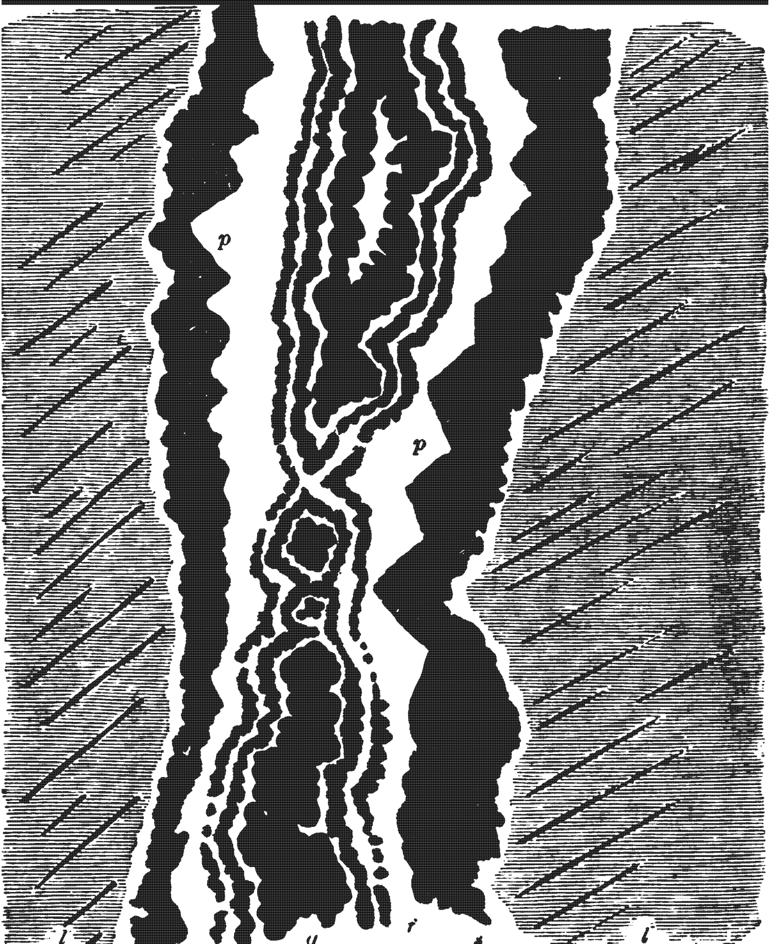

A guide to geology

John Phillips

GEOLOGY.

LONDON
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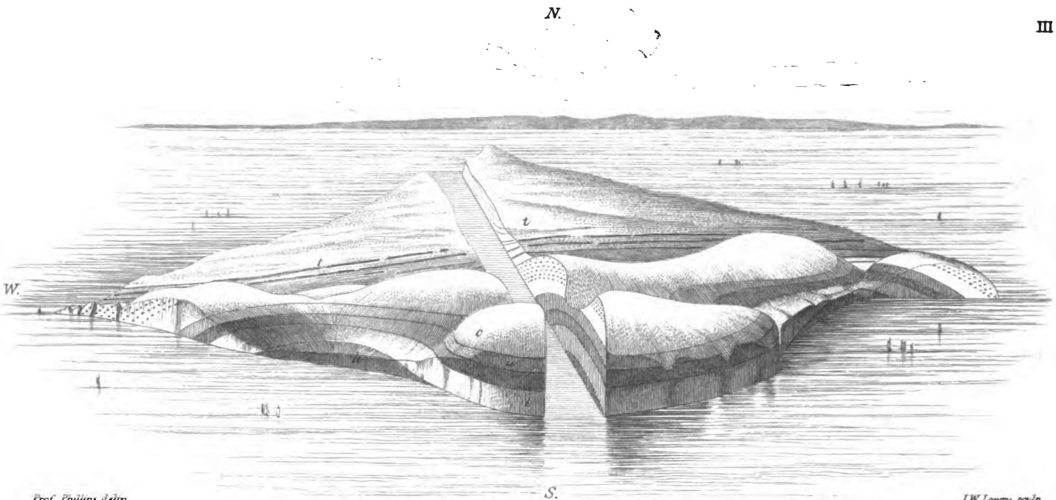

Prof. Phillips delin. J.W. Lowry sculp.

GEOLOGICAL VIEW OF THE ISLE OF WIGHT.

h. Hastings sand. — l. Lower green sand. g. Gault. — u. Upper green sand. — c. Chalk. — t. Tertiary.

A GUIDE

TO

GEOLOGY.

BY

JOHN PHILLIPS, M.A., LL.D., F.R.S., F.G.S.

PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF OXFORD;
HON. MEMB. IMP. ACAD. OF SCIENCES OF MOSCOW, OF THE ACAD. OF SCIENCES OF PHILADELPHIA, ETC.

Et mare contrahitur, siccæque est campus arenæ
Quod modo pontus erat, quosque altum texerat æquor
Existunt montes. Ov. *Metam.*

FIFTH EDITION.

LONDON:
LONGMAN, GREEN, LONGMAN, ROBERTS, & GREEN.
1864.

TO

THE VICE-CHANCELLOR

AND MEMBERS OF

THE UNIVERSITY OF OXFORD

THIS VOLUME

IS MOST RESPECTFULLY DEDICATED

BY THEIR

PROFESSOR OF GEOLOGY.

PREFACE

TO

THE FIFTH EDITION.

When, almost thirty years since, the 'Guide to Geology' was first given to the public, it was readily accepted as meeting the frequent demand of a grammar containing elementary truths, and theoretical inferences confirmed by observation. Every succeeding year was then marked by fresh discoveries, and enlarged reasonings among geologists, which surprised even men of science, and gave an uncomfortable shock to minds trained in a different school. Even they who had released the imprisoned power of steam, and compelled the black residue of primeval forests to illuminate our streets, and forced the mimic lightning to speak our language and perform our will — even they were startled by the idea of many systems of life, which came and passed away before the birth of man. They heard with surprise, if not with displeasure, of lands without quadrupeds, skies without birds, and seas without fishes; hot and cold fits in the climates, and all but universal changes in the position of land and sea. If an almost easy faith in the 'wonders of geology' has now succeeded to that not unreasonable hesitation, it is to be ascribed to the precision of the statements of fact, and the moderation of the theoretical views put forth by geologists. If we are to retain this precious confidence, we must persevere in the methods which have won it, carefully shunning speculations without data, and conclusions which transgress the just limits of time and force, and conflict with contemporary local conditions.

It results from my experience as a teacher of this science that three orders of persons require a guide to geology. 1. What has been settled by these enquiries into the early conditions of the earth? what changes has it undergone since it became a globe, and received its ornament of life? Questions of this order must be asked by every person who enquires at all. 2. Are these conclusions to be trusted? what are the facts and reasonings by which they are supported? This is the reasonable demand of a mind trained to accept what is true, admit what is probable, and reject what is false. 3. There is yet another and more earnest order of enquirers—real students of Nature — who desire to add to the facts, complete the reasonings, and advance the conclusions, so as to take part in the further progress, and be counted among the discoverers of the new truths of geology.

I venture to hope that, in its new and enlarged form, my 'Guide to Geology' will, to a considerable extent, meet the reasonable expectations of enquirers and students, and concur with the works of other writers having the same object—to train up followers better and wiser, if not more zealous or more fortunate than ourselves.

OXFORD: *Jan.* 1, 1864.

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A GUIDE TO GEOLOGY.

CHAPTER I.

THE MASS OF THE GLOBE.

OBJECTS OF THE SCIENCE.

GEOLOGY is that part of science which includes the natural history of the earth. The present state of the earth is found to be in harmony with general laws affecting its whole mass and its separate parts. These laws represent or express in a comprehensive form the mechanical, chemical, and vital phenomena which make up the system of effects now observed on our globe, composed of land, water, and atmosphere. The earth contains monuments of earlier states through which it has passed, to which these same laws are found equally applicable. When so applied, they enable us to compare any two states of the earth, to determine their difference, and to measure, estimate, or conjecture (according to the completeness or imperfection of the evidence *in each case*) the degrees of force and the length of time due to the effects which are observed.

Prosecuted impartially, this method of remark, which is quite in the spirit of the inductive philosophy, assures us that no special feature of the earth or sea or air, not a single mountain, river, or lake, remains as it was in primeval times, is clothed with the same plants, or affords residence to the same races of animals. Yet it is equally true that no phenomenon of which traces remain in the hills or in the valleys, nor a single peculiarity in the ancient forms of life, is inconsistent with the general laws regarding matter and organisation which now prevail. Geology is full of great and unexpected discoveries of ancient phenomena, but none of them appear to deviate from the present laws of modern nature, so as to require the supposition of any other forces than those known to be in operation. These laws, in fact, appear to us to be the expression of the fixed purpose of the great Maker, independent of time and exempt from change.

Geologists have discovered in the earth monuments of its ancient conditions, enough to allow of reconstructing several of its earlier aspects, to mark out boundaries of land, depths of sea, and courses of rivers, and to assign to the different regions their proper inhabitants, races of plants, and animals. The changes thus exhibited between remote epochs in the earth's history are total—what is now land was sea:

> Quodque fuit campus, vallem decursus aquarum
> Fecit, et eluvie mons est deductus in æquor.

Giant reptiles have been expelled, giant cetaceans have supplied their place;

> Inque brevi spatio mutantur secla animantum.

The effects of these changes between particular epochs are so great, especially in regard to living beings, as to justify the expression now common in books of geology, of successive systems of life on the earth. On comparing these systems in their proper 'order of succession'—the order of time—it is soon ascertained that they are not placed arbitrarily as the letters of an alphabet, but in mutual relation, like numerals in a progression—the preceding influencing or determining its follower. And as in such a series of numerals the earlier terms are never repeated, so in the progression of the systems of animal nature, the forms and combinations of forms once passed, recur no more: in this point of view nature has no backward steps.

The whole series of life is regarded by many geologists as *beginning* with a few forms, and growing fuller and more varied in each successive system with the lapse of time, as if it were unfolded or *developed*, whether by this is meant a real descent by offspring continually more and more unlike the parent, or an enrichment by new creations added from time to time to an original stock. And this idea of a *beginning* of life on the earth is confirmed in their opinion by the study of the series of chemical and mechanical phenomena, which were contemporaneous with these systems of life. For thus it appears on good evidence that the earth was once in a state quite incompatible with the presence of animals or vegetables; that it had no such distinction of land, sea, or atmosphere as we now enjoy—a globe of melted matter, enveloped in a vast misty expansion, in which the water was suspended which now fills the ocean. The history of such a globe is not for geology to trace, except by aid of other branches of knowledge. Physical astronomy comes to our aid, and leads us one step farther backward into the depths of time and space—shows us the globe dissolved in a vast nebula, the parent of the solar system; traces the condensation of this nebula, the separation of it into rings and globes round a condensed central mass; accounts for the rotations and revolutions of the planets; and opens to the mind the contemplation of an immensity of past duration before the earliest dawn of the progression of life, which geology has traced with so much labour and success. This is cosmogony, and geologists are not to be blamed if they refuse to take notice of inferences or speculations relating to phenomena which were ended before the history of the earth which they strive to recover began. Yet it is for the advantage of geological theory not to neglect the comprehensive conclusions of mathematicians and astronomers regarding the former probable, and the present actual, state of the mass of the earth. If the history of the earth be a progression of phenomena, all the terms are of importance to be known, and especially the earlier ones, for their influence still remains.

THE EARTH AS A PLANET.

The earth is known to the greater part of mankind as the stage on which men and women are merely players, the heap of dust from which they came and to which they will return. To the botanist and zoologist the earth reveals herself as the fertile mother of flowers and fruits, the many-breasted nurse of innumerable forms of animal life. The geographer contemplates its all-embracing waters and divided lands, its snowy mountains and winding rivers, and admires the congruity of its diversified surface to the various wants of mankind. The astronomer finds it to be a somewhat uneven globe—one of many such spheroids which travel round the sun, receiving from it both heat and light, and interchanging these beneficent rays with millions of other suns and other worlds, far away from our own system of revolving planets, yet all subject to the same laws, possibly all evolved from ancient nebulæ, like some now visible in space, which may be undergoing the change into other suns and planets.

In all these respects the earth is known to geology, which throws over them all the lights and shadows of successive periods of ancient time, and is thus gradually converting the whole into a natural history of the vicissitudes of the ground we tread on.

In this vast research, geology rests on no traditionary fable, no theological dictum: but full of faith in the certainty of the laws appointed by the Maker and Governor of Nature, and in the power of the human mind to appreciate their observed effects, it calls on every science which treats of the properties of matter and the functions of life, to aid in the great attempt of constructing a continuous history of the globe and its inhabitants;

> . . . primaque ab origine mundi
> Ad sua perpetuum deducere tempora carmen.

The earth, sea, and air, which constitute our globe, are in all their parts and at every instant of time undergoing change — not a diminution or augmentation of the whole mass, but a change in relative proportions or places, or other conditions. What is solid becomes liquid or gaseous, what is aeriform contracts to liquidity or hardens to stone. During these changes compounds are resolved to their elements, and the released molecules enter into new combinations. Thus for everything terrestrial which is compound there is not only always conceivable, but there is in many cases actually proved, another and simpler condition of existence—the condition of uncombined elements. The combinations which actually prevail are maintained such as they are by definite natural forces, which are *general*, as gravity, and affect all matter in a certain way, or *special*, affecting different sorts of matter in different ways or in different degrees, as chemical attractions.

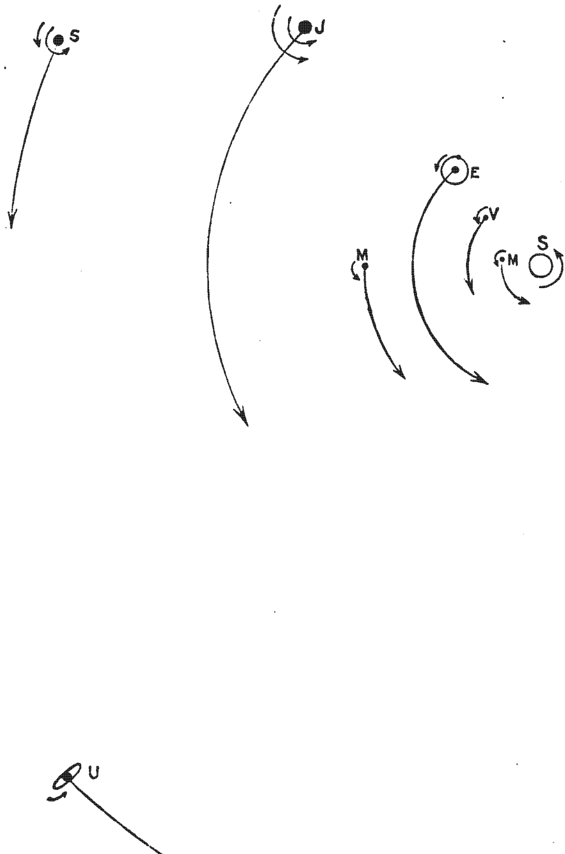
These forces do not all tend in the same direction, nor, except under the same general conditions, is the resultant of their action uniform. If we imagine the conditions to change, the result must be supposed to change likewise. One very striking example of this truth is afforded by the change of condition which the earth experiences every day and night, and in the course of every year; for by the mere difference of the quantity of heat-rays received from the sun, the invisible vapour of the clear sky is condensed to water or crystallised to snow. With a certain elevation of temperature of the surface of the globe there would be no snow, with a further augmentation there would be universal fog, and at a still greater heat the seas would be laid dry. In the same manner it is easy to perceive that, if the elements should 'melt with fervent heat,' limestones would release carbonic acid, minerals would give up oxygen and sulphur, metals would be sublimed, and the great globe itself, 'yea, all which it inherit, would dissolve,' and expand into a vast mass of uncombined elementary matter. I say this is a conceivable result of the application of great heat to the mass of the globe; it is, indeed, an actual result of ordinary experiment on many parts of the substance of the globe best known to us—those parts whose history it is most important for us to know.

Whoever examines the substance of a mixed rock—granite for instance—separates the constituent minerals, analyses these into their elements, and considers the laws of their crystallised aggregation, can scarcely avoid the belief that all the elements thus brought together by forces acting in definite directions were free to obey those forces—in other words, were free in space, as the parts of liquids and gases are. Now, half of what appears solid in the substance of the earth is really condensed oxygen gas — the vital air, which, if free from its confinement, would in the existing temperature and under the actual pressure of the atmosphere, expand to 2,000 times the bulk which it occupies in the rocks. Let it be supposed free, as it must once have been, and our earth-mass appears at once expanded into something like a planetary or cometary nebula, of which several examples appear in the heavens.

Undoubtedly, the most probable conclusion on this subject to which mechanical and chemical philosophy lead, represents the globe as condensed from an immensely expanded and attenuated mass, in which all, or a great part, of the constituent elements now combined in liquids and rocks were separate, the most probable general cause of their condensation and combination being a reduction of the temperature of the mass.

A similar conclusion, though founded on different data, and having much wider applications, is adopted by many astronomers after the suggestions of the elder Herschel and Laplace. In their judgment, the component parts of our solar system exhibit so many important analogies, and, in regard to their movements, such remarkable conformities of direction, as to render very probable the supposition of their having all derived origin from a common source of matter and motion. The planets revolve round the sun in orbits which lie nearly in the same general plane, so that the plane of the sun's equator or the plane of the earth's orbit, called the Ecliptic, being taken for

DIAG. 1.



comparison, the planes of the orbits of the other planets correspond within a few degrees. Conceive, then, the sun to be in the centre of the whole system of planets, Mercury M, Venus V, Earth E, Mars M, Jupiter J, Saturn S, and Uranus U, and to turn round on its axis in the direction of the arrow. Each of the planets turns round on its own axis in the same direction, as the arrows show, and each performs its revolution round the sun in the same direction, and nearly in circular curves. Again, the moon, the earth's satellite, revolves round the earth in the same direction, and nearly in the same general ecliptic plane, and turns on its own axis in the same direction; and so do the satellites of Jupiter and Saturn. The divided rings of Saturn also revolve in the same direction.

Towards the boundaries of our system, indeed, this remarkable harmony fails—in the case of the four satellites of Uranus, which revolve round the planet in a plane nearly perpendicular to the ecliptic, and in a direction which appears retrograde when compared with the general orbital movement. Whether the one or more satellites of Neptune, which are hard to see at all, conform to the general rule, is not yet known. Comets deviate from the general rule.

As Laplace informs us,* these numerous and

* Expos. du Système du Monde (1808), ch. vi.

agreeing motions require one general anterior condition for their explanation; planetary movements in the same direction, and nearly in the same plane; the movements of satellites in the same plane as their primaries; the movements of rotation of these different bodies and of the sun in the same direction as their movements of direction, and in planes not very different; the small degree of eccentricity of the orbits of planets and satellites; and, finally, the great eccentricity of the orbits of comets whose inclinations have no approach to uniformity: these are the facts for which one general anterior condition is the postulate. The answer of Laplace gives for this condition an immense expansion of the matter of the planets into a vast circumsolar atmosphere.

