour of sudden and violent movements of incomparably greater energy than those by which most of the old conglomerate rocks were formed.

Geologists to whom this reasoning is not satisfactory may take as a basis of deduction the other speculation, that the ocean has been violently thrown over the land.

This is impossible as an ordinary occurrence. No ordinary combination of circumstances could much augment the fluctuations of the ocean beyond their present amount: if the equatorial course of the tide were free, and the impulses of the sun and moon could be supposed to conspire in augmenting the rise, successively, as isochronous applications of small forces will enlarge the vibrations of a suspended bar, this would not correspond either in magnitude or violence to the phenomena which require explanation. It is impossible, therefore, to assign a physical cause for such a mighty overflow of the ocean, except we suppose the earth's figure to be changed; its axis displaced, and thus the sea moved in mass, or its crust broken, and thus new basins opened to the waters. The displacement of the earth's axis cannot be assumed, on satisfactory grounds, as a thing within the range of probability; for the earth is a figure of equilibrium, and therefore its *axis is fixed*, as far as any ordinary tendencies in the mass itself are concerned; and neither comets nor planetary attractions are thought to be influential for such an object. We are, therefore, reduced to the supposition of violent disruption of the crust of the earth, if we wish to explain diluvial phenomena by one or many transient overflows of the sea.

Whether, therefore, we suppose the dry land to have been covered by boulders through an inroad of the elevated sea, or the unequal bed of the sea to have been raised, in either case it is necessary to admit violent fracture of the earth's crust, and on either view we may venture to generalise the phenomena connected with the dispersion of boulders from the Grampians, Scandinavian ranges, Cumbrian rocks, and primary strata of the north of Ireland, in one point of view. For the same speculation of a rise of land parallel to an eastward or north-eastward line, if it will account for the phenomena in the north of England, will also explain those of the other localities, if the axis be taken far enough south, and the area moved be supposed to extend at least as far as the Irish, Scotch, and Scandinavian coasts; and a great oceanic current from the north or north-west, if possible and applicable in the case of Shap and Stainmoor, must be supposed to have left traces of its power on other mountain ranges. It is unnecessary to extend these reflections arising from the phenomena of the dispersion of Cumbrian rocks farther than to observe, that the line followed by the blocks southward from Shap through Lancashire, and northward to Carlisle, is in a great depression parallel to the fault of the Penine chain; and that the depression on Stainmoor, and that farther north near Brampton, by which similar blocks have gone eastward, are occasioned by cross faults which break the continuity of that same chain. These circumstances are obviously important.

The most prevalent direction in which the blocks have been transported in the British isles, is from north to south; but, in general, the natural configuration of the ground appears to have had considerable influence in determining many minor currents. The same conclusion, of the influence exercised by the local configuration of land, results from the laborious examination of the phenomena of the dispersed blocks of the rocks of the Alps. The existing valleys are the lines by which the fragments of the mountains have been drifted away to the lower grounds of France, the Pays de Vaud, Switzerland, the great vale of the Danube, and the plains of Lombardy. Not that the rock masses are carried along the course of the actual stream, or even confined to the course of the valley; for mountains lying in the *main direction* of the valley, through 3000 or 4000 feet high, are as thickly, and even, in the case of the Salêve and Mont Sion near Geneva, more thickly, covered than the hollow of the Arve, or the banks or bed of the Rhine and Leman Lake. It appears, therefore, that some great violence of water acting along the line, but not limited to the level, of the present drainage, has brought the blocks from the western Alps, by the valleys of the Isere and the Durance, to the plains of the Rhone: thus have the rocks wasted from around Mont Blanc, and the Col di Balme been strewn over the valley and along the hilly borders of the Rhone, even to the height of some thousand feet on the Jura; near Soleure, the same range of mountains bears the spoils of the Bernese Oberland, swept down by the valley of the Aar, the Glaris boulders have gone to Zurich, and those of the Grisons have descended the valley of the Rhine. But, after thus falling to the great Swiss tertiary basins of Geneva, and the valley of the Aar, the blocks have crossed those hollows, and been driven up the opposite slopes of the Jura to a level 2000 feet higher. De Luc (Mém. de la Soc. d'Hist. Nat. de Génève) notices the origin of other rocks besides the granites dispersed in the basin of Geneva, and they support the same conclusion of the decided influence exercised by the present configuration of the country in modifying the direction of diluvial currents.

This influence is, however, in other cases, less sensible. For example, the zircon sienites, porphyries, and transition limestones of Sweden and Norway, have been transported southwards over the country of Scania and across the Baltic, and scattered over the sandy plains of Westphalia, Hanover, Holstein, Zealand, Mecklenburg, Brandenburg, Pomerania, Prussia, and part of Poland between Warsaw and Grodno. Thus, from the Ems and the Weser to the Niemen and the Dwina (and even to the Neva), the country is covered with ruins of the Scandinavian rocks brought across the sea, and carried toward the Carpathians, and the Bohemian and Westphalian mountains, contrary to the natural currents of drainage. De Luc and Brongniart have given many details concerning these remarkable boulders, which appear not equally spread over the large tracts of country mentioned, but assembled in groups in particular situations. These groups are often elliptical in form; the major axis of the figure pointing north and south, or toward the Baltic Sea, across which they have been transported.

Bruckner mentions a *trainée* of blocks north of Mecklenburg Strelitz, which runs from N.N.W. to S.S.E. They are said to be in general more abundant on the elevations than in lower ground, the largest masses being nearest the summits, as if the lighter gravel and sand had been removed from them.

De Luc observed, in Lower Saxony, circular ridges of hills with a single outlet from these natural amphitheatres; and on the inner faces of the hills abundance of granite, porphyry, &c. There can be no doubt that the great masses of granite, porphyry, transition limestone, &c. scattered over the north of Germany, have been derived from the Scandinavian mountains, because the limestones contain organic fossils peculiar to the transition rocks of Sweden; the porphyries and granites are equally identified by their mineral characters; and the distribution of the groups of blocks on the south of the Baltic, as well as the traces of their passage across Scania, completely agree with this conclusion. The era when these blocks were drifted across the Baltic, though modern when compared even with tertiary strata, is yet very remote, for they lie under the ancient peat mosses of East Friesland; and there appears reason to think that more than one such migration of erratic blocks has accompanied the upward movements of the Scandinavian primary regions. "Almost the whole surface of North America, as far as examined, may be said to be covered with an investment of earth, pebbles, and boulders, obviously of diluvial origin. The thickness of this deposit varies, though its average depth may be said to be from ten to twenty feet. All that low and level tract described as the Atlantic plain, and also the lower sections of the great valley of the Mississippi, appear to be the districts where it conceals the underlying strata to the greatest depth." — "The boulders may almost invariably be traced to formations which lie at some miles' distance to the north-west and north. This distribution of the diluvium from the north and north-west is not confined to the rivers whose valleys run in these directions, but belongs, it is believed, to at least all the middle and northern latitudes of the continent. It is seen west of the Alleghanies, throughout the regions of the Ohio and Mississippi, as well as extensively over the Atlantic slope and the tertiary Atlantic plain. Bigsby, and the travellers to the north, have already shown it to prevail in the latitudes north of the United States."*

These and many other cases demonstrate —

1. That the course of the blocks from their original site has been influenced by the present configuration of the country; because they are accumulated in greatest abundance in the lower regions of the earth, and have often gone by the line (though not limited to the level) of the great drainage hollows of the surface.

2. The mechanical forces which transported these boulders must have operated under totally different conditions from those which determine the course of the actual streams; because the boulders have crossed great vales and seas, and ascended ridges, quite contrary to the course of existing drainage.

3. It is impossible to comprehend the phenomenon as one capable of being produced by the watery agencies now at work in nature, except under different dynamical conditions; such as a disturbance of the oceanic level to an enormous degree, hardly conceivable except as the result of a general change of the figure of the globe, produced by a displacement of its axis of movement; an incredible and irregular alteration of dimensions; or a series of elevatory and depressing movements operating in certain directions. Ignorant as we are of the extent and character of diluvial phenomena in all the southern zones of the world, it is desirable to avoid a decision on the much controverted origin of the erratic blocks, especially as some of the proposed solutions are mechanically absurd. One of the most ingenious, and perhaps least hypothetical, of the modern notions on the subject, is,

* Rogers, in Reports of Brit. Assoc. vol. iii. Dr. Bigsby's Observations on the travelled Boulders about Lake Huron and Lake Erie (Geol. Trans. vol. vi. pt. 2.).

that the great blocks of the Alps and Scandinavia were floated away on icebergs, and so dropped on the sea bed or on the temporarily submerged land. That icebergs are detached from the land with stones on their surface is known to northern navigators; it is a phenomenon well understood in the Gulf of Bothnia; and, to an imaginative mind, the mer de glace, with its border of moraine, might seem a natural component of such a glacier current as that to which the Salêve, the Jura, and the borders of the Lake of Geneva are supposed in this hypothesis to owe their accumulated blocks. It is thought to be a plausible argument in favour of this speculation, that the blocks of granite, porphyry, limestone, &c. are grouped together in distinct patches *according to their local origin*, both in the vicinity of the Alps and on the plains of northern Germany.*

Ossiferous Gravel, Pebbly Clay, Sand, etc.

While a few remarkable cases of dispersed boulders have engaged the attention of geologists following in the track of Saussure and De Luc, thousands of examples offered themselves of accumulations similarly at variance with the existing agencies of water; but they were never accurately studied till they acquired a new interest from the discussions of De Luc and the splendid researches of Cuvier into the bones of quadrupeds which lie abundantly in these deposits. Large portions of England, Wales, Scotland, and Ireland are covered by irregular aggregations of gravelly sands and pebbly clays, locally stored with the bones of various land quadrupeds, which appear to have lived not far from the spots where they now occur buried. The parts where they occur were therefore dry land, or, at least, not far removed from the native haunts of the animals.

The pebbles constitute the essential and characteristic part of these deposits, and enable the geologist to decide,

* See Mr. Lyell's Geology; Brongniart, Tableau des Terrains; De Luc's Letters, &c.

in some cases very positively, as to the direction in which they have been drifted. Generally, in all the north of England, the diluvial gravel has been transported by the same routes or the same points of origin as the boulders; but there is some variety in this respect worthy of notice. On the eastern side of the island, from the Tyne to the Humber, the gravelly deposits appear partly of local and partly of distant origin. On the Yorkshire coast, local gravel, derived from the chalk wolds or oolitic moors, lies in very irregular beds, distinct altogether from the clays full of pebbles brought from the Cumbrian and Penine mountains; at Bridlington, local chalk and flint gravel lies *over* the other diluvium, and at Hessle, on the Humber, similar local gravel lies *under* it.

It might be proper, in these cases, to confine the term diluvium to that portion of the gravelly masses which, by the abundance of the fragments from very distant parts, requires the supposition of extraordinary circumstances for its accumulation. It is not solely, nor, perhaps, even principally, in this proper diluvium, that the bones of elephants, hippopotami, horses, deer, &c. occur; they seem, on the contrary, to be rather more plentiful in the local gravel deposits. Cases, however, occur, as at Brandsburton, and at Middleton on the Wolds, near Beverley, of elephantine and other remains in the midst of erratic gravel derived from great distances.

The most singular circumstance attending the accumulation of the proper diluvium is the extreme confusion, and almost total want of laminar or stratified structure, in its mass: pebbles, and fragments of rock, of all sizes, of different nature, and from different regions, lie mixed indiscriminately in clay many yards in thickness; which seems clearly to prove that the whole was rapidly accumulated, and that the particles had not time to be arranged according to magnitude or specific gravity, but were heaped confusedly together by a force of extraordinary intensity and short duration.

Similar explanations seem applicable to the pebbly clays of Lincolnshire, Huntingdonshire, and Northamptonshire, &c.; and to the whole track of the diluvium from the lake mountains through Lancashire, Cheshire, Staffordshire, &c.

Many parts of England are almost totally free from the accumulation of proper diluvium, — as the Yorkshire coal field, the Wealden denudation, large tracts in North Wales, the vicinity of Bath, &c. But these districts contain abundance of local gravel deposits, which sometimes appear to be quite as ancient as the diluvium, and may justly be styled "Ancient Alluvium;" for their aggregation seems not, in general, to require the supposition of watery agencies flowing in, other than the directions of actual streams and inundations. Much of the gravel which is collected below the openings of the valleys which descend from the Grampians is of this local character; but that which abounds in the central plains of Ireland, constituting the "escars" of that country, has been drifted from greater distances, and appears due to more general agency.

Mr. Murchison's examination of the Welsh border appears to show that the gravelly deposits formed from the waste of those districts, and forced down to the great hollow uniting the vales of the Dee and the Severn, were transported, according to the descent of the country, previous to the dispersion of the erratic blocks from Cumberland; and he supposes that, between the mountains of Wales and the oolitic ranges, the vale of the Severn was submerged, and constituted part of a long strait uniting the Irish and Bristol Channels, since the northern zones were inhabited by quadrupeds. The abundance of shelly deposits mixed with and lying under the detrital accumulation of Cheshire, Worcestershire, &c. appears to justify this view.

It is, therefore, by no means a simple problem which the superficial gravel deposits of even a limited district offer to the reasoning geologist. Gravel is not necessarily of diluvial origin; does not necessarily imply the action of violent forces, or currents moving in directions which could only be rendered possible by a great change of the relative level of land and water. We must, in all cases, distinguish between the local and general agencies which, separately or in combination, effected the transfer of the gravel. The pebbles on the plain of Crau at the mouth of the Rhone, and those vast heaps brought from the Alps of Dauphiné by the Isère and the Durance, have one local origin; almost every valley of the Alps and the Grampians has served for the passage of a peculiar suite of broken rocks; only at one point of the Penine chain of England have the Cumbrian rocks been drifted to the drainage of the Humber. Geographical circumstances appear to have been more important in determining the *distribution* of gravel, than of erratic blocks, even though we assume the effects in all cases to have been produced by the same agencies. Before any particular masses of sand, gravel, or pebbly clays can be pronounced to be of diluvial origin, and adduced in evidence on the question as to the origin and operation of violent waters, it is indispensably necessary to show that, under the present configuration of the surface, with ordinary measures of local watery forces, the accumulation of such masses is impossible. This can be shown, if the component pebbles of the presumed diluvium can be referred precisely to the situations whence they were dislodged, and these situations are separated by natural obstacles from any part of the drainage hollows connected with the locality where the gravel is found. Some gravel is, or may be, of *local origin*, the effect of existing streams, or of waters which may be conceived to have formerly flowed according to the present slopes and physical features of the country; and descriptions of gravel deposits are almost useless, in which the question of local or distant origin of the masses is not examined.

Supposing this point settled, and the deposits to possess the characters of diluvial accumulation, the next thing is to determine how far similar deposits are traceable in the neighbouring districts, and toward the presumed origin of the fragmentary masses, so as to determine the direction really followed by the currents which transported them. The circumstances of the accumulation should be carefully studied. If accompanied by local gravel, does this lie upon, or below, the diluvial masses? for both these cases occur. Is the mass in any respect stratified? Does its composition suddenly vary? Is there oblique lamination of any of its (sandy) parts? Are large and small, heavy and light, masses indiscriminately mixed? Are the fragments angular, greatly rounded, or flatly elliptical? Are bones of quadrupeds or shells of mollusca found in the mass, or lying in marly beds above, below, or inclosed? The problems thus suggested are of great importance toward a correct view of the origin of the diluvial accumulations, and the contemporaneous races of organic beings.

Ossiferous Caves, and Fissures in the Rocks.

The land animals mentioned in the last section appear to have been, for a considerable geological period, inhabitants of the countries where their remains are buried in the gravel; for their bones are also found in caves, and fissures of the rocks, under circumstances generally indicative, and often demonstrative, of their habitual existence in the cave, or the vicinity of it. Here, buried in mud, or covered by calcareous deposits, inclosed and perfectly preserved, lie the separated bones of many kinds of extinct quadrupeds, young and old, — entire, broken as by falling into a pit, — worn by currents of water, or gnawed by ravenous beasts; but often perfectly recognisable, and capable of being rigorously compared with living races of mammalia.

The result is extremely remarkable: instead of a large proportion of the existing species of animals, which, during the early periods of history, if not in later times, might have been expected to fall into fissures, retire into caves, or be dragged by wolves to their dens; we find the greater number of bones to belong to elephants, large feline animals, the rhinoceros, hippopotamus, elk, hyæna, indiscriminately entombed with oxen, deer, and many smaller animals. The contents of the caves have a considerable general analogy in a given country, as England; but they exhibit some characteristic differences, when different districts, as Franconia and Yorkshire, or Narbonne, are compared. These local differences are important additions to the evidence afforded by the state of inhumation and conservation of the bones, in favour of the conclusion that the animals found in the caves were really the inhabitants of the neighbourhood. The following general list of the species of mammalia found in alluvial and diluvial deposits may be useful for reference. Man is included in the catalogue, though it appears improbable that the remains of the human race found in the caves of Bize, Belgium, &c. are really of the same date as the elephantine exuviæ in northern climates. (See Desnoyers' Report to the Geol. Society of France.)

GENERAL TABLE OF VERTEBRAL REMAINS IN POST-TERTIARY ACCUMULATIONS.

Name.	Alluvial.	Diluvial.	Breccia.	Caverns of all Periods.	Volcanic Detritus.
Man and human constructions -	Guadaloupe, Baden, Köstritz, Austria	- -	Nice - Dalmatia	Bize, Sommières, Rancogne, Ussát, Miallet, Engissoul nr. Liège, Paviland, Mendip, &c. &c.	
Elephas primigenius, Blum. -	- -	Europe, N. Asia, N. America	- -	Kirkdale, Mendip, Muggendorf, Zahnloch, Fouvent, &c.	Auvergne.
priscus, Goldf. - -	- -	England, Germany, Prussia.			
Hippopotamus major, Cuv. -	Lancashire -	England, France, Germany, Tuscany.			
intermedius - -	- -	Dep. Maine and Loire.			
minutus, Cuv. - -	- -	Near Bordeaux.			
Rhinoceros tichorinus, Cuv. -	- -	Siberia, England, Germany, France, Italy	Haute Saone	Harz, Kühloch. Chockier, Kirkdale, Derbyshire, Preston.	
leptorhinus, C. - - -	- -	Tuscany.			
incisivus, C. - - -	- -	Eppelsheim.			
minutus, C. - - -	- -	Moissac, Elgo in Switzerland, near Magdeburg	- -	Pondres ?	
asiaticus, Bl. - - -	- -	- -	- -	Chockier.	

Tapir giganteus, C. - -	- -	S. of France, Bavaria, Austria, Eppelsheim.			
parvus, C. - - -	- -	Languedoc?			
? - - -	- -	Irawadi R. - -	- -	- -	Auvergne.
Mastodon maximus, C. - -	- -	N. America, Auvergne, Siberia, Ural.			
angustidens, C. - - -	- -	America, Italy, England, Germany, Montpellier.			
andium, C. - - -	- -	S. America.			
Humboldtii, C. - -	- -	Chili.			
minutus, C. - - -	- -	Saxony.			
tapiroïdes, C. - - -	- -	Europe.			
latidens, Clift - - -	- -	Irawadi R.			
elephantoïdes, Cl. - -	- -	Irawadi R.			
Tetracaulodon mastodontoïdeum, Godman	- -	Newbury, N. America.			
Elasmotherium Fischeri, Desm. -	- -	Siberia.			
Sus priscus, Goldf. - -	- -	Scania - -	- -	Mendip.	
arvernensis - - -	- -	- -	- -	- -	Auvergne.
vulgaris - - -	England, Scania, &c.				
Equus caballus - - -	England, France, &c.	Beibecks, Yorkshire -	- -	Lunelvieil, Oreston, Kirkdale, &c.	
angustidens, Meyer - -	- -	Eppelsheim.			
small species - - -	- -	Yorkshire - -	- -	Pondres, Argou.	
Palæotherium - - -	- -	- -	Villefranche, Lauraguais.		
Chœropotamus Parisiensis -	- -	- -	Ditto.		
Felis spelæa, Goldf. - -	- -	Yorkshire, Kent's Hole	- -	Germany, England.	
antiqua - - -	- -	- -	- -	Germany.	
large - - -	- -	- -	Nice - -		
small - - -	- -	- -	Nlce - -		
- - -	- -	- -	- -	- -	Auvergne.

Name.	Alluvial.	Diluvial.	Breccia.	Caverns of all Periods.	Volcanic Detritus.
Hyæna fossilis, Cuv.	-	Canstadt, Abbeville, &c.	-	Germany, France, England.	
monspessulana (Christol)	-	-	-	Lunelvieil.	
intermedia, M. de Serres	-	-	-	Ditto.	
gigantea, Holl	-	-	-	Oreston.	
Mustela spelæa ?	-	-	-	Gailenreuth.	
vulgaris, Lin.	-	-	-	Kirkdale.	
martes, Lin.	-	-	-	Gailenreuth.	
Talpa Europæa, Lin.	-	-	-	Chockier.	
Canis lupoïdes, Cuv.	Yorkshire	Yorkshire	-	Kirkdale, Gailenreuth, Chockier.	
aureus ? Lin.	-	-	-	Gailenreuth.	
vulpes, Lin.	-	Val d'Arno	-	Ditto.	
familiaris, Lin.	-	-	-	Lunelvieil.	
Parisiensis, Cuv.	-	-	Gibraltar.		
?	-	-	Sardinia.		
?	-	-	-	-	Auvergne.
giganteus	-	Avaray (on the Loire).			
Ursus spelæus, Bl.	-	-	General	Very general.	
cultridens, Cuv.	-	Val d'Arno	-	Kent's Hole.	Auvergne.
priscus, Goldf.	-	-	-	Gailenreuth, Sundwig, Pondres.	
Pittorii, De Saus.	-	-	-	Fauzan, Sundwig.	
?	-	-	-	-	Auvergne.
Meles vulgaris	-	-	-	In the Muggendorf district, Lunelvieil, Liège.	

Gulo spelæus, Goldf.	- -	- -	- -	Gailen. Sundw. Rösenbeck.	
Nasua nicaensis	- -	- -	Nice.		
Talpa Europea, Lin.	- -	Chockier.			
Vespertilio murinus ? Lin.	- -	- -	Sardinia -	Gailenreuth.	
Sorex araneus ? Lin.	- -	- -	- -	Gailenreuth.	
Cervus euryceros	Yorkshire, Ireland, Isle of Man	Essex, Rhine Valley, Paris, Italy	- -	Kent's Hole.	
tarandus priscus	Scania - -	Rhine Valley, Lund, Griesswald	- -	Breuque.	
(elaphus) primordialis, Cuv.	England - -	England, Sweden, France, Rhine Valley, &c.	- -	Very generally, Germany, Liège, England.	
(dama) Sömmeringii, Cuv.	- -	Sommethal - -	Gibraltar, Cette, Antibes.		
alces, Lin.	Scania, Cleves, &c.				
capreolus, Lin.	Scania, in peat, Dep. de la Somme	- -	- -	Argou - -	Some species of cervus in Auvergne.
?	- -	- -	- -	Bize.	
Reboulii	- -	- -	- -	Bize, Argou.	
3 species	- -	- -	Nice, Pisa, Gibraltar	Some cervi in Kirkdale Cave.	
giganteus	- -	Albeville.			
Bos urus priscus	Scania - -	Yorkshire, Siberia, Rhine Valley, N. America	- -	Kirkdale, Mendip, Liège, Bize, &c.	
fossilis	- -	- -	Gibraltar.		
moschatus, Lin.	- -	On the Lena R.			
Americanus, Lin.	- -	Ohio.			
Arni, Lin.	- -	Siberia.			
Capra ovis	Yorkshire -	- -	Sardinia -	Gailenreuth.	