And this expanse, vast enough to include Neptune, and a radius of three thousand millions of miles, he regards as depending on a former high temperature (*chaleur excessive*) pervading all this space. By contraction of this primitive nebula and the internal changes coincident therewith, he conceives our planetary system to have been derived, and gives as an illustration of such internal changes — the famous new star which in 1572 shone brightly for some months in the constellation of Cassiopeia.*

* 'Nous devons donc croire qu'une cause primitive a dirigé les mouvemens planétaires; surtout si nous considérons que

Comets, with the long duration of their revolutions, the great eccentricity of their orbits, and the variety of their inclinations, he regards as naturally explained by the resistance of such an atmosphere to their paths—a resistance which has destroyed the movements of very many others, whose eccentricity was less, and united their masses to the sun. Only a residue of the comets originally sweeping round the sun in various directions now remains, all or most of those whose orbit was wholly or partially contained within the original solar atmosphere, and continually impeded by its resistance, having fallen into the sun. Hence the orbits of the comets which remain are quite independent of the plane of the solar equator and of each other; their eccentricity is great, and their periods are long.*

On the contrary, the paths of the planets being nearly circular, it is evident they did not at any time, like comets, plunge into and traverse the circumsolar atmosphere; it is probable that they were formed at the successive limits of that atmo-

l'inclinaison du plus grand nombre de ces mouvemens à l'équateur solaire est peu considérable et fort au-dessous du quart de la circonférence.'—*Exp. du Système du Monde*, vol. ii. ch. vi.

* Laplace wrote in 1808. Since then the discovery of Biela's comet and Encke's comet, both of short period, and subject to great changes in their elliptical path, rather confirm than weaken the general argument.

sphere by the condensation of the zones which it released (*qu'elle à dû abandonner*) in the plane of the equator, while the whole was cooling and condensing on the surface of the sun. These zones of vapours might, by their cooling, form liquid or solid rings round the central body, of which condition one remarkable case, but only one, appears to remain in our system, viz. the rings of Saturn. Such rings would in the course of time generally be broken up and collected into several globes, which, by the superior attraction of one, might form a considerable planet.

These globes, retaining the velocities of the rings from which they were formed, would necessarily turn on their axes in the direction of their movements of revolution. Satellites might be formed in the same manner out of the atmospheres of their primaries.

The five main phenomena of the solar system already mentioned are thus the natural consequences of the nebular hypothesis; the rings of Saturn and the numerous asteroids discovered between Jupiter and Mars, at about the mean distance from the sun, add to its general probability.*

THE TERRAQUEOUS GLOBE.

Following the course of the changes produced

* See Appendix for Tables of the masses, distances, and periodic times of the planets.

in a planetary nebula by condensation toward a centre and rotation on an axis, three main facts appear prominent. First, the mass formed by approximation of the parts would not be spherical but spheroidal, its axis of rotation being in the shortest diameter.

Secondly, the special affinities among the parts of the nebulous mass would effect particular combinations having different specific gravity and different relations to heat and moisture, light and electricity. From the first moment of condensation in a nebulous mass chemical affinity must have begun to produce a variety of inorganic combinations; compositions, decompositions, and recompositions among the elements of matter are the inevitable consequences of general changes of density in the supposed nebulous mass.

We may readily believe that some of these compounds, carried toward the centre of the mass, have left no trace near the surface, and may be of a nature wholly unknown to us. On the other hand, by a study of the great variety in the modes of chemical combination we learn that elements very different in weight and other properties are united in definite aggregates, and thus are encouraged to suppose that from the land, sea, and air we may obtain representatives of the greater number of distinct substances which exist in the globe.

The elementary substances, and the compounds of them, exist in one or other of three states, which are termed solid as rock, liquid as water, and gaseous as air. But they are not limited to any one of these states, except by the accompanying conditions, the most important of which are temperature and pressure. Thus carbonic acid gas becomes liquid under a pressure of 36 atmospheres at a temperature of 32° Fahr.; suddenly released from this high pressure, it expands greatly; its temperature sinks to − 180°; it appears as a white solid substance resembling snow, and may be held in the hand; mixed with ether it causes such intense cold as to freeze, solidify, and crystallise mercury, which is liquid at common temperatures, and yet, even in the summer weather of England, rises in vapour, a metallic gas, and deposits globules on the interior of the glass tubes employed in barometers.

From such examples we perceive the importance in the history of the globe of the phenomena which may be ascribed to changes of temperature and pressure; and these are precisely the changes due to the contraction of the nebula and its conversion into planets. By this contraction, the temperatures would rise, at least relatively, towards the centres of pressure, while at the circumference, and indeed through all the mass, the cooling influence of the unlimited spaces around might be incessant and effective.

THE ATMOSPHERE.

The atmosphere, thus considered, is an uncondensed part of the original nebula; still undergoing condensation by the absorption of oxygen in chemical processes, unless this be restored to it again by other compensating chemical reactions. According to some observations of Fusinièri on the effects of lightning, it appears that the atmosphere contains, besides the gaseous elements oxygen, nitrogen, carbonic acid, and vapour of water, which constitute its principal substance, small quantities of metallic and earthy matters.

Speaking on this subject many years ago with Dr. Dalton, he remarked to me that not these substances only, but most of the solid materials of the earth, ought to be looked for in the atmosphere — that being only an unsolidified part of the planet. The atmosphere in an earlier period must have been much more contaminated, if we may so speak, with the numerous sorts of matter known to exist in the earth, as well as with others only just beginning to be disclosed by the power of flame analysis. It seems very probable that at the present time the luminous envelope of the sun contains a considerable proportion of the same elementary substances as those which exist in and about our own globe. By flame analysis Kirchoff and his followers have discovered that potassium, sodium, magnesium, calcium, iron, nickel, chromium, manganese, cobalt, hydrogen, aluminium, strontium, and barium, exist round the sun; a result not a little favourable to the speculation of Laplace, founded on other considerations.*

Extending this view in both directions far into the past and far into the future, we perceive that in the earlier periods the free envelope of our planet was quite unsuited to the functions which it now performs by reason of its abundant extraneous contents, and that it may again become unsuitable to these functions by the abstraction or diminution of some elements essential to the performance of them. Life has not always existed on this globe — will not always exist; even as not even Ætna—

> Ignea semper erit, neq enim fuit ignea semper.

We must learn to look on our earthly system as we do on the history of a people — only as one phase in the series of changes due to previous revolutions, and destined to be productive of others.

This view is perhaps more strongly illustrated by considering the part of the atmosphere which is composed of aqueous vapour; for the quantity of this over an unlimited watery surface is dependent only on the temperature of the air-space

* Miller, Pro. Roy. Soc., 1863.

in which it is diffused. That temperature, according to our general argument, was diminishing as the whole globe was cooling; as the temperature was lowered, the quantity of the aqueous vapour suspended was reduced, and in a greater proportion; by this process continued long enough, more and more of water deposited from the atmosphere would be gathered on the solid globe, perhaps to constitute a shallow expanded ocean, much too hot, however, for the sustenance of life. If we suppose all the water on the earth's surface (which if spread equally over the whole area would be about one mile in depth) to be again restored to the atmosphere, it would, as vapour, exert a pressure about 160 times as great as that we now experience. The temperature requisite to maintain the water in the state of vapour under this pressure would be about 640° Fahr. near the earth; much less upward; and at a certain considerable distance reduced to freezing and much lower degrees, so as to support little or no moisture in those cold spaces.

Perpetually ascending as vapour through heat derived from the earth, perpetually descending from the cooled upper zones, first as snow and finally as rain, this long enduring circulation of water would gradually exhaust the surface heat of the globe, and collect upon it an ever-growing ocean, whose temperature would become lower and lower with the lapse of immeasurable time.

THE OCEAN.

According to the arguments we are following, the initial temperature of what may be called the primitive ocean may be taken at about 640°—a temperature much below that at which any considerable portion of the substances which compose the globe would be fusible. The parts of the earth near the surface, once fluid, must then have been consolidated from fusion; a 'crust of the earth' must have become the basis of the earliest ocean; but inasmuch as many of the solid substances which appear in the crust are soluble in heated water, we must not be surprised if, among the earliest rocks, the presence of water and deposits from aqueous solutions should be found. In fact, this is already established in the case of the quartz of granite, which, by Sorby's researches, contains cavities partly filled with water.

Strictly speaking, these small quantities of water enclosed in quartz do not prove that beautiful substance to have been crystallised from an aqueous solution; they prove water to have been present in the mass from which the crystal was formed, even as lava contains water, and has been supposed by Mr Scrope to derive its fluidity from that cause—to be, in fact, in a state of aqueous fusion. It is hardly conceivable that, under the enormous pressure of the primitive atmosphere of thick vapour, water could be altogether separated from the interior substances, though fluid with heat, with which it was previously mixed. We are too apt to reason as if the atmospheric conditions were constant, as if the action of heat and the action of water were incapable of combination, except in the manner now commonly observed at low temperatures and under low pressures.

What appears, however, the most important of the effects attributable to the rising and falling of the watery envelope of our planet, in obedience to the impulses of heating and cooling, is a mechanical effect. Rain, as it falls at present in Borrowdale or on the western mountains of India, surprises the meteorologist by its annual quantity and occasional violence; but the 160 or 330 inches of rain which fall in a year in these localities, and waste the surface of the earth at the rate of an inch in a hundred or a thousand years, can hardly give the faintest idea of the deluge pouring from the skies, and destroying the hardly firm crust of the primitive globe. Mr. Babbage* has considered this subject, and regards the rain as having the impetus of a violent torrent rushing

* Ninth Bridgewater Treatise, Note F.

downward perhaps for thousands of years, so that 'the excavation of the largest valleys, or even of ocean beds, is not too much to expect from such a force.'

If we consider, moreover, the state of the solid crust and of the fluid parts below it, there may be good ground for admitting that the whole would be thrown into commotion, and that very perplexing mixtures of substances crystallised from fusion, but arranged in sedimentary forms under the mechanical agency of water, might result. The action of the water being by the conditions, for the most part, irregular and disturbed, the resulting sedimentary structures should be also, for the most part, of the same character, and only as exceptions manifest the uniform and parallel planes commonly observed in quietly deposited clays, sandstones, and limestones. These characters are found exactly in certain rocks, called gneiss by the German geologists, which exhibit no material difference from granite, except in the partial stratification which is marked by discontinuous layers or gatherings of mica. Some granites show this character by more or less distinct bands, in which mica is scattered unequally, so as to form indefinite parallel shades of grey tint, from a few inches to a foot or more apart.*

Moreover some other rocks, also called gneiss

* Observed at Killiney, near Dublin, 1857.—J. P.

and mica slate, less resembling granite, are found in a few localities below all the stratified rocks containing organic remains: as, the Laurentian rocks, in Canada, observed by Logan, and the Hebridean rocks of Murchison. These rocks may be regarded as metamorphic, but not in the sense signified by that term for part of the rocks in the Scottish highlands and along the border of the granites of Wicklow. They may be viewed as almost original products of coincident heat and watery action, which have been imitated again and again in the truly metamorphic rocks of various ages, in which the watery action has been followed after a long interval of time by local and limited heat. They may all without impropriety be regarded as having their principal characters from the action of heat directly conducted, or through the agency of water.

The nature of the operation here referred to may be in some degree illustrated by the case of the volcanic island of Sciacca, thrown up in our own days off the Sicilian coast, and composed in a great measure of small grains of crystallised augite. This only partially coherent mass was soon distributed on the adjacent sea-bed by the action of the agitated water, and now forms a shoal, composed of matter originally crystallised from fusion, but now gathered into a stratified form, round the place where it rose to the surface.

Similar, but more marked, effects must be attributed to the conflict of the hot ocean and thinly crusted lava of earlier geological periods; and generally we may perceive in this process, continued at intervals during all periods, the origin of sedimentary strata, in materials obtained from the disintegration of rocks which had been previously consolidated from igneous fusion.

PRIMITIVE LAND.

From the epoch when the atmosphere, by the general cooling of the planet, had shrunk to its present proportions, inequality in the distribution of solar heat must have produced effects somewhat like what we now perceive — more rapid evaporation in the equatorial regions, more rapid deposition in the circumpolar spaces. The wasting effects of the descending torrents in earlier times must, however, have been distributed without reference to the differences of surface temperature as depending on the sun, because, through the vast atmosphere of cloud and vapour which we have been considering, no radiant heat—not even that of the sun—could penetrate to reach the earth.*

The process of solidification would, however, inevitably produce inequalities of another order

* See notice of Dr. Tyndall's remarks on this subject, Roy. Soc. Proceedings, February 7, 1861.

which must have been influential in the distribution of the torrents. The principal part of the interior masses of the planet, as far as we know them, are compounds of metallic oxides, alkalis, and earths with silica — the basis of flint acting the part of an acid, itself a compound of a metal with oxygen. Among these silicates some of the *less fusible* are felspars, with a large proportion of silica.* Rocks containing these are found in enormous proportion in the crust of the earth, below the ordinary strata; they appear by several considerations to have been consolidated from igneous fusion at an earlier period than certain other rocks in which hornblende is more abundant, and silica † less so, and which are *more fusible.* The felspathic class is specifically lighter, the hornblendic group heavier.

Wherever on the earth's surface consolidation was beginning through loss of heat, the rocks first produced would be the trisilicated compounds, as requiring the highest temperature for fusion; these grown solid, and being lighter than the residual fused mass, would be *lifted* above the general level. Thus they would be further cooled, and become local centres of cooling, attracting

* The felspar of granite is a trisilicate of potash and monosilicate of alumina, and contains sixty-five per cent. of silica.

† Hornblende is a silicate of magnesia, lime, iron, &c., and contains about fifty per cent. of silica.

rain, and suffering waste by the violent action of the rain. The action thus set up would tend to increase in effect; the local cold would be augmented by the rainfall; the isothermals would sink under the solid rocks, and propagate solidification downwards; the new solids would be lifted up to grow colder, and be more and more wasted by the falling torrents.

By this mutual reaction of the vaporous envelope of the globe condensing into water, and the melted interior crystallising into rock, irregularities of form, inequalities of level, ridges of land and basins of sea, were sketched out from the very beginning of the changes which it is the special business of geology to trace in the history of the terraqueous globe.*

* This theoretical view of the general cause of relative change of level of land and sea, and the consequent effects, was proposed by the author in his first treatise on geology (*Encycl. Metrop.*, 1832).

CHAPTER II.

THE CRUST OF THE EARTH.

ELEMENTARY SUBSTANCES.

To penetrate all the mysteries of Creation is not the privilege of the most favoured creature. But it is neither presumptuous nor irrational to enquire into the changes which have happened to created things in consequence of the operation of the appointed *laws* of nature, provided there be *monuments* of such changes. If these monuments be *sufficient, open to observation, and capable of interpretation,* the problem of the 'revolutions' which the earth has undergone is not obviously impracticable, though it may be found on trial really too difficult for determinate solution. The earth is the monument of the changes which it has undergone; its spheroidal figure is a measure of the *mechanical* forces under which its constituent matter has been arranged; this mineral matter is the result of the operation of exact *chemical* laws; and as the forms of life now on the globe are kept in harmony and subordination to the *physical* conditions which these mechanical and chemical laws maintain, so the more ancient series of plants and animals, having been subject to similar laws, but under different conditions, teach us in some degree what these conditions were.

That such teaching is often imperfect, and often hard to follow, none know better than geologists; but no 'lover of nature,' who sees in all the universe of space and time the steady hand of Divine Providence, will undervalue or neglect to use the privilege by which, quitting the earth, and free from the little measures of days and years, the mind can speculate through boundless space, and associate its thoughts with the long ages that have gone darkly by, and the longer and brighter periods which are yet to come.

The leading facts concerning the earth which are furnished to us by astronomy, become, when interpreted by the aid of the general mechanical theory of the universe, monuments of the earliest physical changes which our planet has undergone. The spheroidal figure of the earth is a necessary consequence of its rotation on an axis; it could only be acquired by a body whose *superficial parts* were capable of free relative motion. The theory of the lunar irregularities which depend on the earth's spheroidal figure, appears to teach us that, for at least some considerable distance downwards from the surface of the earth, the materials are arranged in conformity with the elliptical outline of the exterior: hence its *interior parts* must have been capable of free relative motion, and it may be very reasonably supposed that they have been in a state of *fluidity*. That such fluidity was occasioned by heat, is a plausible or rather necessary hypothesis, for no other known agent is adequate to the effect. But our confidence in this hypothesis becomes strengthened when we find that the results of careful experiments, repeated in various parts of the world, agree in demonstrating that the interior parts of the earth, at small depths, are now sensibly hotter than the surface, and that this augmentation of heat follows some regular ratio to the depth.

The earth, indeed, appears to be exactly in the condition which the supposition of its former fluidity through heat and long exposure to the refrigerating influence of space would require; cooled at the surface, but, within the external crust, still sensibly warmed by the remains of its original heat. The *nucleus of the globe* may even now be partially fluid with heat. It is no objection to this view, that the surface temperature of the earth is regulated by the sun: this cannot be otherwise while a thickness of solid rock near the surface conceals and almost stifles all sensible heating effect from within.

The mean density or specific gravity of the whole mass of minerals near the surface of the earth, is about twice and a half that of water; but astronomical and general physical researches concur in proving that the mean density of the whole planet is above five times that of water; consequently the matter in the interior of the earth is heavier than that near the surface. This is all we really know of the *nature of the nucleus* of the earth. Whether the substances of which it consists be of the same kind as some of those near the surface, or of another kind altogether, can only be matter of conjecture.

We may *conjecture* them to be of the same general nature as those thrown up to the surface by modern volcanoes; and perhaps this opinion may be confirmed by the fact, that mineral compounds in several respects like these, and evidently the produce of heat, lie under all the strata, or have burst through them from some miles below, thus giving a considerable range of positive information in regard to the crust, but little in regard to the nucleus of the earth.

The next class of monuments from which we may hope to gather information concerning the most ancient conditions of the globe, are furnished to us by chemistry. Analysed by this powerful science, the apparently innumerable varieties of rocks and minerals are reduced to their elements; and thus all the known ponderable matter of the globe is found to be *composed* of about sixty-one substances, which we regard as simple or elementary, because they appear incapable of further decomposition.

Of these FIVE exist in a separate state as gases; viz. hydrogen, oxygen, nitrogen, chlorine (fluorine?).

NINE are non-metallic solids and liquids; viz. sulphur, phosphorus, selenium, tellurium, iodine, bromine, boron, silicon, carbon.