Name.	Alluvial.	Diluvial.	Breccia.	Caverns of all Periods.	Volcanic Detritus.
Capra ammon	- -	- -	Nice.		
Antilope	- -	- -	Nice.		
Mericotherium	- -	Siberia - -	- -	Montpellier, Villefranche, Lauraguais.	
Trogontherium Cuvieri	- -	Sea of Azof.			
Lepus timidus	- -	- -	Gibraltar -	Chockier, Liège, Su ndwig, Kirkdale.	
cunniculus	- -	- -	Gibraltar, Cette, Pisa	Kirkdale.	
Lagomys sardus	- -	- -	Corsica, Sardinia.		
Corsicanus	- -	- -	Corsica.		
Castor	Dep. de la Somme, Newbury, Berkshire.				
Arvicola	- -	- -	Corsica, &c.	Gailenreuth.	
	- -	- -	- -	Ditto.	
Hypudæus amphibius	- -	- -	Corsica, Sardinia, Cette	Kirkdale, Chockier.	
arvalis, Pallas	- -	- -	- -	Kirkdale.	
œconomus, Pall.	- -	- -	- -	Kirkdale.	
Mus musculus, Lin.	- -	- -	- -	Lunelvieil.	
sylvaticus, Lin	- -	- -	- -	Lunelvieil, Chockier.	
rattus, Lin.	- -	- -	Sardinia, Gibraltar	Chockier, Kirkdale.	
terrestris, Lin.	- -	-	Corsica.		

Porcupine - - -	- -	Val d'Arno.			
Osteopora platycephalus, Harlan -	- -	Delaware.			
Megatherium australe, Okes -	- -	Buenos Ayres, Lima, Paraguay, Darmstadt	- -	Francisco River in Brazil.	
Megalonix boreale, Okes -	- -	- -	- -	Virginia, Brazil.	
Manis gigantea, Cuv. - -	- -	Avaray, near Orleans.			
Dasyurus - - -	- -	- -	Australia.		
Hypsiprymnus - - -	- -	- -	Ditto.		
Phascolomys - - - -	- -	- -	Ditto.		
Halmaturus - - -	- -	- -	Ditto.		
Gryphus antiquitatis - -	- -	- -	Gibraltar.		
Motacilla, Lin. - - -	- -	- -	Cette.		
Corvus - - -	- -	- -	- -	Kirkdale.	
Alauda - - - -	- -	- -	- -	Ditto.	
Phasianus gallus ? - -	- -	- -	- -	Lunelvieil.	
Gallinacea - - -	- -	- -	- -	Pondres.	
Columba - - - -	- -	- -	- -	Kirkdale.	
Anas (sponsor ?) - -	- -	- -	- -	Kirkdale.	
4 undetermined species - -	- -	- -	- -	Chockier.	
7 species - - - -	- -	- -	- -		
Ardea - - - -	- -	Yorkshire.	Sardinia.		

The accounts of fossil reptiles in terrestrial accumulations are very indefinite.

Balænæ and mondontes occur in the Forth valley. A variety of land and freshwater mollusca and conchifera, all of existing species, lie in the breccias of Nice, the caves of Bize, Pondres, Villefranche Lauraguais, and in the ossiferous marls and gravel beds of Yorkshire.

The origin of the caves and fissures is obscure, yet the following facts seem to favour the opinion that they owe their formation partly to disturbing movements, and partly to the solvent power of water.

It is a remarkable and general fact, that the ossiferous caves and fissures are situated almost exclusively in limestone, not only in England, but in France, Belgium, Westphalia, Franconia, Wurtemburg, along the Mediterranean coasts, in North America, in Australia. This is, however, not at all peculiar to ossiferous caves, for it is a rare thing to meet with considerable cavities underground in any other rock than limestone.

It does not appear that these cavities are specially abundant in districts where subterranean movements have been most powerful or numerous; hardly one cave in the North of England can thus be accounted for; but it is certain that, in two districts of the same calcareous formation, caves may abound in the thick and massive rocks, but be unknown in those where thinner layers are associated with sandstones and shales. This is remarkably the case with the carboniferous limestone of Yorkshire and Derbyshire: where several hundred feet of "Scar" limestone exist in one thick mass, caves abound, as at Matlock, Castleton, Buxton, Yorda's Cave, Wethercote Cave near Ingleton, Gowden Pot Hole in Nidderdale, Dunald Mill Hole near Lancaster, &c.— but not a single cave is known among the thinner and more varied "Yoredale Rocks."

Kirkdale Cave is in a very thick part of the coralline oolite, and calcareous grit; the Franconian and other German caves are also in *thick* rocks of limestone.

It appears remarkable, that so large a proportion of the known caves are situated near, and open on the sides of, existing valleys, though often much above their actual level; along some vast bodies of water are now running, and daily enlarging the passage (Peak Cavern, great cavern in Nidderdale); and from the mud mixed with the bones in even the driest repositories, from the decomposition and wearing of the surface of the bones, the stalagmitic floors, stalactitical canopies, and other signs, there is no room to doubt that in *all* the ossiferous and common caves the solvent and mechanical powers of water have been exerted in modifying the size and form of the cavities. Inspection of the sea coast demonstrates how, at this day, the wasting and undermining agency of water forms caves very similar, in general character, to those containing fossil bones. In some cases (Kirkdale, Rabenstein in Franconia), it appears probable that the existing valley has been deepened since the time when the cave was tenanted by wild animals, because the mouth of the cave opens on a steep breast of rock several yards above the bed of the valley. Let us admit, then, as sufficiently proved, the existence of open caves and fissures in limestone rocks, at the time when elephants, tigers, hyænas, rhinoceroses, &c. lived in Europe; and inquire further how it happened that their bones came to be entombed in the dark chambers of the rocks.

1. Into open fissures they might fall alive, or be drifted by inundations when dead. It seems difficult to account otherwise for the nearly entire skeleton of a rhinoceros found enveloped in mud and pebbles in the Dream Cavern, near Wirksworth, described by Dr. Buckland (*Reliq. Diluv.*). Some such mode of explanation must be resorted to for explanation of the accumulation of bones in Banwell Cave, Hutton Hole, and other singular fissures in the Mendip hills. The osseous breccia, as it is called (a mixture of red loam, pieces of stone, and bones), which fills fissures of the calcareous rocks on the Mediterranean coast of Aragon, France (Antibes), Italy (Nice, Pisa), Corsica, Sardinia, &c., appears to have been introduced by currents of water; and from the occurrence of land shells and marine shells and zoophyta in some of these repositories (Villefranche), it is clear that both freshwater inundations, and overflowings of the sea, have influenced the results. The probability seems to be, that the land has there experienced changes of level: in some cases (Palermo) the bones are thought to have been deposited in the sea near

the shore, and subsequently the whole coast raised. (Pratt and Christie, in Geol. Proceedings.)

2. Into other caves it may be thought other tribes of animals, especially predacious races, might retire to die in quiet. This is the supposition of De Luc, Cuvier, and Buckland, with respect to certain German caves filled to admiration by an enormous mass of bones and decomposed animal matter of extinct species of bears; and the habits of that tribe of quadrupeds, and the circumstances of the caverns, seem to justify this hypothesis, which is also adopted by Blumenbach. In particular, it appears that Rosenmuller has found "bones of a bear so small that it must have died immediately after its birth, and other bones of individuals that must have died in early life." Caves thus characterised are situated in the transition limestone of the Harz and Baüman's Höhle; in magnesian limestone near the Harz (Scharzfeld); in the Carpathians; abundantly in the Jurakalk of Franconia, near the sources of the Mayne (Gailenreuth, Mockas, Zahnloch, Rewig, Rabenstein, Schneiderloch, Kühloch); on the south-western border of the Thuringerwald (Glüchsbrunn, Leibenstein); Westphalia (Kluterhöhle, Sundwick). M. Cuvier states, that the bones in these caverns belong to the same species of animals, over an extent of 200 leagues: that three fourths of the whole belong to two species of bear, both extinct (ursus spelæus, U. arctoideus); two thirds of the remainder to extinct hyænas; a few to a large felis, a glutton, wolf, fox, and polecat.

In all the caverns, M. Rosenmuller found the bones disposed nearly after the same manner; sometimes scattered separately, sometimes accumulated in beds and heaps of many feet in thickness; they occur from the entrance to the deepest recesses; never in entire skeletons, but single bones mixed confusedly from all parts of the animals, and animals of all ages. The crania are generally in the lowest parts of the ossiferous mass, the longer and lighter bones above, the lower jaws always detached from the skull. They are often buried in a brown argillaceous or marly earth in which a considerable proportion of animal earth has been detected. *No teeth marks* are mentioned on the bones, which appear to have been somehow agitated together by the water which introduced the argillaceous loam. This loam sometimes contains pebbles. The general fact is, that on the solid and sometimes worn and polished rock lies a quantity of sand or loam, sometimes 20 or 30 feet thick, full of bones, and over the whole *one* layer of stalagmite, which has been formed by the droppings from the roof and tricklings from the sides. (*Reliq. Diluv.*)

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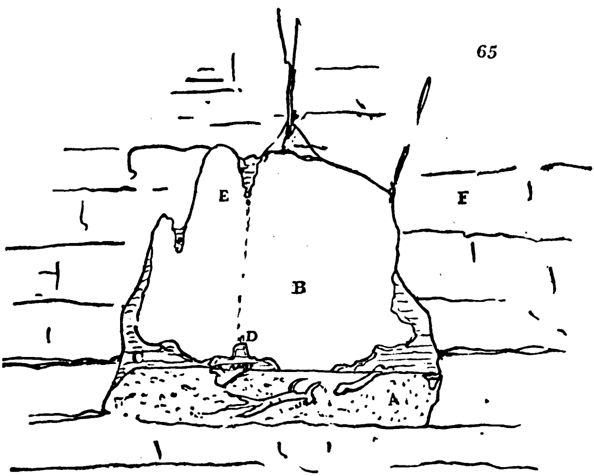

KIRKDALE CAVE.

A. Mud on the floor of the cave, one foot thick, including bones.
B. The cavern, usually less than four feet high.
C. Stalagmitic crust over the mud, partly inclosing bones.
D. Stalagmitic boss on the crust, derived from dropping water.
E. Stalactites hanging from the roof.

3. It is sufficiently ascertained, that some particular caverns, rich in bones, as Kirkdale Cave in Yorkshire, Kent's Hole at Torquay, &c., have not been filled by inrushing of water, nor by the voluntary retirement of wild animals for shelter or for quiet death, but heaped with bones by ravenous beasts, who used the cavern as a den, and dragged into it the carcases of other more peaceful quadrupeds then living in the vicinity. This inference is so important for the right understanding of the ancient condition of the country, both as to level, climate, and productions, that it appears proper to explain clearly the evidence on which Dr. Buckland founded his opinions.

Kirkdale Cave, accidentally discovered by workmen employed on the road, is about twenty-five miles N.N.E. of York, above the northern edge of the broad vale of Pickering, on the east side of the Hodge Beck, and thirty feet above its waters. (This is from our own measurement.) Its floor is upon the great scale, level for the whole length yet explored,—250 feet,—and nearly conformable to the plane of stratification of the coralline oolite in which it is situated. In some parts, the cave is three or four feet high, and roofed, as well as floored, by the level beds of this rock; in other parts, its height is augmented by open fissures, which communicate through the roof, and allow a man to stand erect. The breadth varies from four or five feet to a mere passage; at the outlet, or mouth, against the valley, was a *wide expansion*, or antechamber, in which a large proportion of the greater bones, ox, rhinoceros, &c. were found. This mouth was, it is believed, choked with stones, bones, and earth, so that the cave was found by opening upon its side in a stone quarry. On entering the cave, the roof and sides were found incrusted with stalactites; and a general sheet of stalagmite, rising irregularly into bosses and ridges, lay beneath the feet. This being broken through, yellowish mud was found about a foot in thickness, fine and loamy toward the opening, coarser and more sandy in the interior. In this loam chiefly, at all depths, from the surface down to the rock (said to have been partially covered by a thin layer of stalagmite *under the mud*), in the midst of the stalagmitic upper crust, and, as Dr. Buckland expresses it, sticking through it like the legs of pigeons through a pie crust, lay multitudes of bones, of the following animals: —

Carnivora.	Hyæna, felis, bear, wolf, fox, weasel.
Pachydermata.	Elephant, rhinoceros, hippopotamus, horse.
Ruminantia.	Ox, three species of cervus (not the Irish elk).
Rodentia.	Hare, rabbit, water rat, mouse.
Birds.	Raven, pigeon, lark, duck, snipe.

The hyænas' bones and teeth were very numerous; probably 200 or 300 individuals had left their bodies in this cave: remains of the ox were very abundant; the elephants' teeth were mostly of very young animals: teeth of hippopotamus and rhinoceros were scarce; those of *water rats* very abundant.

The bones were almost all broken by simple fracture, but in such a manner as to indicate the action of hyænas' teeth, and to resemble the appearance of recent bones broken and gnawed by the living Cape hyæna; — they were distributed "as in a dog-kennel," having clearly been much disturbed, so that elephants, oxen, deer, water rats, &c. were indiscriminately mixed; and large bones were found in the narrowest parts of the cavern. The peculiar excrement (album græcum) of hyænas was not rare — the teeth of hyænas were found in the jaws of every age, from the milk tooth of the young animal to the old grinders worn to the stump; some of the bones are polished in a peculiar manner, as if by the trampling of animals.

This evidence of the former occupation of Kirkdale Cave as a den of hyænas acquires much force by comparing the fragmentary state of the bones of oxen, hares, &c. in it, with the far more complete condition of the same animals in other caves, which, like Banwell, contained few or no relics of hyæna, and with the productions of Kent's Hole, which are similar in all respects to those of Kirkdale, and among which hyænas' bones and teeth abound. We may therefore admit, as a thing sufficiently proved on the evidence of caves and ossiferous gravel beds, that Kirkdale, and some parts of the neighbouring country, were dry land in the "elephantine period" of the northern zones of the world. But was the whole of this part of Yorkshire dry land? or was the vale of Pickering a lake, as Dr. Buckland conjectures, on whose margins lived elephants, hippopotami, &c.? an arm of the sea, as the occurrence of a raised shelly beach at Speeton may perhaps lead some to suppose? or a strait connecting the German Ocean with the water which may be imagined to have flowed down the vale of York from the Tees to the Humber, according to the views of some authors on the distribution of diluvium?

Whatever may have been the condition of these comparatively low lands, there can be no doubt that, above the level of Kirkdale Cave (itself only 200 feet above the level of the sea), the land in the N. E. of Yorkshire was wholly dry at the period of the existence of elephants; and this is a point of great importance among the many partial truths which must be established before we can look for a general theory of diluvial deposits.

General Considerations on Diluvial Phenomena.

It will appear from what has been said, that we look upon the erratic blocks, ossiferous gravel and clays, bone caves, and fissures, as phenomena related to a certain geological period, and a particular set of dynamical agencies. Such effects are not, at this day, in progress; nor, in general, can we conceive the possibility of their being produced by the operation of existing agencies operating with their present intensities, or in their present directions. Compared with tertiary phenomena, we must allow that the pebbly conglomerates on the flanks of the Alps are really detrital deposits of an earlier era; and it seems not at all improper to class under the same point of view the pebbly deposits of an earlier stage in the history of the tertiary strata, viz. the plastic clays and sands of London and Paris. So strong is this analogy, that Dr. Forchhammer has adopted the view of the "boulder formation" of Denmark being one very long series of detrital deposits, including the whole tertiary series, and extending from the plastic clay group beyond the ordinary dilúvial epoch.

Whether this be correct or not, it is certain that we must apply, for solutions of the problem of the distribution of the diluvial blocks, to the same agencies which have been invoked to explain the accumulation of the tertiary molasse of Switzerland, and the conglomerates of the red sandstones of England. All these causes we do not know; but the predominant one is known to be great change of the level of land and sea, and the consequent origin of new and powerful oceanic currents.

The principal difficulties of the question relating to the agencies concerned in the dispersion of diluvial detritus would be not removed, nor, perhaps, even diminished, but rendered at least more definite, and therefore more within the scope of geological and physical research, could we be quite sure of the fact whether this mass of heterogeneous materials was deposited by great inundations upon the land, or thrown into the sea. We know that the violence of the watery movement was great, and the accumulation of the materials rapid, since, in some considerable deposits of diluvium, there is no sorting of the materials into portions according to their weight or magnitude; but the finest clay has large bouldered rocks scattered through its whole thickness in the utmost confusion.

Further, it appears from some examples (Holderness, vale of York), that gravelly and detrital beds, intimately associated with ordinary diluvium, and full of blocks and boulders brought from great distances, contain marine shells. If we should consider these to be, like the Lancashire and Cheshire examples, raised parts of the littoral bed of the sea, the diluvial deposits resting upon them may plausibly be viewed as accumulations in the same water, depending on convulsive movements of the areas from which the materials were drifted.

On the other hand, it seems clear, from the occurrence of the bones of land mammalia among some of the diluvial gravel and clays, that the track of the watery currents was, in places at least, over the solid land; though it seems not *necessary* to imagine that the ossiferous accumulations in question (Brandsburton gravel hills, Overton near York, Wilford in Essex, Harwich, Brentford, &c.) were heaped upon the land. They might be finally aggregated in the sea; and thus the seemingly contradictory evidence of marine shells and quadrupedal bones, in the same set of deposits, be reconciled.

However this may be, it appears absolutely certain that none but oceanic currents are adequate to explain the extensive ravages of the solid land which produced, and the violent currents which distributed, the diluvium. Nor would the ordinary currents of the sea be adequate to the effect. It is requisite further to conceive that the sea was most violently disturbed, either over the points whence the detritus was brought (which supposes those points also to have been under the waves), or at some other situation. In the latter case, we may, perhaps, imagine so great a violence of water to be generated, as to permit the waves to be thrown to some height over the land; and it seems not impossible hereafter, when the geographical relations of the diluvium are well understood, to offer some reasonable explanation of the whole matter, on the principle now known to be true, of great and sudden changes of relative level of land and sea, which, though limited in the area of the masses moved, might have very extended effects through the agency of water. Floating glaciers may also be called to aid the speculation; but they would be useless for any other purpose than to explain particular cases of erratic blocks, and small tracts of peculiarly associated gravel masses.

Zoological and Botanical Character of the Diluvial Period.

The diluvial deposits appear, in general, characterised by the presence of a great number of land animals, and some sorts of trees, which are much more similar to existing forms of life than are the tertiary quadrupeds and plants. But this general or average result requires to be limited by several considerations: first, there are deposits reputed tertiary, as the sandy deposits of Eppelsheim, on the Rhine, in which occur a vast number of species very nearly approaching to existing races; secondly, among the animals of the diluvial period are species, and even genera, as totally distinct from the actual creation as any of the tertiary groups; thirdly, in deposits of undoubtedly tertiary date, as the subapennines of Italy, the sands and marls of the Danube, and flanks of the Carpathians, the crag of Norfolk, bones and teeth of elephant, rhinoceros, mastodon, and other genera of the diluvial period, have been found, though not frequently. It appears, therefore, certain, on this evidence, that the transition from the tertiary to later periods was not accompanied by a sudden destruction of old or a general creation of new quadrupedal forms of life. The same appears to be true with reference to the buried forests so often associated with diluvial deposits. It is confirmed by the gradual change in the proportion of existing among extinct species of tertiary shells; so that the most recent groups of tertiary strata contain 40 to 90 per cent. of living forms, while among a dozen or twenty shells in the gravel of Holderness, one extinct species is met with.

On the other hand, it must be remembered, that no palæotheria, lophiodontes, or other genera, chiefly belonging to the older tertiary genera, are mentioned as occurring among the diluvial accumulations; though in certain freshwater deposits, as at Gmünd, lophiodontes, oxen, hippopotami, &c. occur together.

Again, certain animals which lived in the diluvial period, as ervus megaceros, appear, by various evidence, not to have been extinct till later times; though we should not venture to adopt Dr. Hibbert's opinion, that they have really lived within the historic ages of Europe. However, it deserves remark, in connection with this subject, that no one has yet succeeded in showing a real and certain distinction between the common red deer and the common ox of Europe, and the analogous bones of Kirkdale and other caverns.

Upon the whole, it seems probable that the palæotherian and other tertiary races of quadrupeds died and became extinct gradually, but not by any one law of uniform progression; that the elephant, and his accompanying tribes, began to exist during tertiary eras, rose to predominance before the close of the diluvial period, and, for the most part, perished in that period, or soon after. Some modern species (stag, ox) were co-existent with the elephant and hippopotamus in northern zones; others (elephas primigenius, rhinoceros tichorhinus), which abounded in diluvial, were also living in tertiary periods; and, perhaps, a few (as the horse) may have been in existence during all these periods. This is a point, however, extremely hard to determine; since, if, among living tribes, the diagnosis of species is far from clear, what errors may not be incurred by pronouncing a verdict on the imperfect evidence of a few fragmented or detached fossil bones?

Ancient Marine Deposits.

Raised Beaches.—Perhaps nothing more fully illustrates the rate and progress of geological research, than the attention given of late years to the phenomena, first brought prominently forward by M. Brongniart, which demonstrate, that within a comparatively modern period, certainly since the actual seas were filled with their existing mollusca, the beds of these seas have been subject to elevation and depression, so that, in particular places, large quantities of shells attached to their parent rocks, or mixed with the pebbles and sand of their native beaches, have been raised 10, 20, 100, or several hundred feet above high water mark. Within the reach of history, slight displacements of the relative level of land and sea have taken place, as the temple of Serapis near Puzzuoli, Lisbon, Port Royal, are supposed to prove. But these phenomena, connected with local earthquakes and volcanic eruption, are small and limited in comparison with the class of facts noticed above; which appeared to M. Brongniart of so general a character as to justify a supposition that the ocean waters had every where suffered a depression of level, even since the creation of existing races of mollusca, and the establishment of the main features of physical geography, though anterior to historic times. To this view of M. Brongniart it is, apparently, a fatal objection, that the *levels* at which the raised beaches appear above the sea, are extremely varied, even on points of the coast of the same country, and much more when we compare distant coasts; whereas, upon his view of a general lowering of the surface of the sea by one depression of the crust of the globe (*affaissement de la croûte du globe dans un point*), should have left accordant indications of the former height of the water.

The following examples are selected to illustrate the nature of these deposits: —

On the coasts of Great Britain, phenomena of this kind have been observed in the valleys of the Forth (Bouè, Maclaren) and the Clyde (Laskey), chiefly in the form of low terraces considerably above the actual flow of the tide; on the coast of Lancashire, about Preston (Gilbertson); at the base of the Forest Hills, and other places in Cheshire (sir P. Egerton); near Shrewsbury; on the Mersey at Runcorn; and on Moel Tryvaen, near Caernarvon (Trimmer).

That an uplifting of the shores of the Moray Frith has taken place subsequent to its having assumed its present ouline, is considered by Mr. Prestwich as proved, by the existence, in several places, of a raised beach. In Banffshire, this beach varies from six to twelve feet above the present high water level; and contains shells now inhabiting the neighbouring sea, as patelia vulgata, patelia lævis, trochus ziziphinus, littorina littorea, turbo retusus. At Gamrie, celebrated for its ichthyolites, Mr. Prestwich found, in light coloured sands, associated with rolled gravel and dark clay beds, the following recent shells: — Astarte Scotica, tellina tenuis, buccinum undatum, natica glaucina, fusus turricola, dentalium dentalis, &c. They were extremely friable, but perfect. The deposit attains, in some places, a thickness of 250 feet, and rises to an height of 350 feet. *

On Moel Tryvaen (1450 feet above the sea), the shells (buccinum, natica, turbo Venus) were in fragments, adhering to the tongue, very much as in some tertiary deposits: they lie in sands and gravel, with granite boulders, 1000 feet above the sea, the country between them and the Menai being greatly broken, the rocks below the bed of shells worn and scratched by the drifting of the pebbly masses. †

In Cheshire, the shelly gravel and sands, containing turritella terebra, murex erinaceus, and cardium edule, are covered by the ordinary sandy diluvium of Cheshire, in which are many erratic blocks from the North of England, as well as pebbles from the Welsh border.

In and near the valley of the Ribble, for some miles inland, from its mouth, near Blackpool, by Preston to the base of Longridge fell, and on Whittle hills, from the level of the sea to 300 feet above it, occur beds of marl, sand, and gravel, *under the ordinary diluvium with erratic blocks*, locally full of shells of mollusca now living on the neighbouring coast — such as turritella terebra, cardium edule, tellina solidula, &c. The lamination of these shelly beds is irregular, resembling a modern beach accumulated under the influence of strong currents.

Somewhat different appearances are seen in the opposite parts of Yorkshire, especially in the district of Holderness, where sandy and gravelly beds, full of pebbles and fragments of Cumbrian rocks, contain, at

* Geological Proceedings, 1837.