SEVENTEEN are metallic, or metalloid bodies, which unite with oxygen to form the earths and alkalis; viz. sodium, potassium, lithium, aluminium, yttrium, erbium, terbium, didymium, glucinum, thorium, calcium, magnesium, zirconium, strontium, barium, cerium, lanthanium.

THIRTY are what are commonly called metals: manganese, zinc, iron, tin, cadmium, arsenic, antimony, copper, molybdenum, uranium, tantalum, niobium, chromium, nickel, vanadium, cobalt, lead, thallium, tungstenum, titanium, mercury, bismuth, osmium, silver, palladium, rhodium, platinum, gold, iridium, ruthenium.

Oxygen combines with so many of these, and in such large quantities with the earthy and alkaline metalloids, which are the most predominant ingredients of minerals, that we may venture even to say that *one half of the ponderable matter of the exterior parts of the globe is composed of oxygen gas in a state of combination.*

This will appear by examples taken from the most ordinary masses, such as sandstone, clay, and limestone, among deposits from water, and the most abundant of thermogenous rocks, granite, from which the materials of some of the sedimentary strata have been derived. In common sandstones composed almost entirely of silica, oxygen exists to more than half the whole weight; in ordinary clays and indurated argillaceous rocks, which contain about two-thirds silica, it is about half the whole weight, and in limestones somewhat less than half.

In granite composed of quartz, felspar, and mica, the case is very similar; the quartz, which is about one-fourth of the whole mass, contains more than fifty per cent. of oxygen; the felspar, which is the most abundant mineral, about fifty per cent.; and the mica, which is in the smallest quantity, less than that proportion.

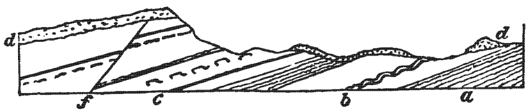
The depth to which it has been found practicable for man to penetrate the crust of the earth, is but a small part of that to the knowledge of which, in some cases, the power of induction has enabled him to attain.

ARRANGEMENT OF ROCKS.

The deepest mines in the British Isles do not reach half a mile from the surface; Monk Wear-mouth Colliery near Sunderland and the Consolidated Mines in Cornwall, about 600 yards, and the Dukinfield Colliery near Manchester, 717 yards. Kitzpühl in the Tyrol, the deepest mine in the world, extends to something above half a mile (2,764 feet). We shall see hereafter that, owing to the way in which the materials of the earth are arranged, the structure of the crust of our globe is really known, in particular instances, to a far greater depth. At present, limiting our statements to the extent of actual observation, we shall show what is the arrangement of the materials of the earth, as they are seen in wells, pits, and mines, on the sides of rivers, and on the slopes of mountains, and in cliffs against the sea.

There is a circumstance to be attended to in the very outset of this enquiry, which it is of much importance to understand properly. The *actual surface* of the earth is occupied by soil (which is often nothing else than the decomposed substance of the rocks beneath), by gravel and sand, and particular sorts of clay, which have been drifted by wind, but more frequently transported by superficial currents of water, and deposited in much confusion upon the solid fabric of rocks. In all the following statements concerning the parts of the globe near the surface, this irregular and variable covering is neglected, and the reader is supposed to look upon the solid framework of the globe, stripped of its fertile soil and all its softer and looser investments. The soil and other loose materials of the surface of the land are worthy of curious and diligent research, and have, indeed, amply rewarded enquiry; but the study of them belongs to another part of the subject. We learn little concerning the *structure* of the earth from these irregular accumulations, which, in fact, only mask and conceal its original features, though they teach very remarkable truths concerning the revolutions which have affected its surface. (See Diag. 2.)

Dia. 2.

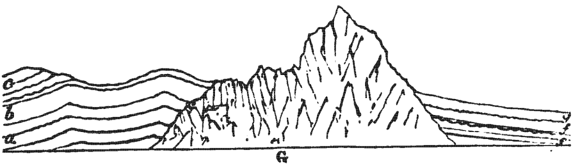


a, b, c. Stratified rocks inclined to the horizon.
d. Superficial detritus.
f. Fault interrupting and displacing the strata.

There are two principal conditions of arrangement, to which all the minor appearances observable in the crust of the earth are subordinate or dependent.

In the first case, the bounding surfaces of the rock are parallel, or nearly so, and extended to great distances, so as to include between them a tabular mass or layer of rock, which is technically called a bed, or *stratum*. Several such beds or strata may be laid parallel one to another, and thus constitute a stratified *formation*. These strata may be of the same or of different thicknesses, of the same or different chemical qualities; they may include the same or different organic exuviæ, or be wholly devoid of them. All these circumstances are worthy of remark; but the important thing to be attended to in the first instance is, that *the rock is stratified*. (Diag. 3, *a b c*, *e f g*.)

Dia. 3.



a, *b*, *c*. Stratified rocks disturbed.
G. Mass of unstratified rock (granite).
e, *f*, *g*. Stratified rocks undisturbed.

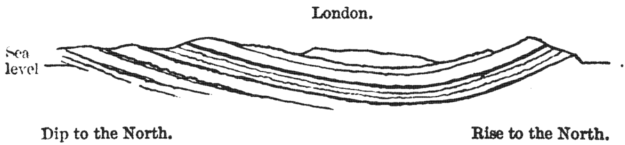
In the second case, no such stratification is observable. Many rocks are columnar in structure; some are formed in large lenticular or spherical concretions; others have a peculiar internal cleavage; others are amorphous. All these and many more circumstances are important; but the first thing to remark is, that *the rock is not stratified.* (Diag. 3, G.)

STRATIFIED ROCKS.

A useful notion of the leading appearances of stratification is most easily acquired by examining the eastern, southern, and western coasts of England, where the cliffs present what is called *a natural section*, and generally display the edges of more than one kind of stratified rock; sometimes many kinds, as limestone, sandstone, and clay, which are placed one upon another, in a certain order, like the leaves of a book. The order of occurrence which the edges observe in one part of the cliff is found to be the same in another part; so that these strata form a series of terms, whose relative place is known. In other countries, other and quite different rocks may be seen, but these likewise show amongst themselves a settled order of succession. Exactly the same conclusion results from the experience of miners and colliers, well-sinkers and quarrymen; it is confirmed by examination of mountain slopes and valleys. So that we may state it as a general truth, that the strata, wherever they occur, by the sea-coast or in the interior of the country, are superimposed on one another in a constant order of succession, and compose one regular series.

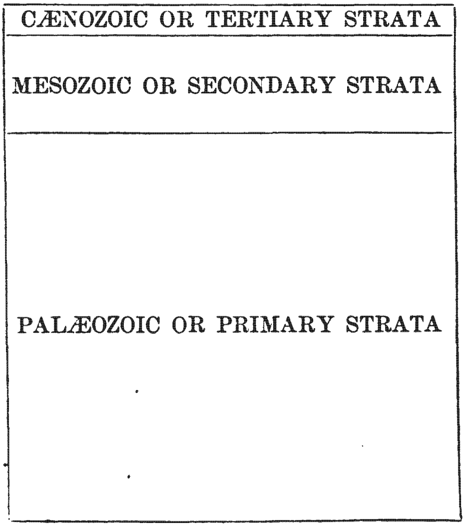
It is observed that the bounding surfaces of the strata, which we shall henceforward designate planes of stratification, are seldom quite horizontal, but declining into the earth, so that along many lines of coast their edges rise from beneath the water to some height above it. See drawing of the Isle of Wight, Plate IV. (Frontispiece). In the interior of a country, in the same manner, the same or other strata decline in some direction, east, west, north, or south, so as in that direction to go deeper and deeper. This declination, or *dip*, of the strata is sometimes at a considerable angle to the horizon, but generally it is so moderate as 1 yard descent in 50 yards' length. All the strata in the same district commonly dip in the same direction. The exceptions to this general law arise from particular and well-known, often local, causes. If, then, the circumstances of the country are favourable, we may see in the cliffs of the coast, or along the valleys and hills of the interior, the several strata rise in succession from the deeper parts of the earth, and end at the surface. We can notice their order of succession, measure the thickness of each, and combine our observations into an artificial diagram, which shall represent truly what *would be* the appearance, if we could perform the operation of cutting the earth along the given line to the required depth. Such a diagram is called an *artificial section,* as this across the vale of the Thames, where under London are shown by dotted lines the continuation of the strata, which appear at the surface on the north and south of that city. By prosecuting these researches until we have found the true place of each stratum in the general series, and its thickness, we come to

Dia. 4.



form a *general table* or *section* of the whole series of strata existing together in any one country. Though we may not be able at any one place to see more than a few of these strata exposed, yet, by examining them as they successively rise to the surface of the earth, and adding all their thicknesses together, we learn the *aggregate thickness* of the whole mass of strata under any region; the depth, in short, which must be sunk in order to penetrate through the whole series, beginning with the uppermost. In Great Britain and Ireland, we may call this known thickness three, five, or ten miles, according to the situation. The following diagram shows how much greater a proportion of thickness is occupied by the oldest, and how comparatively thin are the youngest of the three grand groups of strata, in the British Isles.

Dia. 5.



Classification of British strata in large groups.

CÆNOZOIC[3]	Pleistocene[15] . .	TERTIARY
	Pleiocene[14]. .	
	Meiocene[13]. .	
	Eocene[12] . .	
MESOZOIC[2]	Cretaceous[11] .	SECONDARY
	Oolitic[10] . .	
	Triassic[9] . .	
PALÆOZOIC[1]	Permian[8] . .	PRIMARY
	Carboniferous[7]	
	Devonian[6] . .	
	Silurian[5] . .	
	Cambrian[4] . .	

METAMORPHIC AND GRANITIC
BELOW

These terms appear to have been first employed, or most fully and clearly employed, by the authors named below: 1, Sedgwick; 2, 3, Phillips; 4, Sedgwick; 5, Murchison; 6, Lonsdale; 7, Conybeare (he included 6); 8, Murchison; 9,German term; 10, Smith; 11, Fitton; 12, 13, 14, 15, Lyell. (See Glossary.)

A knowledge of the exact series of strata existing in any given district may thus be easily acquired, and it has in fact been possessed by practical men in almost every local district where natural sections can be observed, or mines and collieries are extensively wrought. But, until Werner and

Smith, independently of each other, compared the stratification of different countries, and discovered laws of accordance in the series of strata over large tracts of the globe, the local knowledge of miners and colliers, for want of combination, was of small geological value, and often led to absurd hypotheses. Any one who possesses this local knowledge is, however, immediately in a state to follow the steps of the great geologists above named. In the first place, he must accustom himself to consider the series of strata, not only as they succeed each other in the earth, but also as they appear on the surface; he must not only draw a section, but outline and colour a map. On the map (Pl. I.), given as an example, some of the principal masses of strata are marked by appropriate shades; the chalk, which is the uppermost term of this series, extends from Flamborough Head through Yorkshire, Lincolnshire, Norfolk, Suffolk, Hertfordshire, Wilts, Dorsetshire, &c. Parallel to it stretch the oolite and lias rocks in an uninterrupted course from the cliffs near Whitby, through Yorkshire, Lincolnshire, Northamptonshire, Gloucestershire, and Somersetshire, to Dorsetshire. Nor is the range of these strata limited to England, for they cross the channel and occupy large spaces, in the same order of succession, on the continent of Europe.

Hence we learn that not only the law of stratification is very extensively recognised over the globe, but also that some particular sets of strata are continuously traceable over large spaces, preserving the same relative position on the surface and in the interior; so that a general table of their order of superposition may be drawn up, which shall apply, allowing for local peculiarities, with equal truth to every part of their ranges, as, for example, to all Europe. Thus we rise to a general principle of great importance, by which we may hope eventually to connect the results of observations of stratified rocks over the whole globe into one harmonious system.

This continuity of the strata is not to be understood of every locally observed bed of the series, nor even sometimes of every set of beds of the same kind; for some of these beds are the effect of very limited causes, and all of them are liable to local variation. Hence it happens that in some countries certain strata are wholly wanting, and others are so much altered that certain parts of the series assume totally different characters. No sets of strata are *universally* continuous; there are no *universal* stratified rocks; but yet it is true that certain groups of these stratified rocks, consisting, for example, of certain kinds of limestones, sandstones, and clays, or of certain gneiss rocks, mica schists, and slate rocks, are so extensively traceable as to give us reason to conclude that very large and uniform operations of nature were concerned in their production.

The organic exuviæ which are found in the stratified rocks offer a wide field of enquiry, from which already rich and valuable results have been gathered. This is not the place to develope that magnificent subject further than to show *what* these remains are, and how they can be brought to afford evidence of revolutions which the earth has undergone. Both plants and animals have left monuments of their existence and traces of their forms in the earth. The ligneous, vascular, and sometimes the cellular parts of plants abound in the earth, and the leaves are so perfectly retained that an exact comparison can be instituted between them and recent vegetables. Of animals generally the soft parts are not preserved in the earth; but the bones of reptiles and other vertebrata, the hard coverings of crustacea, the shells of mollusca, the stony and even membranous coverings, supports, and cells of zoophyta, are abundant. Generally speaking, the fossil species both of plants and animals are not identical with existing kinds; often they belong to different genera, and sometimes admit of no close resemblance with any living form. In certain strata of the least ancient date, both plants and animals occur not distinct from existing species. Fossil plants and animals do not exist in all the strata, nor everywhere in equal abundance in the same stratum or set of strata. They are not confined to any particular kind of rock; they are not always present in rocks of a certain kind; nor, except in a few instances, always absent from other rocks. These remarks are sufficient for the present course of argument.

UNSTRATIFIED ROCKS.

The *principle of stratification* is universal; that is to say, in every country of sufficient extent stratified masses occur in a certain consecutive order; and in many very large districts removed from the mountains none but the stratified rocks are seen. Any one whose notions of the structure of the earth were drawn from observations in south-eastern parts of England would certainly suppose, as Werner did, that all rocks were stratified. On the contrary, the inhabitant of mountainous regions finds a great variety of rocks, such as granite, syenite, porphyry, &c., in which no trace of stratification can be seen — many others, like gneiss and slate, in which this structure is so anomalous as to convey to his mind a very indistinct notion of its true nature. These separated observers can therefore hardly understand each other; and it is no wonder if theories based on their observations are found to disagree.

In many countries, however, the stratified and unstratified rocks occur together; and it is then seen that, while the former follow a regular arrangement and lie nearly parallel to the earth's surface, the latter appear in irregular, often unconnected, masses beneath all the strata, or protruding through them in insulated peaks, or traversing them in vertical masses called dykes, or penetrating them by veins. Not only have they no constant relation to the stratified rocks, but they have no constant relation to one another, either of position or mode of occurrence; so that it is impossible to form anything like a regular series of them. Hence they are very properly called by D'Halloy *roches hors de série.*

Further examination shows that the mineral ingredients of which the stratified and unstratified rocks consist are either very different or in a very different state. For, while the stratified rocks, amidst all their variations of colour, hardness, and chemical constitution, can be described as limestone, sandstone, clay, ironstone, coal, &c., the unstratified rocks are wholly different, and consist of minerals of many kinds, variously aggregated together. The former are often composed of grains, the latter of perfect crystals; the former generally contain organic exuviæ, the latter almost never. Whenever these appear at the surface, the former are more or less disturbed and confused in position; and the result of comparative examinations upon them is invariably found to be a full belief that they were produced by different causes acting independently, and, in most instances, at different periods.

We shall now class the phenomena presented by these rocks in such a form as to exhibit their distinctive peculiarities, and put them in comparison with the modern effects of natural agencies upon the globe. In this way we may expect to learn the causes concerned in their production.

ORIGIN OF THE STRATIFIED AND UNSTRATIFIED ROCKS.

In the modern system of nature we recognise two great agencies employed in producing changes on the face of the globe — Water, which wastes away, grain by grain, the elevated portions of the land, and deposits its spoils in lower situations, thus ever tending to equalise the levels of the surface; Heat, which raises matter in masses from the interior of the earth, and thus tends to increase the inequalities of its surface. Both of these agents act chemically; water dissolves, heat fuses. Both also act mechanically. The mechanical effects of water depend on the general force of gravitation, and ever tend downwards, so that the lowest part of any aqueous deposit is the oldest; but the mechanical force of heat is independent of gravitation, and ever struggles to overcome it. Water is a tranquillising, heat a disturbing, agent.

Rocks are formed both by aqueous and igneous agency in the present economy of nature, and the products of these agents are in general easily distinguishable. The deposits from water are composed of limestone—which is sometimes a chemical product, sometimes a mechanical or sedimentary deposit—or of sandstone and clay, which are always of sedimentary origin. The accumulations formed in the beds of lakes, at the mouths of rivers, and in gulfs of the sea, are so stratified and composed of such materials. Moreover, these modern strata enclose remains of terrestrial, freshwater, or marine organic bodies, according as these existed in, or were transported into, the water; and they are deposited in the strata according to the periods when these were formed. In every respect, then, the modern aqueous deposits are exactly similar to the stratified rocks produced in former conditions of the globe. Whether they are equally extensive is another question; but it is clear that processes of the same kind have occasioned all these phenomena.

On this determination of the aqueous origin of stratified rocks enclosing organic exuviæ of aquatic animals, rests the doctrine of the relative antiquity of the rocks, according to their relative place in the scale of stratification. In the same manner as we cannot doubt that the lowest layer of the sediment from a pond, lake, river, flood, or inundation of the sea, is the most ancient, and the upper layer is the least ancient of all those which exist together, so, in the series of stratified rocks, which were likewise deposited from water, the lower are the older, and the upper are the newer. It is not here a question of what periods of time elapsed between the deposition of the oldest and the newest; the general principle only is required to be granted, and it will be left to future investigation to draw the proper inferences on the lapse of time during the accumulation of the strata.

There can also be no reasonable doubt on another important topic. As at the present day (except under special circumstances), so in ancient times, we may be sure that the marine stratified deposits would assume the character of level, or nearly level surfaces, because this is the result of the ordinary action of agitated water. In whatever positions these strata are now found, we may always agree that they were at first deposited nearly level.

The rocky accumulations from modern igneous agency are exhibited to us in volcanic regions, where we see that the lava thrown out does not form true strata, except for very limited areas, though, in consequence of successive eruptions, it may be laid in many consecutive stream-like deposits. Even the scoria which is ejected from the volcanic cone, and falls more or less on all sides of it, is accumulated in such a way amongst the streams of lava, and with such a relation to the slopes of the ground, that it does not form true strata. The lava frequently forms dykes and veins.