† Geological Proceedings.

particular spots (Brandsburton, Paul, Ridgmont), layers of shells, all marine, and all, except one, now living in the neighbouring seas. Besides the strong shells of turbo littoreus, purpura lapillus, and buccinum undatum, we have mya arenaria, tellina solidula, t. tenuis, mactra subtruncata, cardium edule, &c.; and it is certainly very strange to discover these and other tender shells in a good state of conservation among the twisted and confused laminæ of so coarse and irregular a deposit as that in the vicinity of Ridgmont.

On the same coast, at Speeton, is a much more regular sandy deposit full of cardium edule, amphidesma Listeri, tellina solidula, &c., on the top of the cliff.

From the Wexford coast of Ireland, Mr. Griffith produced, at the Dublin meeting of the British Association, shells of existing, and also of extinct, species, from what seemed a raised beach. A similar deposit, on a very extensive scale, occurs on the coast of Devon. — (Murchison and Sedgwick.)

From these short notices, the reader may be assured, that, even on the British coasts, the phenomenon of raised beaches is one of the most general yet known: that the deposits called by this name were accumulated under considerably different circumstances, is certain; their high antiquity is proved by the superposition (in general) of the erratic boulders; and the general analogies they offer to the Sicilian and other tertiary deposits are obvious and important. A philosophical study of these till lately neglected phenomena will certainly reward investigation, and probably strengthen in a high degree the basis of geological induction.

Turning to other countries, we find abundance of analogous facts. As on the south coast of England, so on the north coast of France, on the hills of St. Michel, formations of the nature above described occur, and have been described by M. Fleuriau de Bellevue and M. Brongniart, under the name of "gravier coquillier." The shells of St. Michel consist of many species, univalves and bivalves; the two pieces of the latter often remaining in their proper position; the whole retaining both their natural colour and texture, and lying as similar shells are associated at this day on the neighbouring coast. Ostrea edulis, anomia ephippium, pecten sanguineus, modiola barbata, murex imbricatus, buccinum reticulatum, are mentioned as the principal species. They are placed nearly fifty feet above the sea. At Nice, similar banks occur at nearly the same elevation; the coasts of Sicily, Greece, and Asia Minor give similar evidence.

Both on the Baltic and the Atlantic coasts of the Scandinavian peninsula, phenomena of the same nature have been long known and rendered famous by the relation they bear to the hypothesis of the gradual subsidence of the level of the Baltic. Von Buch, Brongniart, Ström, Lyell, and Forchhammer have investigated the facts with attention and success. On the western coast of Sweden, at Uddevalla in the province of Gotheburg, in a little bay of gneiss rocks, occurs so vast a quantity of shells, 70 mètres (76 yards) above the sea, that they have from time immemorial been collected for use on footpaths. In hollows of the gneiss rocks, M. Brongniart found balani yet adhering, and detached fragments to prove the interesting fact.

In a recent visit to Sweden, Mr. Lyell has confirmed and extended these observations, and connected the results with the general question of subterranean movements and the local speculation of the lowering of the Baltic,—an expression which may very properly be transformed into a rising of the borders of that sea. Near Stockholm, remarkable ridges of sand and gravel called sand oasar (äsar), 50 to 100 feet high, range north and south, and yield good road materials. Under one of these ridges in the same sand and gravel, 30 feet above the Baltic, are found shells in abundance, such as now live in the Baltic, viz. cardium edule, tellina Baltica, mytilus edulis, littorina crassior, l. littorea, &c. At other spots, 70, 90, 100 feet above the sea, shells in general similar to the above (with neritina fluviatilis and bulimus lubricus, a land shell) were found abundantly, about Stockholm, Upsala, and Gefle; and sometimes *covered by erratic blocks* (Upsala). It was noticed at Uddevalla, that several species of fusus occur there, though none are now found in the Baltic. From the whole investigation it appears certain, that both on the Atlantic and the Baltic shore, the land has in some ancient periods risen considerably (200 feet at least), so that Lake Wener on the west, and Lake Maeler on the east, were formerly parts of the ocean: it also appears probable, that a part of the Scandinavian peninsula is, at this day, *gradually* rising higher above the sea, but this rise does not affect the south of Scania; the rate of rise is supposed to be three feet in a century at Löfgrundet, north of Upsula.

In connection with this subject, we may mention the extended deposits of sea shells (though their identity with existing species may be doubtful) on the plains round the Caspian; the shelly sands at the Cape of Good Hope; the elevated terraces of shells on the coast of Valparaiso, and on the plains of Patagonia; the coral masses in the interior of Antigua; the shelly beds of Barbuda; the Keys or sand islands on the coast of Florida; and the sandy portion of the Atlantic plain which borders the United States (Rogers, in Brit. Assoc. Reports); for it seems difficult not to recognise, in these and many other examples, proof of the very great extent to which the level of land and sea has been and still is locally variable.

But in order to guide generalisations on these striking phenomena, it is desirable to establish the experiments suggested by Mr. Whewell at the Bristol meeting of the British Association, and, by means of two lines at right angles to one another, to ascertain perfectly whether at this time, in England for example, the presumed movements of the land take place; whether there be an axis of movement, such that on one side of it the land rises, but on the other sinks; what is the direction of such axis, and the rate of the movement.

Marine Deposits in Progress.

The elevated portions of the borders of the modern oceans which have been noticed, are so fraught with instructive analogies to the processes of nature in more ancient times, that we cannot help feeling regret at the limited means which man possesses of penetrating the great deep, and watching the phenomena which happen on its quiet bed. There we should behold, it is probable, a number of circumstances connected with the life of marine mollusca, radiaria, crustacea, fishes, which would throw quite a new light on many of the problems of old geology; inform us of the probable depths, distance from the shore, and river mouths, and other conditions, most important for us to know in constructing trustworthy inferences regarding the formation of the fossiliferous rocks.

Coral Reefs.—That the very deep parts of the sea (nine miles is a probable estimate for the Atlantic depths) are as devoid of life as the centre of an African desert of moving sand, is extremely probable, from the known fact of the dependence of organic life on air and light; the former must be greatly modified, the latter extinguished, in passing through such a mass of absorbent fluid. The voyagers of modern date (captain Beechey, MM. Quoy and Gaimard, Freycinet, Stutchbury, Darwin) concur in removing one error of importance on this subject; they have rendered it highly probable that the coral reefs and coral islands which abound so much in the Pacific Ocean, do not rise from even the depth of many hundred yards, but commence on the summit of some volcanic elevations, or other submarine ridges and rocks, not far below the surface of the sea.

These coral islands and reefs, which may be viewed as lines of islands, are certainly remarkable for their extent and mass of matter, even as compared with the ancient calcareous rocks, which derive much of their substance from zoophytic exuviæ. They form the basis of, or surround, the shores of most of the islands in the warm parts of the Pacific, and stretch for a thousand miles parallel to the north-east coast of Australia, in a narrow reef of several hundred miles' length. In like manner, about the Indian and West Indian islands, in the Red Sea, Persian Gulf, and Mediterranean, coral abounds, so as to constitute a considerable portion of the products of the sea.

It has long been the custom to compare the rapid and abundant growth of coral islands with the limited breadths of marine limestone which lie amidst the sedimentary sandstones and shales of the stratified rocks; and on the comparison conjectures have been founded that the stony crag of Orford, the coral rag of Wilts, the transition limestone of the Eifel and Plymouth, were, in effect, ancient coral reefs. It appears, on a first glance, a fatal objection to this view, that these ancient rocks are regularly stratified; the corals in them occupying particular (often thin) beds, not lying confusedly through the mass, nor growing one to another, so as to resemble in structure what is popularly understood by a coral reef. But this notion of a coral reef, exact enough in many instances, is incorrect when applied to the Bermudas, which grow up a mingled mass of coral, shells, comminuted calcareous substances, and sands drifted by the current of the gulf stream. Parts of this calcareous mass, raised above the sea in hills, are drifted by the wind and dispersed into beds.* In such accumulations, not far from land, under the influence of sea currents, we ought to find very different results from those which take place in the broad calm waters of the wider ocean.

In Mr. Stutchbury's excellent dissertation on the formation and growth of coral reefs and islands (West of England Journal), the construction of the principal part of the coral mass is ascribed to the genera caryophillia, meandrina, astræa, porites, and madrepora; while the

* Neilson, Geol. Soc. Proceedings.

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ornamental parts are made up by a diffusion of the other forms of Linnæan madrepores, viz. fungia, pavonia, agaricia, monticularia, echinophora, pocillopora, seriatopora, and oculina, together with gorgonia, isis, corallium, melitea, corallina, spongia, alcyonium, actinia, &c., independent of the locomotive asteriæ, echini, testacea.

The coral islands are classed by Mr. Stutchbury as circular, flat, long narrow, and encircling high land.

The coral islands of the Dangerous Archipelago (lat. S. 12° to 27°, long. W. 130° to 155°) are all of the first kind, and consist of strips or belts of coral of an annulate or circular form, from 400 or 500 yards to one mile across the ring which always incloses a lagoon; seldom raised above the water more than from 4 or 5 feet; abrupt towards the ocean, which rapidly deepens to more than 120 fathoms. The islands vary from 2 or 3 to 150 miles round; the ring, being often divided across by a fissure, admits vessels to enter the lagoon. The depth at which the coralligenous zoophyta commence their labours is said not to exceed 15 or 20 fathoms (Quoy and Gaimard say 20 or 30 feet, Mr. Darwin has recently given the same estimate as Mr. Stutchbury). The bottom of the lagoons is seen in calm weather at a depth of 100 feet or more, strewed over with *dead shells and broken fragments of coral, rarely showing any living specimen below sixteen or seventeen fathoms;* at which depth, smaller reefs rise within the lagoon; and beyond which depth, broken masses of rock may be seen without any living portion attached.

It would appear that, during the formation of a reef, portions of it become compact, and as dense as any limestone rock; a circumstance indicative of the partial dissolution and re-precipitation of the coral masses, and apparently analogous to the process whereby coral shells, &c. have been imbedded in the compact limestone of ancient stratified rocks. Extensive beds of particular shells appear among the islands.

Islands often occur of a flat or tabular form, generally oval or irregularly rounded at their circumference: of this form are the group called by Cook the Friendly Isles, consisting of numerous islands, the majority of which are tabular.

There are also many crescent-shaped reefs, with the most convex portion of their arc the highest, often denoting themselves to the mariner only by the breaking of the waves, and here and there a rock above the level of the ocean, while the horns of the crescent are depressed, and gradually lost in the greater depth: in a few instances, as at Gambier's Island, they are sufficiently raised to have become verdant and inhabited.

Of those which form long narrow strips of land, Mr. Stutchbury refers to Tehuro, a few leagues from Tahiti, and the great reef which takes the course of the north-eastern shore of New Holland, which Captain Flinders describes as being more than 1000 miles in lenth; in the course of which there is a continued portion exceeding 350 miles with scarcely a break or passage through it.

Of the last group of coral islands, or rather reefs, encircling elevated land, the Society Islands, including Tahiti, offer striking examples; being often surrounded by coral reefs, generally situated 400 or 500 yards off shore, with a deep channel between, having numerous openings, through which ships can enter and lie at anchor in perfect safety. These breaks in the coral barrier are, in most instances, opposite the mouths of freshwater rivulets.

The islands Raiatea and Tahaa (U lietea and Otaha of Cook) are divided by a strait, by which ships can enter at the windward side of the islands, and get to sea again through the leeward channels. These two islands are entirely surrounded by one coral reef, extending throughout the circumference of both; the openings through the reefs are, in most cases, denoted by the points being rather higher and more verdant, having trees, principally cocoa nut trees, planted by the natives upon them. The passage is seldom more than 100 yards in breadth, with the depth varying from 3 to 15 fathoms.

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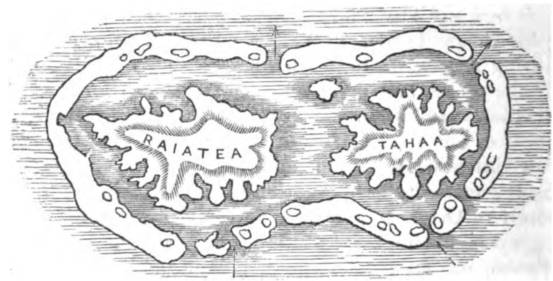

The dark part is calm water round the islands and within the coral reef. The arrows show the entrances and exits for vessels.