The materials of these eruptions are not limestone, or sand, or clay, but consist chiefly of a variety of crystallised minerals, in which the bases of these rocks are united with other earthy, alkaline, and metallic substances. Finally, it is only by peculiar accidental circumstances that any remains of animals or plants occur in them. When the melted lavas come in contact with previously solidified rocks, some changes occasionally happen, which may be imitated by artificial heat. In all these particulars the modern products of fire resemble the ancient unstratified rocks. We may further remark that the most abundant and characteristic mineral substances now obtained from volcanic rocks are equally abundant and characteristic of their older prototypes; that in both classes these minerals are often found grouped together in the same manner; that some of the most abundant of the older unstratified rocks are not distinguishable from certain modern volcanic rocks; and that there is such a general resemblance between the two classes, and so much analogy of combination and appearance continually observable between them, that we cannot hesitate to pronounce the unstratified rocks generally to be the products of heat. It would not be right to say they were ancient volcanic rocks, for volcanoes are only a particular case of the general effect of subterranean heat; and there are various facts connected with the history of the older rocks which do not often permit us to assign to them a real volcanic origin. On the contrary, certain differences, almost always existing between these old plutonic and modern volcanic rocks, appear sufficiently marked to lead us to a theory of their origin, which may explain at once their general dependence on subterranean heat, and their particular differences from volcanic products.

There are some rocks which appear both stratified and crystallised, as certain limestones; others which are neither stratified nor obviously crystallised, as serpentine, and some sorts of felstone. Yet even these, and some other cases, which on a first view appear to confuse the classification and disturb the inference, are capable of satisfactory solution. It is known by direct experiments that artificial heat is capable, under particular circumstances, of changing sedimentary limestones into crystalline limestone. Thus, Sir J. Hall actually converted chalk into granular limestone. Now the granular or crystalline limestone, above alluded to, sometimes occurs in such a relation to rocks of igneous origin that its crystalline structure is with much probability referred to the local influence of heated rocks in that situation. In other instances we may easily imagine the interior heat to have produced the same phenomenon, though no igneous rocks be actually exhibited in the neighbourhood.

With respect to uncrystallised rocks, which are also unstratified, we may remark that though, among the modern effects of volcanic fire, we have selected crystallised rocks as characteristic of these effects, and have noticed the analogy in this particular of the old unstratified and modern igneous rocks, yet neither in one class nor the other is it meant to be understood that such rocks are the only ones that exist. Here, again, we are aided by actual experiment. Mr. G. Watt has shown that the very same mass of fusible substance, perfectly melted and allowed to cool, will become glassy, earthy, or crystallised, according to the rate of its cooling. The same thing happens in volcanic products; the same thing, hardly in a less degree, did happen amongst the ancient igneous rocks. We have, therefore, the means of explaining all the apparent exceptions to the general rules given above, and by a careful study of the cases shall probably in time arrive at a clear understanding of the conditions which occasioned all the phenomena.

STRUCTURE OF ROCKS.

It has been already remarked that the most important distinction in the structure of rocks is that of their being stratified or unstratified. The fundamental idea of a stratum of rock is that of a widely extended mass of matter, which settled to rest, while in an incoherent state, under the influence of gravitation, with or without any lateral impulse. According to this view we may imagine strata to have been formed by the falling or drifting of sand in the air; by the deposition of particles in a calm or agitated liquid; and by the solidification of a fluid mass.

Let us examine these cases in succession. The ashes thrown up from a volcanic crater fall around it, and collect in concentric laminæ sloping on all sides from the centre (see Pl. II. fig. 9). This may be called conical lamination: it is, in general, easily distinguishable from a case of conically uplifted stratified rocks, by the irregularity and discontinuity of the layers.

Sand, drifted by the wind, collects into particular forms, according to the nature of the obstacles to its progress. It is heaped against the old temples of Egypt; accumulated into irregular hills on the sea-coast, round the roots and stems of *Elymus arenarius* and *Arundo arenaria*; but on the wide plains of Western Norfolk, and on a greater scale in the African deserts, it is scattered in a more equable manner. Where a river impedes its progress the sand often fills up the stream on one side with a shallow projection, and causes it to excavate the opposite bank. Similar phenomena happen on the sea-side. No true strata are formed by such irregular and accidental causes.

Particles minutely disseminated in a quiet liquid, whether by chemical decomposition or mechanical disturbance, produce, when they fall therein, strata proportioned in thickness to the quantity of matter suspended above; that is, generally, proportioned to the depth of the water. Hence, in the freshwater lakes of Central France, it has been observed that the calcareous strata grow thinner toward the edges of the basins. The same happens to the very fine clays which, under the name of warp, are deposited on the low lands adjacent to the tide-rivers of the North of England.

But the matter which falls from an agitated liquid partakes, in its arrangement, of the lateral influence of the currents and eddies. From the stormy waters of the Arve falls abundance of sediment, full of oblique and crossing laminæ which indicate the variable direction of the currents. The same structure is often noticed in sandstone strata, as in the cliffs under Nottingham Castle and Knaresborough Castle. For such cases the term oblique lamination is conveniently employed (Pl. IV. fig. 12 *l*).

A different result happens when a rapid stream delivers coarse detritus into a deep and quiet lake; the Rhone, for example, falling into the Lake of Geneva, communicates to the sediment a horizontal force, which, combined with the influence of gravitation, causes the particles to describe curves in the calm water. Parallel to these curves, which deviate more and more from the horizontal as the particles descend lower, the matter accumulates round the point where the river enters, and thus a peculiar concentric lamination is occasioned. In the deeper parts of the water the curves of descent are too steep for the matter to lie at rest, and consequently the laminæ are found to follow nearly conical slopes (Pl. IV. fig. 11). (See Mr. Yates's paper on this subject, Edin. Phil. Journal, 1831.)

It is evident that the most extensive and uniform strata are produced from a corresponding diffusion in water of substances which slowly and equally settle on its bed. The regularity of the strata of limestone, shale, and coal is very remarkable; the irregularity and discontinuity of coarse conglomerates are no less striking: both these results are in conformity with effects daily produced on a smaller scale. The ocean is to be viewed as an unquiet lake, receiving sediments of various kinds under different conditions. The restless agitation of its surface-waters tends to diffuse far and wide the lighter matter contributed by rivers, or obtained by its own warfare with the coasts, while the coarser and heavier matter remains near the shore, and thus the materials are sorted, and transported to various distances, till they quietly settle in extended strata, which tend more and more to become horizontal, the further from shore and the more tardy the deposition.

In this way, we may see the means of distinguishing the truly oceanic from the truly littoral portions of old stratified formations: the former may in general be known by the regular and continuous stratification of the limestones and shales; the latter by the irregular mixture of local conglomerates, coarse shales, and debased and attenuated limestones.

The last cause of stratiform accumulation, viz. the solidification of a fluid mass, is exemplified in modern lava, and in old plutonic rocks of several kinds. Modern lava has generally been consolidated in air, but the older igneous products most frequently under the pressure of water or a great thickness of incumbent rocks. The form assumed by lava, which has flowed and been indurated in the air, depends almost wholly on the shape of the ground. Round a volcanic cone the basaltic lavas are in the form of narrow irregular streams, directed down the slope, and thickest toward their base: in the valleys of Iceland, almost lakes of liquid rock have congealed, with all possible irregularity, owing to the cooling of the surface before the flowing of the under current ceased. Even when successive lava-streams have been laid one on another, hardly the least character of stratification is produced.

Some of the older plutonic rocks, which were poured out on the bed of the sea, have, indeed, on one surface a stratiform aspect, because they take the shape of the stratified rock beneath them; but their upper surface has those irregular bosses and protuberances which must inevitably result from the cooling of a partially fluid mass. Igneous rocks, which have been forced between strata of other materials, assume a tabular form, which might mislead a beginner uninstructed in the history of such irruptions. Many such *interposed beds*, as they are termed, occur in the Island of Arran.

Besides the stratified structure, which is coeval with the deposition of certain rocks, there is another pervading *all* rocks, which has met with less attention than it deserves. All rocks are traversed by certain divisional surfaces, commonly called *joints*, which in basalt occasion vertical prisms, in clay-slate parallel tables, in shale rhomboidal faces, in limestone cuboidal blocks. There are many kinds of joints:—

Cracks (Pl. IV. fig. 12, *c*), which in general do not pass through even one bed of stone. Some of these minute internal fissures are empty, others filled with carbonate of lime or small veins of metallic substances; some have their surfaces marked with a beautiful radiated crystallisation of oxide of iron or manganese, like delicate plants.

These are often called *dry cracks* by the workmen. All these substances have, no doubt, been transferred through the pores of the rocks by electrical or other subtle agency; that they are not contemporaneous with the rocks is proved by the fact that, whether empty, sparry, or metalliferous, the cracks sometimes pass through shells, fishes, plants, and even divide the pebbles of conglomerate rocks, in the Righi, at Oban, and at Kirby Lonsdale (see Pl. IV. fig. 12, *p*).

Joints go through a whole bed, or several beds of the same description (Pl. IV. fig. 12, *j*).

Fissures pass through a great variety of strata, though of different nature, as sandstone, limestone, shale, and coal. They even divide strata belonging to different formations. They are either empty, partially lined, or entirely filled with crystals of carbonate of lime, metallic oxides, &c. (Pl. IV. fig. 12, *f*).

There is amongst the great or master-fissures in a given district of stratified rocks a remarkable parallelism, and a tendency to particular directions, which, at least in some instances, coincide with the lines of convulsion. The minor joints seem to be characteristic of the different sorts of rocks by their relative number, closeness, parallelism, and angles of intersection. In slate rocks the joints and fissures intersect one another with almost geometrical regularity; they are very symmetrically arranged in laminated shales; but in thick sandstones only the great fissures hold any regular course.

In unstratified rocks the joints have been little attended to, except when they appeared to produce a prismatic arrangement, analogous to that of basalt.

The production of joints in rocks may be referred to the condensation of their mass from an aqueous or igneous expansion; but the symmetry of their arrangement can only be referred to some kind of crystalline action; and the parallelism of the great joints over large tracts of country seems the effect either of electrical currents controlling that action, or of peculiar, perhaps undulatory, movements affecting large parts of the crust of the globe.

POSITION OF ROCKS.

It is sufficiently evident that the rocks of aqueous origin were deposited in nearly horizontal strata, and the thermogenous rocks mostly raised from below, and placed in various circumstances of contact with the former. The actual position of stratified deposits, with reference to horizontal surfaces, to one another, and to the masses of thermogenous rocks, constitutes an important element in descriptive geology. Over very large portions of the globe the strata are still nearly horizontal: the deviation of their surfaces from the spherical surface of the globe, or the horizon of the place of observation, is called the dip or declination of the strata. Measured by the clinometer the dip is often found less considerable than it appears to unpractised eyes. A descent of $2\frac{1}{2}°$ for a large tract of secondary rocks is always thought remarkable. Scarcely any road, however dangerous from its steepness, slopes more than 10° to 15° from the horizon; mountain sides are abrupt if they decline 18° or 20° (Carrock Fell in Cumberland), and covered with loose detritus, as the western front of Ingleborugh, if they slope 45°. Very few precipices exist in the interior of Great

Britain over which, as at Whitestone Cliff in Yorkshire, the plummet line may swing freely by the side of 100 feet of solid rock.

A line drawn on the surface of the strata at right angles to the dip is of course horizontal, and is called the 'strike' of the beds. The strike and the terminal edge, or 'outcrop,' of the strata are on a great scale parallel; but if the dip is very gentle, and the country much varied in elevation, the difference between them may be very considerable. The direction of the strike is always dependent on the situation of the points or lines which are the centres or axes of subterranean movement, and from or towards which the strata decline.

If there be a conical elevation of strata (as nearly happens in the valley of Woolhope, Herefordshire), the dip is quaquaversal, or radiates in all directions from the centre, and the lines of strike are concentric; if the axis of elevation be a straight line (as the range of the Malverns, the escarpment of Cross Fell, &c.) the lines of strike are parallel to it: between these extremes are found many gradations constituting elliptical elevations (as Greenhow Hill, &c., in Yorkshire).

The strata are sometimes continuous over the axis, and sometimes wholly or partially removed, constituting what has been called a Valley of Elevation (as at High Clere in Hampshire). An anticlinal axis is such that the strata decline *from it* on both sides (see Pl. II. fig. 5); a synclinal axis is such that the strata dip *toward it* on both sides. Some of the great lines of subterranean movements in England and Wales range ten, fifty, or a hundred miles.

In some cases the axis of subterranean movements is a *fault*, or complete fracture and displacement of the whole series of strata (Pl. II. fig. 6) along a vertical or inclined plane, the beds being relatively depressed on one side, and elevated on the other. The extent of displacement, or vertical measure, in inches, feet, or yards, of the difference of level of the same strata on the opposite sides of the fault, is often called the *throw*, *shift*, or *cast* of the fault; and the 'throw' is said to be *up* or *down* according to the side which is taken as the standard of comparison; it is often impossible to say on which side of the fault the strata were really displaced. If, as frequently happens, the fault is not vertical, its inclination (the angle *a s v*, Pl. IV. fig. 13) is called 'hade' or 'underlay,' terms applied to mineral veins; its declination from the horizon being the angle *a s h*.

By the sides of faults, the strata are often slightly or considerably bent, sometimes in the direction tending to unite their disrupted parts, as *a*; sometimes in the contrary way, as *b* (fig. 13). In the former case they are said to 'rise to an upthrow and dip to a downthrow,' in the latter they 'rise to a downthrow and dip to an upthrow.' These are circumstances of greater importance than the slight attention paid to them by geologists might seem to indicate. They conduct us by an easy transition to the cases where the violence of the disturbing agency has been sufficient to render the strata for great distances directly vertical, so that they 'stand on end,' as in the Isle of Wight, and the escarpment of the Pennine Chain, or even bend backward, as in the Malvern Hills. To the same violent agency operating on yielding materials we must ascribe the singular *contortions* of strata which occur in the limestones and shales of Yorkshire and Berwickshire, and on a far grander scale in the limestones of Altorf, Lauterbrun, Wallenstadt, and the Valley of the Arve (see Pl. IV. fig. 14).

In a certain sense all these phenomena of unusual position of stratified rocks are geological accidents; yet they are not without their laws, and some of these are partially known. Faults, for example, are most frequently found to dip or decline under that portion of the divided strata which is relatively depressed, as *a* and *b* in Pl. IV. fig. 13., not as *x* of the same figure.

Contorted strata appear most frequently along the sides of elevated chains of mountains, where great lateral pressure may be supposed to have acted (Pl. II. fig. 6, *c*), and in soft or thinly laminated rocks which might yield in undulations, not snap in fissures.

Axes of disruption and elevation are usually accompanied by cross rents or faults, and sometimes by parallel faults, producing two sets or systems of fractures in the crust of the globe, more or less rectangular to each other. The philosophical study of these and other laws of phenomena of unusual position of strata in relation to the structure of the rocks and the forces concerned in displacing them, one of the most attractive in modern geology, has been well opened by Mr. Hopkins's Memoir on Physical Geology in the Cambridge Phil. Trans. See also Illustrations of Geology of Yorkshire, Part II.

As convulsive movements happened in the crust of the globe at various epochs after the accumulation of some strata *c* and before the deposition of others *d* (see Pl. II. fig. 7), it is frequently found that the older dislocated strata are covered over by the undisturbed newer deposits (Pl. IV. fig. 15); and when this is not the case, some great difference of dip, either in amount or direction, as seen in neighbouring natural sections, or some great difference of strike and outcrop, as traced on the surface, will at once reveal to the careful observer the geological epoch of the convulsion. To all such cases of discordant position of adjacent strata the term 'unconformity' is usefully applied; it always marks the occurrence of subterranean movements, and changes of level in the period between the ages of the newest dislocated and the oldest undisturbed strata, their ages being in fact the limits of error of the problem. Thus in some cases the geological date of the disturbance is accurately, in others approximately fixed.

Bearing in mind that there is an important relation between the lines and centres of subterranean disturbance and the exhibition of thermogenous rocks, the student must complete his researches as to the position of strata in any given district by determining the situation and phenomena of the nearest erupted masses of these rocks. If rocks of this kind appear along a great axis of elevation, as in the SE. of Ireland, the Lammermuir, Cumberland, Malvern, &c.; on the flanks of a mountain group, as in Westmoreland; or in minor anticlinal lines, as the Breiddyn Hills, the Wrekin, &c., their nature, the chemical and mechanical changes produced when they come into contact with the stratified masses, alterations of composition, texture, structure, hardness, occurrence of spathose and mineral veins, minute contortions and fractures of beds, and other phenomena, must be accurately noticed. Along and near to great lines of disturbance, basaltic, porphyritic, and other *dykes* frequently occur, and sometimes are accompanied by remarkable alterations of the neighbouring rocks (Isle of Arran, banks of the Menai, Teesdale, &c.): but one of the greatest lines of subterranean movement in Great Britain, the Tynedale, Pennine, and Craven Fault, is only partially marked by the occurrence of such rocks in or near its long and flexuous course, and the great upturning of the chalk and tertiaries in the Isle of Wight is without any superficial indication of igneous agency.

PHYSICAL GEOGRAPHY.

Having thus arrived at a clear view of the origin and relative position of the rocks composing the crust of the globe, we must turn our attention to the surface, which, as before observed, is formed upon the edges and planes of these rocks (fig. 2), and enquire what connection there may be between the physical features of the surface of the globe and the subjacent rocks. Taking the most general view which the subject admits, we may consider the mountainous regions of the globe as rising in the midst of the broad plains and gently undulating regions, like islands in the sea. Some particular plains are surrounded and defined by the chains of elevated ground, as the Plain of Bohemia; but it is a more general fact that the plains spread round and enclose the mountain masses. The depths of the sea appear to balance the ridges on the land. There are in the sea certain lines and certain centres of depression, as on the land are particular chains and peaks of elevation. If we could remove the whole of the ocean, it is probable that the greatest depths of the basins of the ocean would be found proportioned to the greatest elevations of the land, and equally limited in area. The far greater part of the ocean is of a moderate depth, as the far greater part of the land is of a moderate altitude.

Putting out of consideration, for the present, the loose water-moved fragments which cover to a small depth in many parts the actual solid framework of the earth (Pl. I. fig. 2), we may state as a general truth, that the great plains and moderately undulated regions of the dry land owe their principal features to the quiet deposition of the stratified rocks below them; while the mountainous lands, on the contrary, owe their peculiar features to the elevation of stratified and unstratified rocks into chains and groups and peaks. It is a general law, confirmed by most ample evidence, that the interior parts of mountainous regions consist of granite and metamorphic rocks supporting all the later strata, and bearing them up to their present elevations. From these elevated points and lines, both the subjacent igneous and the superior stratified rocks descend at various angles towards the plains and more level regions, beneath which they sink and pass for various distances, until they again emerge in some other mountain group having similar characters. In consequence of this arrangement, it happens generally that the oldest strata, those which sink deepest under the plains, rise highest against the mountain slopes; a circumstance easily understood, though sometimes called *a geological paradox* (Pl. II. fig. 5). The most constant of all the facts connected with this part of the subject is the developement of granitic or some other thermogenous rocks about the centres of the elevated groups from beneath or amidst the lowest strata there occurring. Very frequently cracks and fissures of the strata are filled by these igneous rocks injected from below, and thus in some cases the proximity of their masses is indicated when they cannot be actually seen.

The surface of the earth derives all its diversity of form and products from the originally different nature of its constituent rocks, the variety of positions into which these have been thrown, and the consequent inequality of effect produced upon them by atmospheric and other modifying agencies. Had the stratified rocks remained in their original nearly level position, all the immense variety of mineral treasures which they contain would have been hidden from the eye of man, and the dry land would have been a monotonous waste, without that picturesque grouping of mountains, that pleasing variety of hill and valley, that ornament of bay and promontory, which we now gladly acknowledge to be a great source of enjoyment and instruction.

And, as we behold how marvellously the animal and vegetable creations are adapted to each other, and both to the local influences of climate, soil, elevation, proximity to the ocean, and other important conditions, produced by geological revolutions, there is no room for doubt that the subterranean movements by which this fundamental diversity of the earth's surface was occasioned, are as much a part of the general plan of creation as the existence of the atmosphere, the proportion of land and sea, or the succession of the seasons.

The sea-coast of every country derives its characteristic outlines, its rocky cliffs and alluvial depressions, from the unequal hardness, various directions, and degree of elevation of the rocks. The long horns of Cornwall and Caernarvonshire coincide with axes of upheaval; Pembrokeshire, like the Isle of Wight, is extended by the operation of similar causes from east to west; Flamborough Head, composed of chalk, projects into a magnificent promontory, round which the currents of the German Ocean turn, with fatal perseverance, to waste the softer clays and sands of Holderness.

The chains of mountains and ranges of hills, and the vales and plains which surround and divide them, are all occasioned by similar causes. The range of Snowdon is the line of an axis of elevation; the Pennine Chain, from Ingleborough to the South Tyne, is formed by a magnificent dislocation, which depresses the strata on the west above 1,000 yards; and where this dislocation turns to the east along the Tyne, and to the east and south-east through Craven, it produces, in the midst of a mountain country, two great irregular valleys across the summit of drainage.

The forms of the individual hills and valleys are occasioned principally by peculiarities in their geological structure. Compare, for instance, the pinnacled rocks of the high Alps with the broad swellings of the oolitic Jura; the fantastic cappings of basalt in Scotland with the serrated slate mountains of Cumbria and the green swelling outlines of the English chalk.

How different are the vertical cliffs of mountain limestone, which have been rent asunder in Mendip and the Peak, from those of other rocks! The streams which foam through many channels among the slate rocks of Lowdore, or rush in white lines down the slopes of Skiddaw, give a totally different effect to the scenery of the Cumbrian glens from that which belongs to the lofty cascade of Hardrow, and other less-known waterfalls, across the ridges of limestone in the magnificent dales of the North of England.

A general acquaintance with geological truths is therefore absolutely indispensable to an enlarged intellect, which is desirous of forming right general views of the arrangements of existing nature, and especially of physical geography.

GENERAL VIEW OF THE STRUCTURE OF THE EARTH.

Leaving the question of the original aggregation and interior arrangement of the matter of the globe to the astronomer, and the laws of the atomic constitution of its mass to the philosophical chemist and crystallographer, we may gather from the preceding statements sufficient grounds for a general view of the structure of the exterior crust or shell of the globe. By far the greater portion of the surface of the earth is occupied by rocks which were deposited by water in the form of strata, more or less approaching to a horizontal position, which succeed one another in a certain order of superposition, are of different antiquity according to this order, and are continuous for less or greater distances. In these strata multitudes of remains of plants and animals lie buried, which are for the most part distinct from the plants and animals of the present day, though belonging to the same great divisions, and formed upon the same general plan of terrestrial and aquatic life. This system of stratified rocks extends to a variable depth, not exceeding a few miles, and below it and amongst it occur various rocks, which are not stratified, and do not contain organic remains, but consist of such minerals, and occur in such circumstances, as to be clearly the result of igneous agency. These pyrogenous rocks are frequently found piercing through the strata in various ways, as if uplifted from below. In some cases, also, the effects of heat are traceable in the stratified rocks themselves, in consequence of which they have partially or generally assumed some of the appearances properly characteristic of the rocks crystallised from fusion.

The dry surface of the earth is formed on the edges and surfaces of the strata and tops of the uplifted thermogenous rocks, in such a manner that while the great plains and moderately undulated regions consist almost entirely of stratified rocks, the mountainous parts usually contain an axis or nucleus of plutonic and metamorphic rocks covered by unaltered stratified rocks; both of which groups decline on all hands from the mountain chains, sink below the more level regions to various depths, and pass to various distances.

Both fire and water have been actively engaged in the construction of the earth. Water has deposited from above, in a settled order of succession, many extensive strata and sets of strata, variously filled with the remains of plants and animals which existed during the several periods; and heat has expanded these strata from below, and thrown up a different set of rocks from the deeper parts of the earth. It is the business of the geologist to trace with accuracy the effects of these agencies, separate and combined; to arrange these effects in a chronological order, and thus to compose a correct if not complete history of the revolutions by which the earth has been brought to its present condition, stored with its present wonderful variety of animal, vegetable, and mineral forms, and made fit for the residence of a being gifted with that human curiosity which prompts him to examine, and that divine reason which enables him to interpret, the works of nature, and through them to hold a sublime communion with the Creator of the universe.

CHAPTER III.

LAND AND SEA.

SUBAQUEOUS PRODUCTION OF THE DRY LAND.

The most important of all the leading truths established by modern geologists was not wholly unperceived by the enlightened philosophers of antiquity. When Ovid ascribes to Pythagoras the opinion that, in the course of the changes of nature, what is now dry land was formerly sea, and the contrary, and illustrates the doctrine by the submersion of cities along the shores of the Mediterranean, and by the occurrence of marine shells far from the sea, it is impossible not to be struck with the force and simplicity of the argument. Ideas of the same kind were distinctly announced by Strabo and others accustomed to the phenomena of earthquakes in Asia Minor. Even Herodotus was attentive to the sea-shells on the hilly margin of the Egyptian valley.* But the poetical notion of alternations of land and sea

* Book II. § 12.

over given regions, suggested by limited phenomena, is distinguishable from the philosophical conclusion, based on universal research, that the whole of the existing continents and islands have been reared out of the bosom of the sea—that all our highest mountains are of comparatively modern date, and that in some former period of the world the ocean-currents flowed over the yet unborn Alps and Pyrenees, as well as over the plains of India, Africa, and America.

Whether, at the time when all our continents were beneath the sea, there were other continents raised above it, is a matter which it is difficult to bring fairly within the scope of inductive science, except in a very limited form, and upon rather doubtful assumptions. The only clear and *certain evidence* for the existence of land in other situations than where it now appears, is to be sought in the history of terrestrial organic exuviæ imbedded in the earth; the only reasonable *presumptive evidence* in favour of such a doctrine must be founded on mechanical considerations connected with the mass and depth of the waters of the ocean. To conclude that because continents were raised in one quarter others *must* have been depressed elsewhere in a certain proportion, is unsafe, because it requires us to admit what is perhaps false, viz. that the spaces occupied by the solid and liquid parts of the mass of the globe have always been exactly and invariably in the same proportion to each other as at present. Who can assure the truth or even the probability of such a law?

The simple argument of Ovid —

> ——Vidi factas ex æquore terras,
> Et procul a pelago conchæ jacuere marinæ —

will probably never lose its power of convincing mankind that they stand upon the elevated bed of the ancient sea. When we find shells and corals, which beyond all doubt must have lived in the sea, deposited in the interior of solid rocks, with all their delicate ornaments of structure uninjured, and lying in these rocks, as they usually do on the bed of the sea, we are compelled to conclude not only that these exuviæ were deposited by the ocean, but that the animals actually lived in or near the very spots where their remains are buried, and were there quietly covered up by the deposits of earthy matter then in progress. Each of the stratified rocks enclosing these remains was really in succession the bed of the ancient sea; and wherever we find the faithful testimony of imbedded marine exuviæ, the conclusion is immediate and unobjectionable, that the ancient bed of the ocean is laid open before us. The extent to which this principle is applicable, varies in different countries. In Europe generally, in North

America, in India, a large portion of the whole area may thus be proved to have been formerly submerged.

Strata containing no organic remains, sometimes alternate with others which do contain them, and they have evidently been subject to the same local conditions, and have had the same oceanic origin. Such strata as red sandstone, and many kinds of slate which, in England at least, contain no organic remains, were as certainly formed on the bed of the sea as the conchiferous limestones above and below them. Moreover, strata which in some countries contain no organic remains, do contain them elsewhere — as, for instance, the red sandstone; and, by combining all these facts together, we arrive at the conclusion that the Ovidian argument, from the presence of marine exuviæ, applies to at least three-fourths of the whole area of the solid land, and to the whole series of strata except those which lie at the very bottom; and to all heights above the level of the sea, and to all attainable depths below it. But even if there were no marine exuviæ in the stratified rocks, yet, because of their composition, texture, and structure, their regular order of succession, and other characters, they speak for themselves, and show most clearly that they are not to be regarded in any other light than as deposits upon the bed of ancient waters. In this case we make no exception, but include with equal confidence the most ancient primary slates and the most modern tertiary sands.

Thus we arrive at the conclusion, that not only all the great plains and all the undulated portions of the land were formerly submerged, but that the flanks and often the very summits of the loftiest mountains are composed of rocks formed under water; for all these are composed of stratified materials of some kind or other.

The same conclusion applies likewise to the plutonic rocks which appear about the centres of mountain groups; for, as we have before seen, these rocks appear in such a relation to the strata of the mountains, that, by a large induction of facts, we are led to conclude that they have been in fusion beneath all these strata, and have, in fact, been upheaved with them from their original situation on the bed of the sea. Therefore it is concluded, as a fundamental maxim in geology, that the whole area now occupied by dry land was formerly covered by the sea. We may next enquire into the agencies by which the land was redeemed from the waves.

ELEVATION OF LAND.

The strata formed upon the bed of the sea could only be laid dry by one of two processes;

either the general level of the sea has been lowered, as Werner imagined, or there have been vertical movements of the solid parts of the earth. The notion of the gradual lowering of the level of the ocean is one of those imprudent suppositions which the constantly increasing connection of geology with exact science has nearly banished from our systems. It was adopted with the view of accounting for the often observed fact, that the strata which descend to the greatest depth under the plains, and are certainly the oldest, are also found rising to the greatest height along the flanks of the mountains. The Wernerian hypothesis assumed that the great physical features of the globe, its mountains and plains, were aboriginal; it not only assumed that rocks were, for the most part, produced from water, but extended this assumption to basalt, porphyry, and granite, and took no steady view of the enormous fractures and foldings by which the whole crust of the earth has been disturbed; and it was to agree with these fundamental errors that the monstrous notion of the gradual and universal sinking of the water-level, from the summits of the mountains to the shores of the actual sea, was framed. This notion is so contrary to common sense, that it will be instantly rejected by every mind which is not prepared to admit an unlimited variation in the quantity of water upon the globe.

No direct collision with natural philosophy can be chargeable upon the other supposition; we must therefore judge it by comparison with observed facts. The vertical movements may have been elevatory or depressing, or both: they may have been sudden and convulsive, or gradual. In every case of *convulsive* elevation or depression along a line or about a centre, the strata, originally deposited nearly level, must be placed in angular positions with respect to the horizon, and the dips or slopes thus occasioned will be most considerable along the line or about the centre of the disturbance. Nearly analogous results would follow a *gradual* vertical movement of the strata within a limited area, if continued until the pressure were relieved by fracture of the strata. If the elevatory or depressing action were exerted over a very broad area, and gradually exhausted, it might happen that no sudden or violent dips should be anywhere traceable, but the effect would be a gradual intumescence or subsidence. These are obvious truths, and they are sufficient for the purpose of examining the question of the desiccation of the land.

It cannot be doubted that both depression and elevation have happened to many parts of the bed of the sea; but when we proceed to those parts of the country which were most affected by these disturbances, we are at once convinced that it is to local elevation of the bed of the sea we must ascribe the existence of mountains. The general fact of the rapid dip of the strata in the proximity of the mountains (Pl. II. fig. 5), contrasted with their gentle slopes or nearly horizontal position, even at moderate distances, is sufficient proof of this. As nothing can be more certain than the dependence of the figure of continents and islands upon the direction of the ranges of mountains, there is no room to doubt that all our solid land has been *raised* out of the sea, parallel to certain lines, and around certain centres of vertical movement.

The confusion of dip (Pl. II. fig. 6) so commonly observed in the proximity of mountains, seems to indicate that the elevatory movements were sudden and convulsive; but the full discussion of this subject would lead to theoretical considerations unsuited for an elementary work. Whether depressions in other parts of the globe corresponded to the elevations in these, is a question of the same character.

We may, however, advance our conclusions, as to the elevation of land, one step farther, by considering the relation of the lines and centres of elevation to the exhibition of plutonic rocks. The appearance of these rocks along the lines of subterranean movement is so constant and characteristic a phenomenon, that we cannot doubt of the dependence of both upon the same local causes. Obviously some pressure from within, determined to particular points, has upheaved the strata with the adjacent thermogenous rocks. In some cases it is probable that the plutonic rocks were upheaved in a solid form; in others it is demonstrable that they were in a state of igneous fusion, so as to flow into cracks and fissures of the strata. The phenomena may be plausibly explained upon the supposition of the local production of great subterranean heat, or by considering the convulsive movement as a paroxysmal relief to a general pressure upon the internal fluid nucleus of the globe. Each of these views has able defenders.

Nothing is more evident in physical geography than that the extent and direction of the land depend on the ranges of mountains; these have been shown to owe their elevation to subterranean movements; and this is generally thought sufficient proof that the elevation of all the solid land is due to the convulsive rising of the mountains. This is, however, not proved, though we may always justly admit that large breadths of land rose with the mountains. But it is not adequate as a general explanation of the desiccation of the continents, for a very sufficient reason, viz. that many mountains were raised by the convulsions, of which they exhibit traces, *before the strata* *were formed, which are now laid dry around them.*

Persons who are aware of this difficulty propose another view. They say, as the mountains certainly owe their elevation to convulsions centred beneath them, so also probably were all the other parts of the dry surface of the earth raised by other convulsions, suitably posited. This is equally erroneous. There is no ground whatever for applying this hypothesis to the desiccation of the eastern and south-eastern parts of England, the north of Germany, and other large tracts of Europe; for in all these cases no convulsions can be traced at all adequate to the effect.

There remains for these cases, which relate to perhaps half the area of the dry land, only the hypothesis of *gradual elevation* of large tracts, either by the manifold repetition of small disturbing movements, or some general expansion beneath a whole physical region. Many of the Swedish naturalists believe that such an expansion is at this moment gently raising a great part of the Scandinavian peninsula. Lyell, from personal examination, has been led to adopt these views, which are also sanctioned by the authority of M. Arago; and illustrated by the well-known historical case of the movements which have happened to the temple of Serapis at Puzzuoli.*

* Babbage in Geol. Soc. Proceedings.

RELATIVE ANTIQUITY OF LAND.

One of the most interesting of the results to which a careful study of the circumstances of the elevation of mountains has conducted geologists, and at the same time one of the most certain, is the knowledge that *the dry land is not all of the same antiquity*; in other words, that some mountain ranges, and some large regions, were raised above the sea long before the occurrence of the convulsions which affected the level of other countries, and even before the production of the strata of those countries. For instance, we have no doubt that the Grampian, Lammermuir, and Cumberland mountains were dry land long before the Alps were reared from out of the sea, and while the greater part of the area of Europe was occupied by the ancient ocean.

How is this ascertained? It depends upon the determination of two leading truths: First, That the series of convulsions to which mountain ranges owe their origin, were effected at many different and relatively ascertainable periods. Secondly, That by these convulsions, or some gradual operation, the bed of the sea was not only *relatively* raised in certain parts, but particular portions of it uplifted above the level of the water.

The relative age of convulsions is known by observing what strata *are* and what *are not* dislocated by them. If, for instance, as on the borders of Cumberland, the *old* slate and limestone strata are *dislocated* in certain directions, while, in the prolongation of these directions, the *newer* strata of red sandstone are *not disturbed*, but lie level over the sloping surfaces and edges of the others, we know that the convulsion happened after the formation of the slate and limestone, but before that of the red sandstone (Pl. II. fig. 7). Again, because on many of the peaks and in many valleys of the Alps tertiary strata are found in a state of dislocation, it is clear that the last dislocations of the Alps were during or subsequent to the tertiary era. Always, the age of a convulsion is less than that of the dislocated strata, and greater than that of the strata which lie undisturbed, and unconformable on or against the former.

That certain parts of the bed of the sea were not only raised in relation to other parts, but absolutely reared above the waters into ranges of high ground, is known by the circumstance, that since the date of the convulsions which can be traced in them, marine strata have been formed around them, and in hollows of their surfaces, in such a way as to indicate that they stood up like islands, amidst the waters, defining the area over which the sea could form its deposits, and producing the vegetables and other remains of terrestrial beings, which are imbedded in these deposits. Thus the Cumbrian group of mountains was dry land at the time of the deposit of the red sandstone around it; the same was the case with Charnwood Forest; and by continuing researches on the principle of combining the evidence of convulsive movements, and subsequent deposition of marine strata, we may hope to see light gradually break in upon the interesting problem of the ancient hydrography of the earth.

PERMANENCE OF THE LEVEL OF THE OCEAN.

It has already been shown that the whole of the dry land was formerly submerged. The preceding statements will probably be admitted as sufficient to prove the justness of the data for our conclusions, that the dry land is not all of equal antiquity, as the strata composing it certainly are not.

We have stated on what grounds geologists conclude that the desiccation of much of this land is a consequence of subterrânean movements, and that for the remainder it is preferable to appeal to a more gradual and general change of relative level of land and sea. It has also been stated that the drying of the land by a general subsidence of the ocean level is a mere delusion, and that the facts can only be explained by internal movements producing locally sudden or gradual change of dimension. Though the Wernerian hypothesis of the gradual subsidence of the ocean, which to suit the phenomenon which it professed to explain must have been to the extent of some miles, is now little regarded, it is necessary to show the line of argument according to which it is allowable for geologists to take for granted the permanence of the level of the ocean, *independently of astronomical vicissitudes.*

In this argument the quantity of water upon the globe is supposed to be constant: we have clearly no right to suppose otherwise. Variation of the level of the water may happen in consequence of internal movements and displacements of the parts of the earth, or from a change of the temperature of the globe. *Displacements* of the parts of the globe may cause land to sink or rise, or both. If any part of the bed of the sea sinks into a cavity, or rises so as to leave a cavity, the ocean level will be altered in proportion to the bulk of this cavity. The greater the cavity out of which any part rises, or into which any part sinks, the greater the change of level. If we suppose three-fourths of the globe to be covered by water, and imagine a portion of the bed of the sea, equal in cubic content to the land now above the water, to sink into a cavity, the dry land remaining unmoved, the depression of level occasioned over the whole ocean would be something more than one-third of the mean height of the land. This we may take at 2,000 feet: consequently the depression of the sea upon this enormous sinking would be something more than 666 feet. If the existing dry land should sink into a cavity, so that it should be just submerged, the level of the sea would remain nearly unaltered.