The form of the coral islands must very materially depend upon that of the base on which they happen to be built; hence their circular, lunulate, oval, or irregular forms give information as to the shape and even nature of the subjacent rocks. In most cases, the base of the small islands appears to be a volcanic crater, entire or broken; islands of volcanic rock, as Tahiti, are surrounded by rings of coral. The elevation of the coral islands is not owing to the mere accumulation by the rough action of the sea, but to a gradual rising of the low islands, and a violent subterranean movement of the lofty ones, like Tahiti, *which bears on the apex of one of the highest mountains a distinct and regular stratum of semi-fossil coral,* and near it, but on a lower level, a volcanic crater with two lateral gorges.

In this case, had the upward movement been gradual, why should not the coral growths have covered the edges of the crater, or rested on other points?

Mr. Darwin has recently been conducted, by a consideration of the structure of coral islands, annular and linear, whether immediately investing, or at a dis-

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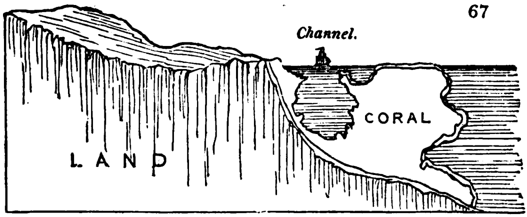

tance guarding, insulated points or long coasts of land, to a remarkable general speculation; viz. that in the Southern Ocean the distribution of the coral masses on a great scale, and their peculiar forms in detail, are explicable on the supposition of certain lines, or rather, long narrow spaces of ocean, in which the land has undergone and is still suffering gradual depressions, and alternating with these other long spaces in which the land is rising. Where depression has taken place, coral is supposed to have grown on the submerged points; and, as the depression proceeded, to have continued to grow and keep the surface as high as the sea. A depressed mountain chain might thus be the origin of a long line of coral islands, or of a continuous reef, as on the east coast of New Holland; a single island of rock, at first skirted by a fringing growth of coral, would, upon further depression, assume the appearance of a central rock, and a circular ring of coral; and, finally, the rock would vanish, and nothing but an annular coral reef appear, inclosing a lagoon, which might subsequently be filled up. The principle of this explanation may be understood by reference to the figures annexed, where a^1, a^2, a^3, a^4, are successive levels of water, surrounding and finally covering the insulated rock *r*, upon which, at *c*, coral began to grow where the depth was small enough. On a further subsidence, more coral, c^2, was added *upon*, but not *within*, the reef *e*; and, finally, c^3 being *raised* to the surface of the sea, while *r* had sunk below it, and fragments of the coral broken

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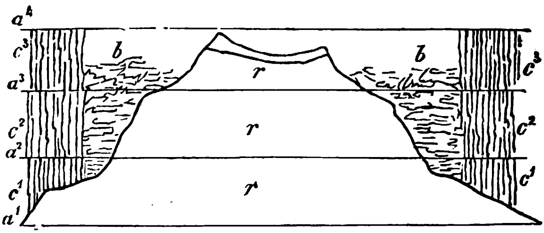

off by waves filling up the space between the reef and the rock, the whole became an annular coral reef inclosing a lagoon. The island and reef would thus present in a plan the following features successively.

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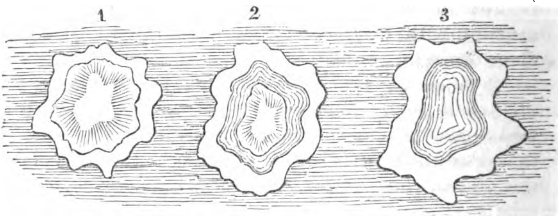

In *fig* 1. the rock is *skirted* by coral; in *fig.* 2. the rock is separated from the coral which *widely encircles* it by a channel of (deep) water; in *fig.* 3. the rock is not seen, but forms the *base* of the lagoon, and is covered by fragmented corals.

If, instead of a sinking, we next imagine a gradual rising or a stationary situation of some island, on which a circle of coral was fixed, the additional growth of this substance would be always on the outside, and the land would never be separated from a *widely encircling* reef by a channel of deep water.

In Mr. Darwin's views, the presence of a lagoon coral island is an evidence of *depression* of the solid land there; and, on the contrary, marginal coral reefs often supply evidence of *rising,* in addition to that furnished by shelly beaches at high levels. Thus may we comprehend, in the former case, the formation of a long bank of coral, by the successive submersion of a line of mountain summits; and the filling of a sea with many small annular reefs, by the sinking of island rocks: in some cases, the circular form of lagoon islands may, however, be as well understood by supposing them to have grown on a submarine volcanic crater. A decisive proof of the truth of Mr. Darwin's views, in the particular instance, would be the discovery of solid coral rock at a much greater depth than that which is stated to limit the existence of the lamelliferous polypi.

The general results of and views arising from Mr. Darwin's investigations include the following very important points: —

1. That linear spaces of great extent in the equatorial regions are undergoing movements of an astonishing uniformity, and that the bands of elevation and subsidence alternate.

2. From an extended examination, the points of volcanic eruption all fall on the areas of elevation. The importance of this law is evident, as affording some means of speculating, wherever volcanic rocks occur, on the changes of level even during ancient geological periods.

3. Certain coral formations acting as monuments over subsided land, the geographical distribution of organic beings is elucidated by the discovery of former centres, whence the germs could be disseminated.

4. Some degree of light might thus be thrown on the question, whether certain groups of living beings peculiar to small spots are the remnants of a former large population, or a new one springing into existence. (From Geol. Proceedings, 1837; and notes taken during the reading of Mr. Darwin's paper to the Geol. Society.)

Shell Beds. — What the circumstances are, which favour in a special degree the accumulation of shells on the bed of the sea, may be partly conjectured; but the subject deserves to be considered as one of the most important problems which geology looks to the naturalist to resolve. Very different conditions are known to govern the aggregation of the different tribes: they choose different soils — so to speak—love different depths, bear unequally the influence of currents, fresh water, climate. Oysters, for example, by their stationary habits and mutual attachment, exclude nearly all other conchifera from those patches of the sea where they thrive. So, among the fossil ostreæ we find whole beds of vast extent; in the Kimmeridge clay (O. deltoidea), and in the lias (gryphea incurva). Near the muddy mouths of tide rivers, uniones, anodontes, &c. abound, and are little mixed with other genera; and their ancient prototypes in the estuary deposits of the coal tracts and Wealden formation are similarly circumstanced. Donati found the Adriatic covered with shells and sediments almost identical with the subapennine deposits; the German Ocean yields sands and shells like those of the raised beach at Speeton; the Bay of Morecambe, upraised, would resemble the deposits at Preston; the Baltic bed, with its living shells, is like the undulated gravel heaps and buried testacea of Sweden; and there can be no doubt that a careful scrutiny of the borders and bed of the existing sea would show many conchiferous formations in progress extremely like those of ancient date. It appears a very general fact, that the existence of living marine testacea is limited to a small depth from the surface. In Mr. Broderip's table (De la Beche's Theoretical Researches), the greatest depth mentioned (for terebratula) is 90 fathoms. It is much to be wished that this interesting subject should attract the attention of the scientific officers of the British navy.

Supposing, what is believed to be true, that the shelly inhabitants of the sea, like the zoophytic tribes, exist in abundance only to a small depth (say 1000 feet), it must follow, that during the formation of the stratified crust of the earth, very general and long continued depression occurred in the ancient bed of the sea: for as the series of strata, full, at least partially, of organic remains, which lived on or near the spots they now occupy, exceeds in almost all countries many thousands of feet in thickness, the successively deposited surfaces of strata must have successively sunk lower and lower, till, the whole depressing force being exhausted, a contrary action raised them again. To this highly important subject we shall recur in another part of this Treatise.

It is further deserving of remark, that if, at this day, contemporaneous deposits of pebbles, sand, clay, and calcareous matter happen even in the same oceanic bed, as the bottom of German Ocean, each strewed with different groups of shells, the distribution of organic fossils in the different primary and later strata, if at all governed by the same laws as those now traceable in nature, though affected by some general characteristics of period, must also exhibit specific relations to the nature of the rocks. We have already shown this to be the fact; and it serves to strengthen our confidence in the reasoning employed, when we find the results of the same causes harmonise in the most ancient as well as the most modern instances.

Banks of Sand, Clay, Gravel, &c. — A very slight observation of the action of the marine currents on our shores is enough to determine many circumstances regarding such accumulations. The first remarkable act, is the sorting of the mingled materials brought down to the sea by inundations from steep land, like the maritime Alps, or gathered from the falling cliffs by the action of the waves. According to specific gravity and magnitude, the masses are separated, transported, deposited — pebbly deposits lie under the gravelly cliffs — the sands are swept to a greater distance — the fine clay carried far in the waters. Of all these circumstances the English coasts offer abundant examples — especially Teesmouth, the Bristol Channel, and the Bay of Morecambe, which, on their wide sands, present a wonderful variety of appearances, proper to furnish the speculative geologist with more accurate and applicable data than are commonly relied on. Among others, the aspect of the surface of the sand —its ripple marks, varying in an exact proportion to the depth of water and the direction of the wind—the numerous little valleys and rills which modify the slopes — the countless *prints* and seeming prints of the feet of birds — the trails of mollusca and annulosa, may suggest to the reasoning geologist *proofs* of the important truth, that all our laminated sandstones and flagstones were *littoral deposits*,— a point of departure for accurate inferences concerning the rising and falling of the level of the land, as compared with that of the sea.

It is hardly necessary to observe, that the *nature* of these deposits varies with that of the supply: near pebbly cliffs, the shore is a shingly beach ; low sandy cliffs, or a rough river, cause expanded breadths of sands sloping gently to the sea; on an argillaceous coast, the bay may be full of sand, drifted by littoral currents, which very much modify all the ordinary results, and are the principal agents in first wasting the high ground, then filling up the low parts of the shore, and thus depositing new land, which subsists either by a natural defence of blown sand, gathered pebbles, or the prudent skill of the engineer, till some unheard-of storm returns to reclaim again the gradual gift of generous nature, or the bold theft of craving man.

The distance to which currents can transport solid matter in the ocean may be well illustrated by the action of the gulf stream which sweeps from the Guinea coast by the Gulf of Mexico, and then traverses so great a portion of the North Atlantic ; for it carries timber and tropical fruits within the influence of the littoral indraughts of Iceland, Norway, and Ireland. Captain Sabine's observations on the sea current of the Maranon show, that, at a distance of 300 miles from its mouth, the fresh water of that mighty river floats on the heavier water of the sea, and retains its earthy discoloration.

Ancient Valley Formations.

I have some time ago proposed this term, for the purpose of combining in one point of view a great number of remarkable ancient phenomena, attesting the former action of water *in existing valleys,* but flowing at higher levels than the actual stream, unless the land has been raised and sunk. Deposits of gravel at the mouth of a valley, in the form of terraces, abound in most mountain countries (*e. g.* foot of Glen Roy), on the sides of a valley (as in Tynedale, above Newcastle), at the head of a valley (as at the head of several Cumberland glens).

In Glen Roy, at a very high level, are two parallel lines, or terraces, which run round the mountain sides, and communicate with other drainage streams. The deposit called Löss, on the Rhine, appears of the same nature, so far, at least, as to indicate the deposition of sediments in water flowing at a level many hundred feet above the present River Rhine, and extending beyond what is now its proper valley on the north side of the range of the Ardennes.*

In some of these cases, there is sufficient proof that the water was not marine, land shells being not unfrequently found in the deposits, especially the finer sorts of sediments. The level character of the terraces, which is the most usual form of these accumulations, seems to indicate the existence of ancient lakes at a high level in the valleys where they occur.