The converse is true. If the bed of the sea should be raised, but not to the surface, and leave below it an internal cavity, there will be a general elevation of the ocean level proportioned to the cavity; if any portion of the displaced mass of earth should project into dry land, the level of the ocean will be raised in proportion to the difference of cubic content between the cavity and that quantity of land which projects above the surface *directly*, and to the new area of the ocean *inversely*.

But if we discard the notion of cavities, and suppose the elevation of one part to be compensated by the depression of another, the ocean level will vary merely as the quantity of land above its surface. It will rise by the sinking of the land under it, and the contrary. If we suppose all the dry land to sink till it be submerged, it will cause the ocean to rise about 500 feet. To such a depth then, and no more, could the ocean have sunk upon the rising of this mass of land. If at all times as much land rose above as sank beneath the surface of the sea, the ocean would remain at the same level.

The effect of a general *change of the temperature* of the globe in altering the relative level of land and water cannot be stated, unless we assume some fixed temperature for the water. In this case the change of dimension must go to some hundreds of miles on the radius before the relative level of land and water would be so affected as to account for the emersion of a large part of the land. A change in the mean temperature of the superficial parts of the globe is a probable geological cause of some fluctuation of the ocean level; but its effect cannot have been considerable.

Astronomical vicissitudes would for the most part be insensible in altering any of the dimensions of the globe: and unless we take into account a great displacement of the axis of rotation of the earth, we are forced to admit that the mean level of the ocean is nearly permanent, and that the dry land has been really *raised* out of its bosom by the force of subterranean movements. What was exactly the nature of these is a problem which must be intrusted to the researches of mathematicians guiding the industry of geologists.

MOVEMENTS IN THE CRUST OF THE GLOBE.

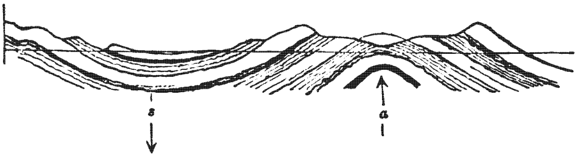
Perhaps the simplest case of these movements is that best known, in detail—the case of mineral veins, trap dykes, and common faults. In each of these phenomena, the earth's crust, so far down as we know it, has been *broken* asunder: by attending to the *direction* of the fractures in a given large district, as Cornwall or Derbyshire, it is found that in certain directions more faults occur than in any others. Often two systems of veins thus appear in such a district—one, the 'right running,' passes from E. or ENE. to W. or WNW.; and another, the 'cross courses,' as their name implies, traverse the first-named veins N. or NNW. to S. or SSE. It is found in some well-examined cases, that these two sets are not of the same geological date, for one system is displaced by the other.

Now, these results are such as would arise if there had been below all the strata which are broken *a general pressure*, such as steam or expanding liquid, producing a strain *across the whole district*, which is occupied by one of the systems of fault.* The general idea of internal pressure, to which we are thus conducted, is strengthened by reference to another form of displacement of the strata, that of the anticlinal axis, a phenomenon observable in almost every mountain chain, and often extending much beyond them. Along or near to these lines of fracture igneous rocks are not unfrequent. Adjacent to a main anticlinal

* Hopkins's Researches in Physical Geology, Cam. Phil. Trans. 1837.

axis, as, for example, that of the Highlands, running north-east and south-west, and that of North Wales, which takes a parallel direction, we often find other anticlinals and synclinals, which preserve, on the whole, parallel courses. They appear to be all of the same geological age, and thus widen still more the inferences that some very extensive subterranean force has been concerned in the effect.

DIA. 6.



a. Anticlinal. *s*. Synclinal.
(The arrows indicate the directions of the pressures.)

But it is to M. De Beaumont that we are indebted for an idea of this force still more general: he has concluded, from many observations, that there is some real dependence between the geological age of disruptions and their direction—those of one particular epoch being parallel, or nearly so, to the same great circle of the sphere, even in very distant localities. If this could be sufficiently established, there would be no doubt of the effect being due to an almost universal internal disturbance, such as might be compatible with the supposition of the earth being internally fluid by heat at the epoch of these dislocations. There are certain phenomena connected with these numerous anticlinal and synclinal folds, which allow of no other supposition than that in the regions where they occur—as in Wales—the strata so bent and folded, occupy an arc of the earth's surface less by much than their own length. In the case of many faults, the contrary effect happens; the broken strata, by their means, are made to spread over an arc greater than the length they occupied before fracture. Each of these cases is consistent with the supposition that formerly the earth's crust floated on an interior molten sea; and the phenomena of volcanoes teach us that at least partially it is so now in certain districts. We may, therefore, consistently ask, is the earth still generally fluid within?

INTERNAL FLUIDITY OF THE GLOBE.

Happily for geology, it is not left in this dark research to its own feeble light. The theory of gravitation here comes to its aid; and, by a careful analysis of one of the most remarkable among the phenomena which characterise the earth's orbital motion, shows, if not the exact truth, the limits within which the truth lies. The phenomenon alluded to—the 'Precession of the Equinox'—is caused by the attraction of the sun and moon upon the protuberant matter in the equatorial regions of the earth. Were the earth a perfect globe, with a symmetrical internal structure, its axis would not describe in the course of ages a large circle in the heavens, nor would the return of the seasons be marked in successive years by continual variation of the equinoctial points among the stars. It is by comparing the perfectly known measure of the precession with what *would have been* the measure if the earth were wholly fluid or wholly solid within, and if its density were uniform, or varied in certain ways, that it has been found possible to solve, approximately, this great and important pròblem. Mr. Hopkins, to whom we are indebted for this and other gifts to geology, concludes, from the whole investigation, that the earth cannot now be *wholly fluid* within until we descend below the surface about 1,000 miles; but it appears not improbable that it may be *partially* so at less depths, provided the fluid spaces were insulated, or had only slight communication.

On this subject we must refer to the laborious memoirs of this accomplished mechanician, in the Phil. Trans., 1839–40–42; and shall only add, that he is engaged in completing the investigation, by experiments on the effect produced by *pressure* on the temperature of fusion—an effect obviously of the utmost importance in questions regarding the internal fluidity of the globe.

CHAPTER IV.

CLIMATE.

TEMPERATURE OF THE GLOBE AT SMALL DEPTHS.

But whatever may be the final result of these enquiries into the *fluidity* or solidity of the interior of the globe, it is certainly *hot* within. We do not appeal for proof of this to volcanic phenomena, because these, extensive as they are, may be conceived to be locally excited by chemical actions. It is by experiments conducted in regions far from volcanic excitement, that the data of most value have been obtained. In mines and collieries the warmth continually augments as we pass lower and lower from the surface; and this increase of heat follows at each place with much regularity a certain rate, seldom varying greatly from the general proportion of one degree of Fahrenheit for every fifteen or twenty yards. At this rate, the heat of boiling water would be attained under London at a depth of 2,400 or 2,800 yards. The same conclusion arises from the 'Artesian' experiments, by which water is procured from considerable depths. In the case of the well of La Grenelle, at Paris, a depth of 1,791 feet gave an increase of temperature of thirty degrees; and the salt spring of Kissingen, rising from a depth of nearly 2,000 feet, was found to give nearly the same result.

The great heat which is thus indicated in the deeper parts of the earth no doubt communicates gradually and slowly a certain warmth to the surface. This effect is not at present sufficient to affect in a sensible degree the temperature of the surface. But in earlier periods, when the thickness of slowly conducting rocks over the source of heat was less, the warmth communicated to the land and sea may have been greater.

The temperature of the earth's surface at present is mainly dependent on heat imparted from the sun, and cold caused by radiation into the clear planetary spaces. The balance of these contrary actions, modified by the atmospheric peculiarities of surface, gives the surface temperature. It is dependent on latitude; but not less so on the form and distribution of land and water, currents in the sea and in the air, height of ground, and other causes.

At any one place on the earth's surface the mean temperature of the year is nearly the same as that at small depths from the surface; but the propagation of heat and cold is so slow through the rocks, that while the greatest heat of summer is felt at the surface about the middle of July, it does not penetrate to the depth of 6 feet before the latter part of August, reaches 12 feet in the beginning of October, and 24 feet about the middle of December, thus reversing at that depth the summer and winter.

The *range* of temperature diminishes rapidly as we descend below the surface. At the surface between the summer and winter, we have about 30°, in the central parts of England, and at a depth of about 70 feet this range is reduced to less than $\frac{1}{1000}$ part, and is practically insensible. The mean temperature, in our latitudes, and amidst all fluctuations, is found to augment as we go downward; after reaching the depth of 70 feet (more or less according to the nature of the rock) this augmentation is steady and constant, because it depends only on the *permanent or slowly changing heat of the interior.*

CHANGES OF CLIMATE.

There is reason to believe that during the long periods consumed in the production of the whole great series of stratified rocks, and in the elevation of these out of the sea, the local temperature and other circumstances which influence the growth of plants and animals, both on the land and in the sea, were subject to remarkable changes. In this branch of the subject, the progress made of late years in philosophical botany and zoology is found of great importance. Without some fixed notions of the dependence of organic forms upon the influence of temperature, moisture, and other conditions—without some clear proofs of the geographical limitation of the existence of species in a natural state, according to definable circumstances, it would be impossible to come to any settled conclusion respecting ancient climate. Besides this, it is necessary for a good argument on this subject that the fossil organic remains on which we found it should be very carefully compared with existing tribes, and their several degrees of analogy or difference noted. It is evident that any conclusions as to the character of ancient climate, drawn from comparison of fossil plants and animals with those which now inhabit particular regions of the earth, will be more or less binding as the analogies obtained are more or less exact and numerous.

In the existing system of nature the forms of life become more numerous toward the equator, and vanish altogether toward either pole. Thus, Humboldt counts only 4,000 species of plants in temperate America, and 13,000 in tropical America; 1,500 in temperate Asia, and 4,500 in equinoctial Asia. In some natural groups of plants, as, for instance, Ferns, the species grow to the greatest magnitude in warm regions, and dwindle to the smallest size in colder countries. These instances serve to point out the principle of the investigation of dependence of organic life upon temperature. The results obtained by this process apply accurately to the sea *at small depths*, and to the land *at small elevations*. In the gulfs of the ocean, and on elevated mountains, variations of temperature obtain which require to be allowed for. Thus, in mountainous regions, the mean temperature of the air diminishes at the rate of about 1° Fahr. for 100 yards' elevation; and the flora of the mountain-slopes varies in a corresponding manner, so that the plants collected from the base of the Alps differ in a nearly constant manner from those of moderate heights. At the greatest height, where the cold is severe, the plants resemble those which in more northern regions flourish near the level of the sea.

The relation of bulk and temperature in water is of a remarkable kind. At a temperature a little below 40° Fahr. fresh water is in the highest state of condensation (under the ordinary pressure of the atmosphere); and therefore in all cases when the temperature of the surface of fresh water sinks to below 40° Fahr. the particles so cooled descend from the surface toward the bottom.

If this process be continued till *all the mass of water* is reduced to below 40° Fahr. the surface may begin to freeze, which is the case with most fresh-water lakes; but owing to the depth of others they never freeze. The case is different with salt water, which continually grows more heavy as it is cooled, even to the freezing point, which is several degrees below that of fresh water. The sea may be looked upon as a great lake, which never freezes except in latitudes where the cold is so extreme as to overcome the downward tendency of the cooled surface-water, and convert it into ice, which, being specifically lighter, floats on the surface. In all latitudes the hottest sea water remains at the surface, or tends to rise thereto.

The greatest difference of temperature in the ocean, according to latitude, exists at the surface; the least difference in the deeper parts. We must therefore direct our enquiries, as to the influence of marine temperature upon organic life, to those plants and animals which constantly dwell near the surface of the water.

The play of oceanic currents materially diminishes the extremes of even its surface temperature, so that the polar ocean is warmer, and the equatorial ocean is cooler, than the adjacent continents. This uniformity of oceanic temperature is partially communicated to all the islands and shores, so as to constitute a distinct sort of climate, which is less subject to extremes either of heat or cold than that of the interior of continents, and is more uniformly charged with aqueous vapour. We have therefore the following scale of climates in relation to latitude:—

Equatorial	Mountainous Continental Littoral Marine Pelagian	Polar.

In agreement with what was before observed, we need not take into account the animals and plants of the pelagian or deep sea, or those which dwell on the mountains of very cold countries. Of the other climates, we may investigate some of the characteristic organic forms very simply.

First, of terrestrial climate as indicated by plants. Humboldt and other scientific voyagers present us with landscapes of the tropical regions, in which the magnificent Palms, the princes of the forest, are surrounded by Bananas, Cycadeæ, arborescent Ferns, Bambusiaceæ, Equisetaceæ, Lycopodiaceæ, Cacti, Euphorbiæ, and Mimosæ. To enjoy the splendid aspect of the tropical plants in the colder zones we must imitate the tropical climates by hot stoves. In the elevated parts of the tropical continents, which have a climate comparable to that of northern latitudes, occur Cypresses, Pines, and Oaks. It is along the moist shores, and on the small islands of the warm zones of the earth, that arborescent Ferns, and Cycadeæ, and Equisetaceæ grow in the greatest abundance, so that in these situations they form a very large proportion, even to half the total number of plants. In the drier interior of the continents, on the contrary, arborescent Ferns are less abundant; but Palms, and especially the succulent Cacti, form the characteristic vegetation. If we suppose that by any means the plants of an ancient tropical region of varied surface were buried under marine sediments, and by subsequent revolutions affecting that part of the globe these altered reliquiæ were laid dry and exposed for examination, the ancient character of the climates, when and where these plants grew, could be satisfactorily inferred, *provided* that, in the actual system of nature, plants of analogous tribes were found really limited in their situation by circumstances depending on climate. Now this is precisely what happens in the case of fossil plants; for the most abundant and characteristic forms of ancient vegetation are Ferns, some of them arborescent, Lycopodiaceæ, Equisetaceæ, Cycadeæ, Palms, and Cacteaceæ. With these, or in separate layers, occur coniferous trees and other plants, apparently indicative of cold regions or elevated land. Upon the whole, it seems the most probable inference, that the abundant vegetation of our coal strata was the produce of a warm and damp region, varied with plains, and shores, and mountains. The state of conservation of the plants, covered with leaves and in a state of considerable perfection, seems to prove that they have not been washed from a great distance; if so, the *places* where they are buried had the same sort of climate as warm regions of the earth in its present state.*

If this conclusion be sound, it will be difficult to avoid believing that nearly the same warmth of climate was felt at the same time in those parts of the globe where now are New Holland, Greenland, North America, and Europe; for in all these countries plants belonging to the same or very analogous species lie in a deposit of the same geological antiquity — the carboniferous system. Humboldt long ago expressed the necessary consequence of this pervading high temperature, by saying that in this condition of the world there was properly *no peculiarity* of climate, but a general superficial warmth, depending on the then greater or nearer influence of the interior heat.

* If the river rolled as far as the Mississippi, cold regions and hot might equally yield reliquiæ to a basin which should be in a temperate zone; or in other ways the inferences might be varied. Currents of the Atlantic bring timber from the tropical shores to Ireland and Iceland.

ANCIENT WARM CLIMATE.

In the existing economy of nature, terrestrial climate is supposed to be in a remarkable manner indicated by the races of vertebral and invertebral animals; but in the application of this principle a difficulty occurs, which is, in a less degree, also experienced in geographical botany. Animals are limited in their distribution by other causes than climate; they are localised between certain chains of mountains, certain breadths of deserts, and particular arms of the sea, and not unfrequently confined even to particular valleys and islands. Moreover, the remains of terrestrial animals are scarce in the earth; and it is perhaps only by a comparison of the forms of reptiles that any trustworthy results can be derived concerning the climate of the land in the northern zones of the world during any part of the period of stratification. Even here the conclusion is not very applicable to the land, because most of the fossil reptiles were marine. While, however, the ichthyosaurus and plesiosaurus might be littoral, and the crocodiles were probably estuary and river animals, the megalosaurus and iguanodon might live along the margins of primeval lakes; and from the whole series of these gigantic beings, compared with the present saurians and other reptiles, we may be well justified in inferring, that as all large reptile forms are now almost peculiar to the warm regions of the globe, so it most probably was in the older time.

The existence of zoophytic animals is subjected, in a very decided manner, to the influence of warmth at small depths in the ocean, and therefore these will furnish the best possible evidence for the temperature of the ancient sea. If we confine our attention to the polypiferous and spongiform zoophyta, we shall find that the stony corals generally, including the madrepores, millepores, and tubipores of old writers, belong to warm seas, as the West Indies, East Indies, the South Pacific, Red Sea, Mediterranean, &c. and hardly appear abundant in any part of the ocean beyond the 33rd parallel of latitude (except along the south-east coast of Australia). The older calcareous strata are so full of remains of stony corals that they have been considered by most geologists as coral-reefs, analogous to those which, in shallow parts of the seas, grow up, like the Bermudas, a mingled mass of coral, shells, and calcareous mud derived from the comminution of these materials in the currents of the sea.

The *corticiferous corallines*, like Gorgonia, Isis, &c. appear equally determined in their general distribution to the warm shores of the sea, but their number in a fossil state is too inconsiderable to serve as the basis of analogical reasoning.

The *Polyzoa* and *celluliferous corallines*, like Flustra, Sertularia, and Cellaria, appear, on the contrary, very abundant in the temperate and colder zones as far north as 60°; nor are they by any means of rare occurrence in a fossil state. Sponges give us some curious results. These half-animalised beings contain, in their durable parts, spiculæ of calcareous or silicious matter, with more or less of a horny substance. In proportion as the horny matter increases in quantity, and ramifies and reunites itself into network, the sponges are more flexible and more useful: those which consist principally of earthy fibres are too harsh for use. The horny sponges belong to warm seas and especially to southern seas, where, as on the shores of New Holland, they grow even in temperate latitudes. The silicious and calcareous sponges are plentiful along the coasts of Great Britain, even to the northern parts. Fossil sponges are much more analogous to the horny than to the earthy kinds.

There would be little advantage in extending this investigation to the Mollusca, Crustacea, or fishes which dwell in the sea; because these animals inhabit various depths in the water, sometimes migrate periodically to the shores, and are not sufficiently characteristic of climate, except by analysis of the families too minute for our argument.