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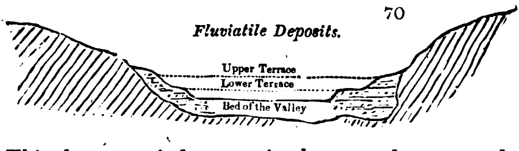

This, however, is less certain than may be commonly imagined; for streams like the rough Arve scatter the detritus brought down from the glaciers over a surface

* Lyell, in Geol. Proc.

gently declining, as the stream runs, but nearly level in the transverse section. If, by any change of the physical conditions, the stream should cut its way to a greater depth, the banks would have that terrace form which belongs to the Lune, the Ouse, the Tees, the Tyne, and many rivers of the North of England. It not uncommonly happens, that two such terraces, at different levels, can be traced for some distance on the sides of a valley, as on the Lune; — occasionally, in the midst of a valley, rises a low hill of gravel corresponding to the lateral terraces. In most valleys, the materials of the terraces are such as the rocks on the sides of the mountains yield; but this is not the case on the Lune about Kirkby Lonsdale, or the Tyne above Newcastle, in both of which situations, boulders and gravel from the Cumbrian mountains constitute a considerable part of the deposit. For this reason, they would probably be called diluvial deposits by some writers, and described as raised breaches by others. The confused aggregation of the pebbles, sand, &c. is such as to imply sudden and violent inundations, which delivered a vast body of detritus in a short time, and perhaps followed the line of the valley, but deposited the coarse earthy matters near the sides when the velocity was lessened, as powerful streams are always found to do.

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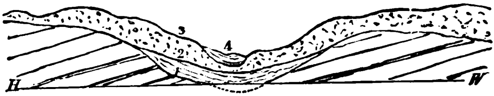


H. W. High water mark.
1. Surface of chalk excavated by water in some ancient period.
2. Surface of ancient tertiary sands, or alluvial sediment left in the chalk valley.
3. Surface of detrital (diluvial) deposit extended over hill and valley.
4. Surface of comparatively modern alluvial deposit in the valley of the diluvium, consisting of chalk and flint gravel.

Existing valleys have, then, in many cases, been traversed by floods of water which have left evidence of their volume, force, and direction. Did they excavate the valleys? or merely follow the traces left by earlier watery violence? Perhaps we must not yet venture to propose a general answer to such questions;—there exist, however, cases which bear very decided evidence with reference to them. At a little valley in the chalk of Yorkshire (represented in the diagram, p. 318.), which opens to the sea near Bridlington, we behold, as in the above sketch, the solid, laminated, chalk, gently declining to the south, excavated in a broad undulation across the laminæ; over nearly the whole breadth of the hollow thus occasioned, rests an irregular sandy deposit very much of tertiary aspect; above this, a thick mass of diluvial clay with bouldered stones in great confusion; the whole surmounted, in places, by a widely laminated deposit of chalk and flint gravel. Finally, the channel of the existing little rill is cut, certainly by that rill, in places through the whole series of deposits, into the solid chalk beneath. What does this teach us? First, the excavation of the chalk by an agent which wholly swept away the spoils; secondly, a less turbulent agency introducing sand and gravel, so as partially to fill up the hollow, but not to cover the parts of the chalk beyond; thirdly, a violent impulse of mud and stones brought from a distance over this valley, and the surfaces for miles on each side of it; fourthly, variable but extensive deposits of local gravel; fifthly, the work of the actual stream, which gathered in the ancient hollow.

As we know the chalk to have been raised from the sea, this upward movement may suggest to us the excavation of the rock by oceanic currents, and the partial deposition of sand; the general accumulation of boulders and clay demands a general disturbance affecting other, and even remote, districts; while the mass of chalk, flint, gravel, seems the natural effect of a more local and less violent convulsion. In some instances, local gravel of this description lies both above and below the proper diluvium.

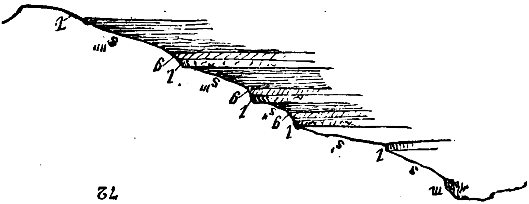
The interval of time here supposed to occur between the original excavation of a hollow or valley in the rocks, and the accumulation in it of the spoils of a violent commotion of water, is indeterminate. So, indeed, is that between the cessation of the diluvial floods (whatever they were) and the commencement of the actual stream. For if the great hollow was both excavated and afterwards filled before the chalk rose completely out of the sea water, we have no easy means of knowing when the whole became dry land, and admitted the descent of fresh water. If, however, the bones of quadupeds which occur in the diluvium be thought sufficient to prove these accumulations to have happened on dry land, the actual stream may be looked upon as a feeble but immediate successor of the devastating floods.

Rock Terraces in Valleys. — There is a peculiar class of terraces in valleys, which indicate in the same manner the successive lowering of the level of descending water (or the successive rising of the land); these terraces are formed by solid rock, with little or no trace of gravel, or other detritus. Such cases are frequent in the mining dales of the North of England, which cut deep into the "Yoredale Rocks," or upper mountain limestone series. *

In this varied series of limestone, sandstone, and shale, almost every limestone which overlies shale projects into a terrace; and this sometimes happens to strong sandstones similarly circumstanced. It is easy to see that, as this occurs in many of the branching lesser dales, as well as in the principal valley, it may plausibly be argued that the whole effect is due to atmospheric action. It is probable, however, that this is not a sufficient cause; since additional débris might thus be expected to be falling every day, or, at least, more of this accumulation should remain than we see. We must further observe, that the presumed levels of the water are only clearly marked by continuous terraces when the strata dip nearly in the plane of the valley. It appears, that just as, at this day, a mountain stream crossing the Yoredale Rocks

* Geol. of Yorkshire, vol. ii.

forms waterfalls and cliffs at every ledge of limestone, of the wearing away of the subjacent shales — so the great currents which anciently flowed in the valley (whatever they were) excavated the softer strata, and left the hard prominent in terrace cliffs, as in diag. No. 72.



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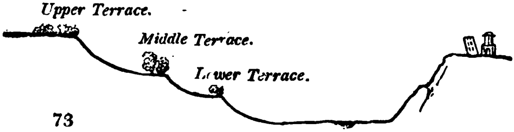
m. Millstone grit summit resting on shales and grits to *l*, which is limestone, and projects over *s*, the subjacent argillaceous beds. The same occurs with each lower ledge of limestone *l*, which, with the gritstone *g*, *usually* found beneath, forms a terrace on the hill sides, above a slope of shale.

A different case occurs in valleys which cross and enter deeply into thick masses of red sandstone, such as occurs at Nottingham, Kidderminster, Bridgnorth, &c. At Bridgnorth, for example, occurs a remarkable triple row of terraces on the east bank of the Severn, which appear decisive as to the successive operations by which changes of relative level of the land and the water which excavated the valley were brought about.

All the terraces represented in the diagram No. 73.



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are formed on the face of the thick and easily excavated red sandstone; but it is only on the left (east) bank of the Severn that they are conspicuous, because this is the salient angle,—for it is always observed among the common daily effects of inundations, that such terrace-like levels are only marked on the projecting land, while the re-entering angle is excavated to vertical or steep faces.

Fluviatile Deposits.

To discuss fully the origin and history of valleys, is an object reserved for a later section; we may now proceed to consider the effects produced, in valleys already formed, and partially filled with old detritus, by the water running therein. This is a large subject; for, besides the mechanical and chemical actions of the rivers and brooks, which vary according to the hardness and nature of the rocks, there is to be examined the influence of atmospheric vicissitudes, heat and cold, moisture, dryness, frost, &c.; and all the complicated effects thus occasioned are, in relation to the valleys, further modified by the form and slope of the surface, the occurrence of lakes, and other circumstances. Streams flowing along a valley under the various conditions which we observe, are to be considered both as eroding and transporting agents; and it is not only conceivable from the admitted instability of the level of land and sea, but perfectly demonstrated by observation, that these seemingly opposite effects have been exhibited at different times by the same river, at the same points of a valley. Moreover, in the course of the changes of level of land and sea, some rivers appear to have quitted their ancient valleys entirely, and to have taken up new courses corresponding to the new conditions; and this, not merely in marshy countries, where a river's course is almost accidental, but in hilly and rocky districts like the vicinity of Ludlow or the borders of Teesdale. It will, therefore, be proper to present as full an account of the phenomena relating to the actual configuration of valleys under different circumstances, as a due regard to reasonable limits will allow. The first thing to be considered is the degree in which the earth's surface is wasted by atmospheric changes and aqueous agency.

Waste of the Earth's Surface.

If we consider that the aggregation of rocks and minerals, whether we regard it as a fruit of chemical or mechanical actions, is no otherwise fixed or stable, than as the forces which tend to keep them united are superior to those which from all sides strive to separate them, we shall be prepared to comprehend how the *variations* of these constringent and divellent forces, according to heat, moisture, new elementary combinations, &c., bring a silent but sure and often rapid decay on all the structures of man, and on all the mightier monuments of nature, which are exposed to the ever-changing atmosphere. It is painful to mark the injuries effected by a few centuries on the richly sculptured arches of the Normans, the graceful mouldings of the early English architects, and the rich foliage of the decorated and later Gothic styles. The changing temperature and moisture of the air, communicated to the slowly conducting stone, especially on the western and southern fronts of buildings, bursts the parts near the surface into powder, or, by introducing a new arrangement of the particles, separates the external from the internal parts, and causes the exfoliation or desquamation, as Macculloch calls it, of whole sheets of stone parallel to the ornamental work of the mason. From these attacks, no shelter can wholly protect; the parts of a building which are below a ledge, often decay the first; oiling and painting will only retard the destruction; and stones which resist all watery agency, and refuse to burst with changes of temperature, are secretly eaten away by the chemical forces of carbonic acid and other atmospheric influences. What is thought to be more durable than granite? Yet this rock is rapidly consumed by the decomposition of its felspar, effected by carbonic acid gas,—a process which is sometimes conspicuous even in Britain (Arran, Muncaster Fell, Cumberland), but is rapidly performed in Auvergne, where carbonic acid gas issues plentifully from the volcanic regions.

Effects of Rain.

Mere rain is a powerful agent of disintegration; and its frequent attacks leave at length, in sandstones and limestones, otherwise very durable, channels of considerable dimensions, which have sometimes been ascribed to other causes. The Devil's Arrows at Boroughbridge, in Yorkshire, are fluted from this cause, from top to bottom (except on the underhanging sides, where they cease not far below the summit)—the work of two or three thousand years: and when we turn from these monuments of man to the native crags whence they were cut, "Brinham rocks," and regard the awful waste and ruin there, well marked by the pinnacles and rocking stones which remain in picturesque desolation, it is difficult to avoid indulging a long train of reflection on the processes of decay and renovation which thus seem to visit even the inanimate kingdoms of nature, subjecting all its material elements to continually renewed combinations.

On the broad limestone floors which support the noble mountains of Ingleborough, Penyghent, and Wharnside, the rain channels are so abundant as to have attracted the attention of artists and tourists; and on Hutton roof crags, as well as among the limestones of the Alps, they change their direction with the slope of the ground, collect into larger furrows like valleys on a broad surface, and terminate in the large deep fissures, as small valleys often end in a great hollow of drainage. Another remarkable phenomenon of the moorland districts of the North of England, which are formed on the Yoredale series of mountain limestone, may perhaps admit of the same explanation. These are the "Swallow" holes, as they are termed, which range above the outcrop edge of the limestone beds, and act as drainage channels from the surface to the jointed calcareous rocks below. These round or irregular pits and holes are smoothed on the faces and joints of stone, as if by the action of acidulated water, the origin of which, from the air or the neighbouring vegetable substances, is not hypothetical.

Effects of Frost.

In no form is the moisture of the atmosphere inefficient in accelerating the disintegration of rocks. Collected in the joints and cavities of mountains, it loosens every thing by its expansion and relaxation; heaped into enormous glaciers on the summits and down the valleys of the Alps, it melts at its lower edges and on the lower surfaces, and thus is ever in motion downwards; augmented from above and diminished from below, its moving masses plough up the solid earth, and, by a wonderful and momentarily insensible energy, pile up, on each side of the icy valley, vast quantities of blocks of stone and heaps of earth, which slowly advance into the lower ground; and these sometimes bear trees and admit cultivation; till, in the course of changes which these rude climates experience, the whole is transported away by the river which flows beneath, and space is left for new augmentations from above. Perhaps no circumstances are so favourable to the collection of materials for rivers to sweep away, as the glacier crown and icy valleys of the Alps, accompanied by the thundering avalanche and frequent landslips, like those of the Rossberg and the Righi. What further happens to these materials, belongs to the history of the river.

Effects of Springs.