We have thus found (after limiting our investigations to such organic races as are eminently and in large groups characteristic of climate in the actual economy of nature, and are also plentiful in a fossil state) clear indications that the ancient climate on the land was such, over a great portion of the globe, as to nourish plants of tropical forms; that the water of the ocean in the same regions, at small depths, was of such temperature as to permit the growth of coral-reefs, and the existence of large reptiles. And as these conclusions will not admit of explanation by calling in astronomical causes, *which probably have not acted*, such as the displacement of the earth's axis, or *others which are not sufficient*, as change of the earth's distance from the sun, we have only two hypotheses to choose between, or to combine. Either we must suppose the local elements of climatal variation to have gone to such an extreme as to nourish tropical forms in arctic zones, or allow that the superficial warmth of the earth was in a great degree regulated by the communication of heat from within. If we adopt the latter alternative, we must view the globe as now cooled at the surface, owing to the accumulation of non-conducting solid rocks over an ignited nucleus, and governed in its temperature by the external influence of the sun.

GLACIAL PERIOD.

But geology has yet another phenomenon to be considered before quitting the subject of the earth's ancient climate. There is reason to think that during very late geological (probably pre-historical) periods, the same northern zones of the earth, which in earlier times had nourished plants and animals resembling those within the tropics, were *chilled* by a general reduction of temperature; so that the mountainous regions of Britain and Ireland were crowned with perennial snow; their rugged valleys filled with gliding glaciers; the seas at their feet occupied by arctic life, and covered by floating icebergs, loaded with rocks from the Mourne, Grampian, Cumbrian, and Cambrian mountains. The *proof* of this in regard to the ancient sea was first presented in a distinct form to geologists by Mr. James Smith,* in 1839, and has been applied in extensive generalisations by Professor Edward Forbes,† in 1846. In general terms we may say that in connexion with some of the later and more superficial deposits—parts of the sea bed and remains of sea beaches—are *found* above a

* Memoirs of Wernerian Society, vol. viii.

† Memoirs of the Geological Survey of Great Britain, vol. i.

hundred species of shells, which are now living in the British oceans, and also in seas more to the northward; while a much larger number of the shells now living in the British seas, whose affinities are to the southward, are wholly and constantly *absent* from the deposits in question. Certain shore shells, as *Littorina expansa*, found in the 'glacial' deposits, are still living in the Arctic, but not known in the British seas.*

In regard to the icy character of the land, we find in all the mountain regions already named, clear positive traces of the *gliding of glaciers* down many of the valleys: parallel striæ, surfaces smoothed by long and equal friction, heaps of *moraine*. Even the movement of the icebergs, which broke off at the seaside from these glaciers, can be traced by the blocks of rocks which on the melting or overturning of the 'berg' were dropped on the bed of the sea. Thus from Shap-fell, in Westmoreland, the blocks have been floated on ice, and drifted by currents, over the hills of Yorkshire and the plains of Lancashire; from the porphyritic summits near Bala Lake, the masses have been conveyed on to the plateaux of the limestone ranges in Flintshire.

It might, perhaps, be imagined that the *higher*

* See on this whole subject De la Beche's *Geological Observer*.

degree of cold which prevailed on the mountains of the north of Europe (we might include Asia and America) was explicable by supposing the whole country to have been *more elevated.* But the facts already proved—viz. the dispersion of 'erratic blocks' on icebergs, and the diffusion of marine shells in connexion with the glacial drift —are inconsistent with that condition. They require, indeed, the admission of the very reverse, and *prove* that the 'glacial sea' had its level about 1,500 feet higher than the present sea, or (which, geologically speaking, is more correct) that the British land was 1,500 feet lower.

This, which at first view seems to increase the difficulty of explaining the peculiarities and changes of ancient climate, opens in reality a way to account for the *greater cold* of the northern zones. For it shows that the cold was preceded by a great subterranean movement—a change of the land and sea. If by such a change, happening at the present day, the flow of warm water from the equatorial regions, by the tidal wave and the gulf stream, were cut off from the north-western parts of Europe, our temperature, now higher by ten or twenty degrees than that of the corresponding latitudes in Eastern America, would lose all this advantage, and might again witness unmelted snows on Ben Nevis and Helvellyn, and icebergs on the surrounding seas.* The British Islands, and the west coast of Norway, are situated on what is now the warmest meridional band on the globe; by a change of circumstances at the surface, quite within the acceptance of geologists, it might become one of the coldest. But by no change of a contrary kind is it conceivable that that which is now the warmest band could be heated ten or twenty degrees more; still less that such a great addition of warmth could be communicated at the same time to a large part of the northern zones, and continued through long geological periods.

We cannot, therefore, dispense with the supposition, which seems obviously indicated by the phenomena, that the internal heat, which is still sensible at small depths below the surface, was formerly much *more sensible*, and that it effectually influenced, and really exalted, the temperature of the now refrigerated lands and seas of the north.

* Hopkins, in *Geol. Proceedings*, 1853.

CHAPTER V.

SERIES OF LIFE.

EARLY RACES.

WERE one who was completely ignorant of geological science required to consider the question whether this globe had been tenanted in some ancient periods by races of animals and plants different from those which now inhabit it, he would perhaps be surprised at the novelty of the idea, but would find himself unable to answer. History, it is evident, can tell us nothing of those times which preceded the existence of man; there is nothing in the Mosaic records of the creation of man, and the present forms of organic life, which in any manner defines the earlier condition of the globe, further than by affirming that it was formerly in a different state, especially as to its enrichment with living beings, from that which it exhibits to us at persent. This latter consideration is too little present to the minds of many sincere readers of the Bible; and, in consequence, a very unhappy conflict has been sometimes occasioned by comparing those results of geology which relate to periods left wholly undefined in the Scriptural narrative with the successive works of creation which are in that narrative distinctly marked. If we take the first words of Genesis as containing a general affirmation in regard to the prior conditions of the world—from the epoch of its orignal creation until THE MAKER saw fit to appoint its present character, and to call into being its present races of man, animals, and plants—and compare this with geological inferences relating to periods anterior to man, we shall find two conclusions inevitable; first, that there is no word in the Scripture narrative which limits in any way the inferences or even the speculations of geology, with reference to those periods; secondly, that nothing can ever be learned about them by human labour, except in the way of geological induction. This is sufficient for the purpose of the present enquiry, which relates to races of animals and plants, not only anterior to man, but even to the elevation of most parts of our continents from beneath the waters of the ocean.

Recurring to the observations concerning the lapse of time which took place during the formation of the stratified crust of the globe, we shall be prepared to enter on a more extended enquiry concerning the races of animals and plants than was necessary in a former section.

The number of species of plants and animals at present in existence is not known even nearly to accuracy, but the following estimate may perhaps be accepted as affording a useful notion of the *relative* proportions :--

	Living.		Fossil.
Plants	80	to	1
Zoophyta	1	„	1
Mollusca	1	„	1
Articulosa	100	„	1
Fishes	10	„	1
Reptiles	4	„	1
Birds	50	„	1
Mammalia	5	„	1

The actual system of organic beings is adjusted to terrestrial and aquatic life; and of aquatic animals, some live in the sea, others in fresh water. The following table gives a comparative estimate of recent and fossil plants and animals according to these conditions:—

	Recent.		Fossil.
TERRESTRIAL.—Chiefly Plants, Articulosa, and Mammalia	100	to	1
FRESHWATER.—Chiefly Mollusca, Articulosa, Fishes, and Reptiles	10	„	1
MARINE.—Chiefly Plants, Zoophyta, Mollusca, Articulosa, Fishes, and Reptiles	2	to	1

From these comparisons it is immediately evident that by far the larger relative proportion of fossil organic remains belongs to the marine division, that the fewest of all are the terrestrial races. This might have been foreseen, for as, when contemplating the strata, we are looking upon the *bed of the ancient sea*, we ought to expect marine remains abundant, and terrestrial reliquiæ very rare. At the present day, only a very small proportion of animals and plants, inhabitants of the land, is carried down to the sea, or even deposited in fresh-water lakes.

It has not been found necessary, in discussing the history of fossil plants and animals, to constitute a single new class; they all fall naturally into the same great sections as the existing forms. Thus, among plants, both recent and fossil, occur the same leading classes, founded on the cellular or vascular structure, and on the floral and seminal parts of the plant. Among Zoophyta we distinguish recent and fossil Polyparia and Radiaria; among Mollusca occur all the divisions of Brachiopoda, Conchifera, Gasteropoda, Heteropoda, Pteropoda, and Cephalopoda; among Articulosa we find Crustacea, Insecta, Annellida, &c.; and among vertebral animals, Fishes, Reptiles, Birds, Mammalia. Moreover, on analysing these classes, and comparing the subdivisions, families, and genera, we find very often, especially in the marine tribes, that the same characters will apply equally well to both the recent and fossil races. Thus, among conchiferous Mollusca we have both recent and fossil shells with two lateral muscles (Plagimyona), shells with one (principal) subcentral muscle (Mesomyona), and shells of a particular and still different construction (Brachiopoda). Again, in Plagimyona some have many teeth at the hinge (Arca, &c.); others striated hinge-teeth (Trigonia); some large ligamental teeth (Mya); some gape at the ends (Lutraria); some bore holes in rocks (Pholas, Lithodomus), &c. All these and many more characteristic forms and habits occur in both recent and fossil shells. Now, as these divisions are all founded upon important points of structure, we are warranted in concluding that the older organic creations were formed upon the same general plan as the modern. They cannot, therefore, be correctly described as entirely different systems of nature, but should rather be viewed as corresponding systems belonging to different periods and composed of different details.

The difference of these details arises mostly from minute specific distinctions; but sometimes, especially among terrestrial plants, certain crustacea, and reptiles, the differences are of a more general nature, and it is not possible to refer the fossil tribes to any known recent genus, or even family. Thus we find the problem of the resemblance of recent and fossil organic beings to resolve itself into a general analogy of system, frequent agreement in important points, but almost universal distinction of minute organisation. Of 10,000 fossil species well examined, not more than two or three hundreds are *identical* with living species. Of 1,000 genera which include those species more than half are peculiar to the fossil state.

GEOLOGICAL DISTRIBUTION OF ORGANIC REMAINS.

Remembering that each set of stratified rocks was successively the bed of the sea, and that the organic exuviæ which lie in these rocks are parts of animals and plants then living in the sea or on the land, we shall be able to compare the organic beings of the several periods of the stratification of the earth's crust with each other as well as with existing tribes. If out of the series of strata, taken in general terms, we select six groups or systems, as under, beginning with the least ancient, viz:—

Tertiary system,	Triassic system,
Cretaceous system,	Carboniferous system,
Oolitic system,	Silurian system;

and consider the numerical relations of the organic fossils which have been found in these several groups in various parts of the world (separating, for the sake of perspicuity, the marine from the fluviatile and terrestrial reliquiæ), we have the following results:—

The first table relates to marine tribes.*

	Plants	Zoophyta	Mollusca	Articulosa.	Vertebrata	Totals	General Thickness of Strata	Number of Species to 100 feet thickness
Tertiary .	13	49	2,728	5	26	2,821	2,000	141
Cretaceous .	14	235	500	13	15	777	1,100	70·7
Oolitic . .	4	275	771	22	70	1,142	2,500	45·6
Triassic . .	6	15	118	1	24	164	2,000	8·2
Carboniferous .	?	84	366	10	10	470	5,000 to 15,000	4·7
Silurian .	4	122	349	65	?	540	20,000 or more	2·7 or less

This table shows in a very striking manner the fact of the far greater abundance of marine organic exuviæ in the newer than in the older strata, and seems to add a strong argument in favour of the prevalent opinion that the lowest of all the primary strata were formed in a period when the ocean was devoid of living beings. If

* The table was drawn up thirty years since, and requires enlargement in every one of the numbers; but I leave it unchanged (except by writing Silurian for Primary, and Triassic for Saliferous), because the main inference which it teaches is still correct.

this conclusion be correct, the archives of nature are almost completely preserved to us, and the history of fossils is that of nearly the whole series of living beings which have successively inhabited the ocean.

Let us now turn our attention to the terrestrial reliquiæ, which are less abundantly diffused through the same systems of strata. We shall confine ourselves to plants of undoubtedly terrestrial and lacustrine origin.*

	No. of Species	Thickness	Number of Species to 100 feet thickness
Tertiary . .	156	2,000	7·8
Cretaceous . .	7	1,100	0·7
Oolitic . .	76	2,500	3·0
Triassic . .	40	2,000	2·0
Carboniferous .	274	10,000	2·7
Silurian . .	1	20,000	0·005

For various reasons we cannot venture to draw any inferences from these data as to the relative numbers of plants really existing on the land during these periods. The principal difficulty arises from the obvious fact that the occurrence of terrestrial reliquiæ at all in the marine deposits is *accidental.*

We may now advance to another view of the

* Drawn up thirty years since. The numbers for fossils should now be augmented, but the results are not materially affected.

subject of the distribution of organic remains in the earth. We may enquire whether the fossils which occur in all these great systems of strata, and which differ more or less completely from existing forms, be indefinitely distributed through the different groups of strata, or whether the series of fossils in each system of strata be distinguishable from those in the other systems. To this the reply is short and decisive. Wherever examined the several systems of strata above enumerated contain wholly distinct suites of organic remains, by which, in every limited district hitherto explored, they may be respectively characterised. As the fossils are distinguishable from recent beings, for the most part by minute differences of organisation, but sometimes by whole genera and families, so the several systems of fossils locally observed differ from one another in the same manner. The Silurian strata, for instance, may be distinguished from the carboniferous system by minute yet clear differences in the several species of shells belonging to the same genera of Orthoceras, Euomphalus, Spirifera, &c.; from the triassic system, by the absence in this latter of Trilobites, and whole groups of corals; and from the oolitic system, by the presence there of new forms of Ammonites, Gryphææ, Trigoniæ, Pholadomyæ, &c.

On this subject two propositions may be

adopted; first, The amount of the differences observable between the fossils of any two systems of strata is greatest in those systems which are the furthest removed, as, for instance, between the primary and the tertiary systems; secondly, The amount of the differences observable between the fossils of any system of strata and those at present in existence is greatest in the oldest system of strata, and least in the newest. Thus, on placing together primary fossils and recent shells of zoophyta, the difference is striking and total; but on comparing tertiary and living forms, it is the resemblance which arrests our attention. In one case we see at a glance the most obvious and complete discordance; in the other it requires careful scrutiny to assure ourselves that they are not identical. Viewed in this manner, the whole living and fossil world of existence, as far as relates to the inferior and especially marine tribes, seems to be almost united into one vast chain of being, which has derived from the same Creator in all past times the same fundamental laws of relation to the conditions of the world, but which shows itself in various forms, because these conditions were made to change. What a lofty view of the superintending care and providence of God through *all* periods of past time is thus opened to our minds! How heedless of plain truths must they be who can ever disconnect geological enquiries from reverential thoughts of the divine Lawgiver of Nature!

The conclusions above stated as to the entire distinctness of the organic remains in the several systems of strata apply with certainty to every limited region; that is to say, in whatever part of the world silurian, carboniferous, triassic, oolitic, cretaceous, and tertiary systems have yet been seen together, the fossils which they respectively contain are different from one another. In every country yet examined it is *locally* true that the systems of strata of different age contain distinct races of organic remains. But enquiries of equal importance now present themselves. Do strata of the same age uniformly contain fossils of the same species? Do they contain fossils of analogous species? Or are the fossils which any rocks contain merely of local occurrence, so that in distant parts of the world strata of the same age contain wholly different organic remains?

This is a mere question of fact: it must not be answered by reasoning upon existing phenomena, or by hasty generalisation from limited data. On this subject we have yet much to learn: the following, however, are ascertained truths.

The same *groups of fossils* which are in a very eminent degree characteristic of certain systems in one country, are also found under the same relations to those systems, not only in adjacent, but in far removed tracts, sometimes even to the distance of thousands of miles. Thus, for example, of the extinct crustaceous animals called Trilobites, the far greater portion of those found in England belongs to the Silurian and lower Palæozoic strata; they also appertain in the same nearly exclusive manner to the same system of strata through Norway, Russia, the Harz, Brittany, &c. They also characterise the same systems in North America.

Again, the extinct plants called Lepidodendra characterise, almost absolutely as a group, the coal strata of Great Britain: they have exactly the same relations to the coal of France, Belgium, Silesia, and North America.

Certain groups of Ammonites belong exclusively to the oolitic system of England: they are equally characteristic of this system in France and Germany, and come to us from the Himalayan mountains associated with other oolitic fossils.

Peculiar forms of Echinida mark the cretaceous strata of England, and the same occur in France, Poland, and along the shores of the Baltic.

Whole families of shells, such as Volutes, Cones, Cerithia, &c. may be viewed as distinguishing the tertiary strata from those below them in all parts of the world.

Instances are known of certain *peculiar species of fossils* occurring in the same series of strata in almost every region where those strata are known. Thus, the Dudley Trilobite (*Calymene Blumenbachii*) is found in Shropshire, Herefordshire, and Gloucestershire; it also occurs in Norway, in the Eifel, and in North America, but only in the same parts of the primary series of strata. *Calamites Suckovii* occurs in the English coal-fields, and in those of Liege, Anzin, Pennsylvania, and Virginia, but not in any deposit of a different age.

The *general aspect and character* of series of fossils derived from the same system of strata in very distant quarters of the globe are often extremely similar; very generally the same characteristic generic forms are repeated at all points in the ranges of the same strata; but there are also local differences always observable, which become the more considerable and obvious the greater the distance between the localities.

From all these considerations, we may conclude satisfactorily that the organic remains found in any one system of strata are of the same general character wherever these strata occur; that many *local* distinctions derived from organic remains between successive systems of strata disappear when the facts are viewed on a great scale; but that, as far as our experience at present goes, each system of strata may be identified through its whole course, and discriminated from the older and more recent systems by a judicious examination of a sufficient number of its organic contents. It is thus made evident that there have been many races of marine animals and terrestrial plants which have been successively called into existence in the same regions of the globe to suit its altered condition, and we may be assured that these successions of organic beings, well understood, will afford a secure and unchangeable scale of geological chronology. What the periods are which this scale of successive creations indicates we may perhaps never know. There is but one mode of approximation to even a plausible estimate of these periods—a knowledge of the length of life of the different sorts of marine animals. If this mode should be found impracticable, we fear the problem must be despaired of.