Collected in the atmosphere, the rain is filtered through the sandy rocks, passes rapidly by the joints of the calcareous strata, and is stopped by the clays, and by dykes and faults; it then issuing in springs. But it is no longer the same water: rain water is, indeed, far from being in a state of purity; it contains always carbonic acid, frequently some muriatic acid or chloride of sodium, besides other irregular admixtures. In passing through the rocks it absorbs lime, oxide of iron, &c., and on issuing in the form of springs, loses its excess of carbonic acid, and again deposits carbonate of lime, carbonate of iron, &c. From some springs the quantity of carbonate of lime deposited is enormous; with the water of others, sand, gravel, fossil shells, and zoophytic fragments issue. Thus the first operation of water in and upon the earth is the same, viz. to consume away the solid substance of the rocks, and either deposit it in new situations not far from the source, or deliver it to flowing streams to be carried further away.

Springs which have an impeded issue to the surface, are the most general cause of landslips: we may consider the great fall of the Rossberg as a case of this kind, the water entering and moistening a particular layer of strata, all inclined very highly, so as easily to acquire a descending force, if the cohesion of the parts were weakened by interposed moisture.

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The spring, or rather river (Arve), which issues from the foot of the mer de glace, near Mont Blanc, brings a vast quantity of detritus, which the grinding motion of the glacier on its rocky bed had broken and rolled to pebbles.

Effects of Rivers.

A river thus fed by springs of water not pure, partially filled with earthy matter, flowing with various velocities through soil and among rocks of unequal resisting power, and formed of particles of different magnitude and specific gravity, must exhibit in its long course a great diversity of appearances. Some rocks and soils it may corrode chemically, others it may grind away by its own force and the aid of the sand and particles which go with it: from steep slopes it must, in general, transport away all the loose materials; but when its course relents, these must drop and augment the land. The finest particles are first taken up and last laid down, the larger masses make the shortest transit.

Rivers, on whose course no lake interposes its tranquillising waters, may be considered as constantly gathering, incessantly transporting, and continually depositing earthy materials. It is, of course, principally in times of flood, that they both gather the most materials, and transport them farthest; yet even in the driest season, the feeblest river does act on its bed, wears by little and little even the hardest stones, and works its channel deeper or wider. This it does, partly by the help of some chemical power, from carbonic acid, and other admixtures, but principally by the grinding agency of the sand, pebbles, &c. which it moves along. In times of flood, these act with violence like so many hammers on the rocks, ploughing long channels on their surface, or whirling round and round in deep pits, especially beneath a fall, or where the current breaks into eddies over an uneven floor of stone. This is admirably seen at Stenkrith Bridge in Westmorland, under the waterfalls about Blair Athol, and in North Wales, and, indeed, very commonly. Not unfrequently, on mountain sides or tops, far from any stream or channel, phenomena somewhat similar occur, sometimes the effect of rain, sometimes, we may suppose, the remaining evidence of the former passage of running water, when the levels of the country were differently adjusted.

As the slopes are greatest in the upper parts of valleys (generally), and gradually flatten towards the sea, it is commonly observed, that, from all the upper parts of these valleys, rivers abstract large quantities of the finer matter, and in times of inundation, not a little of the coarser fragments of rocks; much of this is deposited in the lower ground, where the current is more tranquil, and generally (unless the river be very deep) slower. We must, indeed, suppose, that every where *some* wearing effect on its bed and sides is produced by every river, even to its mouth; but this effect grows almost insensible far from the high ground which gives birth to the streams; and long ere we approach the estuary, the wide flat meadows, which fill the whole breadth of the valley for miles in length, show what a mass of materials has been drifted away from the higher ground. Finally, where the tides and freshes meet, the sediment of both is disposed to drop; and some rivers may be viewed as sending little or no sediment to the sea.

Thus the whole effect of drainage, including all the preliminary influences of the atmosphere, rain, springs, &c., is to waste the high ground, and to raise the low; to smooth the original ruggedness of the valley in which it flows, by removing prominences and filling up hollows; and notwithstanding the length of years that rivers have flowed, they have, in general, not yet completed this work: they still continue to *add* materials to the lower ground, and, in a few instances, to carry out sediment into the sea.

The whole surface of the earth, then, is changing its level, by the mere precipitations of the atmosphere, and their subsequent effects; the high land sinks, and the low land rises; but what is the rate of this progress, we have no complete means of knowing. Few ancient measures of the height of the land which has been wasted, or the area of that which has been accumulated, are worthy of notice; we are, however, sure, from various causes, that many valleys have not been altogether worked out by the rivers now running in them; and some natural chronometers have been pointed out by De Luc and others, which rudely limit the length of time during which rivers have flowed, and might be more usefully employed to determine the rate and amount of fluviatile action.

Rivers certainly did not excavate the whole valley in which they flow, for they have not even removed the diluvial detritus brought into them from other drainages, and heaped on the previously excavated rocks.

Rivers have certainly not excavated more than an inconsiderable part of their valleys, for otherwise the Lakes of Geneva and Constance would have been long since filled by the sediments of the Rhone and the Rhine, which issue from these lakes of that lovely hue and transparency which marks their total freedom from all tinge of earthy impurity. When, indeed, we look at the small but growing deltas of the heads of the English lakes, as Derwentwater, Windermere, or Ulswater, and consider the Derwent or the Rothay in its time of furious flood, we shall be disposed to set a high value on De Luc's opinion, sanctioned by Cuvier, Sedgwick, and others, that these deltas prove the comparatively recent date of the present disposition of drainage on the surface of the earth. Rivers flow in certain channels, because these were previously formed by eonvulsions, and violent movements of water; they have exerted all their force in merely smoothing and filling the inequalities of their valleys, and this partial labour they have not accomplished. Will any one, after this, require to be told that rivers did not make their own valleys; and only yield to this truth when, on the chalk and limestone hills, hundreds of valleys are shown him, down which water never runs, and which, indeed, have no trace of a channel?

The upfillings of a valley by the operations of a river ever tend to be formed in horizontal laminæ;

or at least their surface is generally level in the direction across the valley, whatever undulations exist beneath, and however rapid may be the longitudinal declivity of the valley. This is well seen in many valleys of the Swiss Jura, the Cotswold Hills, &c.

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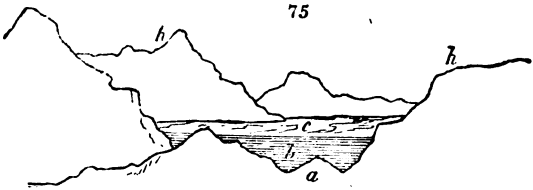
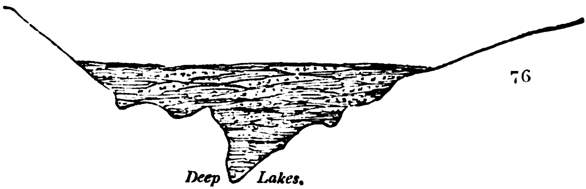


a. Irregular surface which is the original basis of the valley. *b.* The sediment left in it, with a plane surface *as if* deposited in a lake. *c.* The surface of the valley, uniformly declining among *h*, the bordering mountains.

When the materials are gravel and coarse sand, deposited by an impetuous stream, the general surface may be level, and yet the laminæ beneath are frequently much inclined, with slopes in various directions, as Mr. Lyell has noticed with regard to the detritus left by the stormy waters of the Arve. The same thing occurs in many of the stratified rocks which appear to have been accumulated under violent agitation near the sea-shore. (See Diag. No. 20. p. 61.)

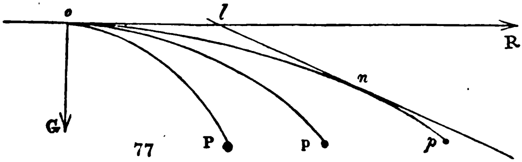
Lakes on the Course of Rivers.

Plane surfaces existing along the course of valleys, are commonly, without further question, supposed to be indicative of the site of ancient lakes, which have been slowly but completely filled: the supposition is often correct, but it is sometimes erroneous. Rapid rivers, which, in times of inundation, drift coarse materials down their rough beds, and deposit them in the expansions of their valleys, are thus partly choked in their courses, and turned into new channels. Thus they wander irregularly over a large area, every where filling it, to about the same height, with a mass of partial deposits, related to the successive positions of the channel, which, when unconfined by man, seeks always the lowest passage. On a cross section of such a valley, these many distinct streams of gravel and sands appear nearly as in the annexed diagram.



But such a distribution of materials appears not to occur in lakes; whether they receive sediments from gentle streams, rapid rivers, or sudden inundations. The reason of this is the great lateral diffusion of motion in water. Where any great depth of quiet water is interposed on the path of a river, the lacustrine sediments assume various modes of arrangement, depending on their own fineness, and the velocity of the water by which they are hurried along.

Deep Lakes on the Course of a River. — On entering a deep lake, the mingled sediment of a river is subjected to a new influence, — the descending force of gravity, in addition to the direct horizontal force imparted by the current, and the lateral movements which it occasions. Each particle, in consequence, tends to fall from the surface of the water, as it moves forward, or to the right and left of the point of entry of the river, and with an accelerated velocity in the lower part. The path of each particle will be more or less influenced by the direct, lateral, or vertical forces, according to its magnitude and weight. Thus, in the diagram No. 77., which is to represent a vertical section along the path of the river as it enters the lake at the point *o*, P p *p*, particles of unequal magni-



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tude, entering together, describe curves of unequal curvature (they are all related to the same vertical axis, G); the smallest particles being transported furthest, because they have, proportionally, the largest surface, and therefore subside most slowly in the water.

On the horizontal plan (No. 78.) the courses of such deposits are shown to be concentrical, or nearly so, to the point of influx of the river. By such deposits, the Delta of the Rhone in the Lake of Geneva, as well as that of the Derwent in the Lake of Keswick, has been formed; and, in fact, in every lake a similar explanation

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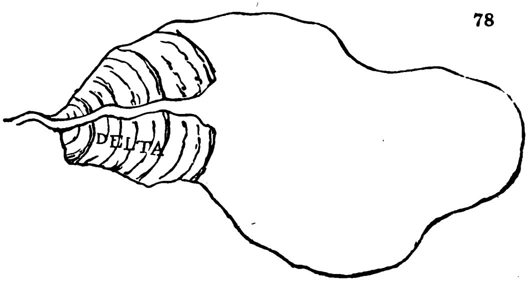
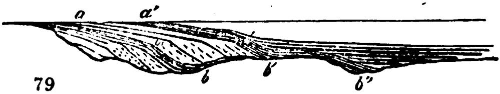


is found applicable. Returning to the vertical section (No. 77.), we may remark, that the parabolic lines there given, if considered as representing successive depositions, require to be modified above and below: above, by the shifting of (*o*) the point of influx forward; below, by the circumstance, that the curve ceases at a certain depth (n), when it coincides with the line $n\ l$ drawn to represent the greatest slope on which the particles will rest. This slope varies somewhat in particles of different size and form. Generally speaking, the structure of these deltas corresponds to the subjoined diagram; where the surface $a\ a'$ is level; the lines $a\ n$, $a'\ n'$ are curved, and lie in surfaces of contemporaneous depo-



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sitions; and the lines $n\ b$, $n\ b'$ are straight lines corresponding to the angle of rest in deep water.

We may further observe, that the unequal dispersion of the sediments in water causes another modification of the lamination of such delta. Fine clay is spread far in the water, and settles at length in a general thin deposit over the curved and sloping faces $a\ n\ b$, and on the bed of the lake $b\,b''$, after the agitation of the water produced by the inundation has ceased, and the coarser sediment has settled to its place.

If further we imagine the waters of such a lake to be calcareous, and liable to slow decomposition, so that layers of carbonate of lime (or shelly marls) are formed, these will be still differently arranged. If the calcareous matter be generally diffused, the layers will not radiate from or collect round a point, but be very generally spread over the bed of the lake; and even when the calcareous substance enters in solution with a particular stream (as often happens), it mixes with the water of the lake so extensively as to yield wider and more regular deposits than those produced by merely mechanical agency.

Shallow lakes, subject to fluctuation, produce on the deposits of coarse gravel and sand, which are brought into them by rivers, an effect intermediate between that of deep water and mere fluviatile currents. The conoidal lamination due to the former is complicated with variation of the point of influx arising from the latter; and thus the upper ends of such lakes become irregular in outline, and are filled by insulated subaqueous banks.

END OF THE FIRST VOLUME.

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TREATISE ON GEOLOGY.

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