It would be impossible, even if it were suitable to the object, to give in an elementary work anything like an extended exemplification of the principles above announced. Fortunately, however, some illustrations can be presented in a tabular form, which will sufficiently evince the truth of these views. If we put in one table some of those genera which in the present system of nature are most rich in species, and in another those which were most prolific in forms in the older periods, we shall see very clearly what analogy or difference may exist. Also, by selecting other genera and families, we may show through what ranges of strata, that is to say, through what geological periods, they existed, and at what epochs they were most numerous. There is no general law on this subject, except that the most extensive changes of the forms of life occur at the limits of the three great periods; and that, while definite 'species' are often confined to one formation, or some one part of it, 'genera' and 'families' frequently pass through several formations, and still larger groups or 'orders' often traverse whole systems, several systems, or even the whole series of deposits from the earliest to the latest. Thus, Trilobites (an 'order') existed during the Cambrian, Silurian, and Carboniferous eras, but are nowhere known in the more recent strata, nor do they exist at present; Productæ and Spiriferæ (genera) pass through the later palæozoic periods and end in the mesozoic; while —a remarkable case—Lingula, one of the earliest of all genera, and Rhynchonella and Terebratula, which are also palæozoic, are found in all succeeding formations, and are still living. On the other hand, certain tribes began to exist at later epochs, as the Ammonite, Belemnite, and many genera of Echini, and their races ended before the dawn of the tertiary period. This will serve to render intelligible the following tables: —

TABLES OF THE GEOLOGICAL DISTRIBUTION OF FOSSILS.

Table I. *Genera containing many living species.*
(*Gasteropoda.*)

	Cypræa	Conus	Voluta	Strombus	Murex	Fusus	Cerithium	Mitra	Pleurotoma
Living .	*	*	*	*	*	*	*	*	*
Cænozoic .	*	*	*	*	*	*	*	*	*
Mesozoic .					?	?	*		
Palæozoic .									

In this table the strong affinity of the tertiary to living forms of animals, and the diminution of this affinity as we proceed to compare recent life with the remains of earlier date, are very decided.

Table II. *Genera containing many fossil species.*
(*Conchifera.*)

	Producta	Spirifera	Terebratula	Trigonia	Pholadomya	Lima	Inoceramus	Gryphæa
Living . .	...	...	*	*	*	*	...	*
Cænozoic . .	...	...	*	...	*	*		
Mesozoic . .	*	*	✱	✱	✱	✱	*	✱
Palæozoic . .	✱	✱	*					

Tables of this kind suggest curious remarks concerning the duration of existence of certain genera. The larger asterisks mark the periods of their greatest fecundity in species. From data thus compared arises an easy distinction of particular sets of strata, by the presence or absence of whole groups of shells, and by the extraordinary plenty of others.

Table III. *Genera of Cephalopoda.*

	Nautilus	Orthoceras	Goniatites	Ceratites	Ammonites	Belemnites	Hamites	Scaphites	Baculites
Living .	*								
Cænozoic .	*								
Mesozoic .	*	*	*	*	*	*	*	*	*
Palæozoic .	*	*	*						
Hypozoic .									

The above table shows, in a strong light, the greater prevalence of Cephalopods in the earlier ages of the world. Yet a few nautiloidal forms continue to this day.

The next table gives the geological distribution of some sections of Belemnites.

Table IV. *Form of Belemnites.*

In and above Greensand	*			
In and above Oxford Clay . . .		*		
In and above Inferior Oolite . . .			*	
In and above Lias				*

It is easy to see how important, in questions concerning the relative antiquity of the different groups of the oolitic rocks, is a knowledge of Belemnites, since whole sections of them are characteristic of certain parts of these rocks.

The last table will show that particular species of fossils are frequently confined to one system of strata. The stars indicate in what strata the species named occur.

Table V. *Species of Mollusca and Zoophyta.*

	Venus æqualis	Lima spinosa	Trigonia clavellata	Avicula socialis	Producta gigantea	Calceola sandalina	Rhynchonella Wilsoni	Galerites albogalerus	Clypeus sinuatus	Encrinites moniliformis	Platycrinus rugosus	Sphæronites tessellatus	Hypanthocrinus decorus
Cænozoic . .	*												
Upp. Mesozoic . .	..	*	..	..	..	..	..	*					
Mid. Mesozoic . .	..	..	*	..	..	..	..	..	*				
Low. Mesozoic . .	..	..	..	*	..	..	..	..	..	*			
Upp. Palæozoic .	..	..	..	..	*	..	..	..	..	..	*		
Mid. Palæozoic .	..	..	..	..	..	*	..	..	..	..	..	*	
Low. Palæozoic .	..	..	..	..	..	..	*	..	..	..	..	..	*

CHAPTER VI.

LAPSE OF TIME.

The magnificent spectacle of continents rising gradually or suddenly from their parent waves is calculated to impress upon even the least attentive mind a sentiment of respect for the sublime subjects of geological enquiry. It is hardly possible to avoid looking around for indications of the time required for the subaqueous production of such a mass of strata, and for their subsequent elevation. Before involving ourselves in the difficulties which beset the research into the source and prior condition of the materials of stratified rocks, we may proceed to examine what evidence they afford of their relative antiquity, and what inferences they will justify as to the absolute length of time consumed in their production.

As the antiquary, who is required to determine the dates of the successive piles of a ruined city, judges by the style and sculpture and state of preservation of the fragments, so the geologists, by deciphering the characters impressed by nature on the rocks, is able to arrange them according to successive eras. If the antiquary be unable to refer his discoveries to historical records, and thus to learn the absolute intervals from one event to another, he is reduced to nearly the same state as the geologist, who desires to ascertain the number of years or cycles of years which elapsed during the formation of the crust of the earth. In both cases certain assumptions must be made before even plausible conjectures can be hazarded. Geology, however, would gain little by even a correct *conjecture* on this subject; and though undoubtedly a vast variety of facts observable in the earth are clearly indicative of definite time, these have been far too little enquired into to give us at present the slightest hope of changing the vague periods of geology into exact terms of years. The following investigation is therefore not intended to accomplish more than to produce a conviction that a long succession of time elapsed during the construction of the visible crust of the globe.

In the production of strata, which are composed of fragmented materials, of any kind, mechanical forces were exerted; for it is chiefly by the influence of waves and currents that sandy and argillaceous matter is brought to the stratified form. When, therefore, we see even a single sandstone rock composed of some hundreds of regular layers of sand and mica, and compare this with deposits from modern rivers or the sea, we shall feel assured that, in assigning to the accumulation of this rock a considerable space of time, we are proceeding in a just spirit of philosophy.

If we consider the common case of alternating clays and sandstones, both of which are mechanical deposits from water, but produced under different circumstances, perhaps brought in different directions, the indications of the progress of time become perhaps more clear and satisfactory.

It is very common to find deposits of limestone, apparently produced by chemical decompositions, lying in frequent alternation with sandstones and clays; and, in such a case, by enquiring of the actual system of nature, we receive an answer that such changes of the mode of action in a given place imply cessations and renewals of chemical and mechanical operations which require time.

By reviewing in this manner the whole series of strata, amounting locally to some miles in thickness, and considering the accumulation of each bed, the alternation of beds of different kinds, the excitement, duration, suspension, and resuscitation of mechanical and chemical agencies, we shall be strongly impressed with the folly of setting narrow bounds to the time employed in these operations.

Some stratified rocks are composed of fragments of various kinds, united by a general cement of a different nature. These are called brecciated or conglomerate rocks, according as the fragments are angular, or rounded by attrition in water. Here there is proof that before the production of one stratum a previously stratified rock had been consolidated, partially broken up, its fragments agitated in water, and then redeposited. In some cases, conglomerate rocks have been *again* broken up, and their fragments submitted to a second process of attrition and reaggregation.

There is another class of phenomena which speaks a language on this subject that can hardly be misunderstood. We are well assured of the length of time required for the growth and maturity of organic beings; when, therefore, a single bed of stone, only a few inches thick, is found to contain a given species of shell, in every variety of magnitude, from the embryo to the full-grown or aged individual, all the specimens having evidently been enveloped quietly on the bed of the sea, and no bed either above or below for 100 yards or more containing any such shells, the conclusion seems certain that even for the accumulation of this one bed of stone the lifetime of that species of molluscous animal was required. Such a case occurs in the coal district of Yorkshire, where a bed of shale only a few inches thick, but extending for many miles, contains *Ammonites Listeri* in every stage of its growth;

but that shell does not occur above or below, through a great thickness of strata.

In some cases whole rocks are literally composed of zoophytes, so as to resemble a modern coral reef, or of shells of many kinds. The extensive strata of coal are derived entirely from immense accumulations of vegetables, and sometimes no less than fifty consecutively deposited strata of this kind extended over a hundred square miles and more.

Strata which contain certain tribes of organic remains alternate with others which inclose none, or quite different races. Strata full of marine exuviæ are separated by others full of trees swept down from the land; and thus we are furnished with evidence of intermitting energy among the agents of ancient nature.

It seems unnecessary to accumulate more evidence in order to obtain an unanimous verdict from all impartial readers that the length of time occupied in the production of the strata, some miles in thickness, which exhibit all this variety of events, was really very great. Whether it may hereafter be found susceptible of some rude approximation will depend upon the knowledge we may be able to gain of the rate of stratification and consolidation, and of the length of life of some of the fossil races. Is this expectation wholly chimerical?

Perhaps one of the best and most interesting cases for determination of elapsed time is that of the English coal formation where it is thickest. The sediments of this formation in South Wales, 12,000 feet thick, are of a nature to be clearly understood as the result of a long series of river currents and inundations depositing mud along a flat estuarine coast. Calculating by the average effect of a great river of the present period like the Ganges, this mass of sediments would require at least 333,000 years for its accumulation. But in this period were many pauses; and at each a growth of some land plants on the spot, and the accretion of others by short drifting. Supposing all the plants to have grown on the spot, they would have required in addition 244,800 years. On the whole, then, I have concluded that half a million of years may probably have elapsed during the growth of the precious deposits of the coal formation.*

* Life on the Earth, under the section of 'Antiquity of the Earth.' 1860.

CHAPTER VII.

SUCCESSION OF ROCKS IN THE CRUST OF THE GLOBE.

GRANITE.

ROCKS of the granitic character, containing crystallised orthoclase in combination with quartz and mica (granite), or with quartz and hornblende (syenite), are very extensively found under the lowest of the strata which appear in any given large district of country. Granite is found in this manner in many parts of the Highlands, in Arran, under Skiddaw, in Dartmoor and Cornwall, the Mourne Mountains, Wicklow, &c. Syenite is similarly recognised in Malvern, Charnwood Forest, and Cumberland.

Rocks of this kind constitute, in fact, as far as we can tell, the general basis of all the known parts of what is called the 'Crust of the Earth.' They are believed to have been consolidated by crystallisation from a fluid mass. Immediately above them lie stratified masses, which in several instances have the same mineral composition, and differ only by their structure.

This structure is admitted to be in many examples derived from distribution of the materials in water; their actual state of consolidation being due to the pervading effect of heat, which seems to have always recemented the particles, sometimes to have recrystallised them, and generated amongst them other minerals — as garnet. By a further action of heat, it is conceivable that these rocks, which seem to have been derived from granite, would be again converted to that rock. This is supposed by Marshall to have occurred in Cumberland, and by Haughton and Scott in some parts of Ireland.

Granitic rocks may be regarded as a fundamental product of fusion, in every age, from which by enormous mechanical and chemical disintegration, and the action of water, were derived the ingredients of the stratified rocks of later date; first, a fundamental gneissic series, which again yielded materials for later deposits in water. It is, however, not easy to assure ourselves of good examples of such primæval granites and fundamental gneiss; for in most cases the age of the granites, if dated from their consolidation, is not so great as their low position might seem to indicate. Indeed, from the once melted granite, the lowest we can reach, ramifications rise and pass off in many places to fill fissures in the strata above. From this it follows that, in such cases, the subjacent igneous rock has been in fusion since the deposition of the strata which it penetrates. As examples of granitic and syenitic rocks underlying the oldest strata of the district, and not sending veins into cracks and fissures of those strata, the best instances known to me are in the range of the Malvern Hills, the oldest stratum being a fucoidal sandstone below shales with *Oleni*, and in Charnwood Forest, where the slates are probably of Cambrian age. In Scotland, Cumberland, Devonshire, and Ireland, the granites send veins into the adjoining strata of whatever age.

Granite, considered in regard to its composition, may be described as essentially a mass of crystallised orthoclase felspar, with variable admixtures of crystallised mica, and more or less quartz, part of which is sometimes perfectly crystallised, and part appears to fill spaces left between the felspathic masses. Felspar mixed with quartz only may be termed binary granite. When the quartz has a particular arrangement, and is included in the felspar, it is called pegmatite, or graphic granite. In ordinary granite of three elements, the felspar varies in tint from nearly white or greenish to red; and in size from mere grains to lamellar masses six inches across. Granites are called porphyritic when they contain large crystals of orthoclase scattered in the general mass. These large crystals of felspar usually include grains or larger portions of quartz and mica, and they are in some cases arranged parallel to the exterior faces of the felspathic crystal. When cavities occur in granite, the constituent minerals are found crystallised on the sides of the hollow. Thus quartz, orthoclase, mica, topaz, and other minerals may be obtained in the granites of Mourne Mountain and Goatfell.

The mica is of various colours and composition, not always uniform even in the same locality, but easily recognised by its peculiar lamellar, generally six-sided plates, and high lustre.

The quartz crystals in some granites (as at Rubieslaw near Aberdeen) contain regular or irregular cavities, in which small quantities of water have been detected by Mr. Sorby, who has, by studying the circumstances, arrived at probable conclusions as to the pressure and temperature under which these granites were formed. Thus, in some cases, the depth at which granite was formed becomes a matter of reasonable inference. In the case of the granites of Cornwall, 40,000 feet of superincumbent rock, and in those of the Highlands 69,000 feet, represent the pressures under which they were consolidated — from eight to fourteen miles. By so much, then, they may have been subsequently raised, and uncovered.*

* Journal of the Geological Society.

The granite of Cornwall is often traversed by curvilinear surfaces, making broad floors; and by vertical or inclined joints, which exhibit some kind of symmetry distinct from crystalline structure, probably due to pressure and tension. Veins of finer or of coarser grain are not unfrequent; some being merely peculiar arrangements of the ingredients, as at Dalkey near Dublin; others really filling fissures, as at Rubieslaw, near Aberdeen.

Veins of granite, as they pass into the substance of the strata in contact with them, grow finer in the grain, as they penetrate deeper into the rocks — a circumstance usually ascribed to more rapid consolidation from a liquid or pasty condition.

METAMORPHIC STRATA OF GNEISS, MICA SCHIST, QUARTZITE, AND LIMESTONE.

It is sometimes clearly seen that strata, of argillaceous composition, where they come in contact with igneous rocks, have themselves undergone fusion and rearrangement of their particles, so that garnets and other minerals, not elsewhere apparent in them, are produced near the surfaces of contact, and the stratification, everywhere else obvious, is there destroyed or complicated with some new structure, such as prismatisation, or other forms which heat is known to produce in rocks. Sandstone under similar circumstances becomes much indurated, the grains cohere, and in some cases acquire—we might say resume—crystalline faces. Limestone becomes granular, in fact, a mass of crystals, like statuary marble. Stratified rocks thus changed in their texture and structure are generally said to be in a *metamorphic* state, and many geologists regard the whole or a great part of the most ancient strata as in this condition. That this opinion is to *some extent* true cannot be doubted; it is the natural consequence of such strata being buried by the accumulation of others over them to a depth of some miles: thus they have been brought under the influence of the heated interior of the globe. But that these strata, such as mica slate, gneiss, &c., are to be regarded, *everywhere*, as derived by metamorphism from *ordinary sandstones and shales*, and that their deficiency of organic remains is to be regarded as one of the effects of this metamorphism, is not proved. On the contrary, it is certain that among these strata in Norway and Scotland are conglomeritic portions, containing *fragments* and rolled crystals; others have preserved the oblique lamination due to original drifting of the grains which compose them (Sorby); and in some of the strata above them, which have not undergone metamorphism to such an extent as to destroy organic remains, these are, nevertheless, very rare, comprised within very few genera and species, and seem to be finally lost in going downwards, as we might expect them to be on approaching the earliest dawn of created life.

Some of the flaggy gneiss and mica schist of the Highlands is regarded by Murchison as overlying the fossiliferous limestone and sandstone of Durness and Assynt; to be, in fact, coeval with lower Silurian rocks. Below these limestones and sandstones are conglomerate, supposed to be of Cambrian date, and below these again occurs the remarkable gneiss rocks of the Hebrides, which are often composed distinctly of little else than hornblende, crystallised in laminæ. This fundamental gneiss, perhaps the oldest rock of stratified origin in these islands, is compared by Murchison with the Laurentian rocks, which are the oldest in Canada.

The narrow bands of rocks composing this series in the vicinity of Dublin, are probably altered clay slates and sandstones of lower Silurian age, and the same may be the case with the whole range of metamorphic beds which adjoin the granite of Leinster. 'Whenever the granite comes to the surface, a belt of slates surrounding it is converted into mica schist with, in a few places, beds of perfect gneiss; crystals of garnet, schorl, andalusite, and staurolite make their appearance in these altered slates in greater and greater abundance as they approach the granite.' *

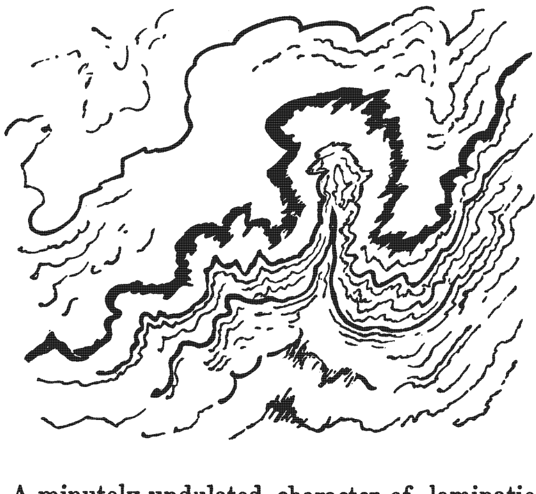
In Cumberland, between Skiddaw and Saddle-back, gneiss and mica schist, very limited in extent, appear in contact with granite, which sends veins through them. Above these rocks are hornblendic and chiastolitic slates, growing more and more argillaceous as we recede from the granite, and finally appearing as ordinary slate, with graptolites and other fossils. In Cornwall, also, slate rocks become indistinctly gneissose, in contact with granite, which throws off many veins. No such changes occur on the west side of the Malvern Hills, where Silurian strata touch the granitic and syenitic rocks, but admit no veins there; yet in the ridge and on the east side, in some places, rocks which were caught up in the igneous mass, or covered by it when it was fluid, are distinctly converted to gneiss. Thus, in this one narrow ridge we have gneiss made by conversion of strata, invaded by the granite and syenite; and also later Silurian strata deposited against those rocks after they were cooled and consolidated.

The thickness of these rocks sometimes amount to many thousand feet; but it is doubtful if the estimates which assign several miles to them in the Highlands can be relied on, because of the singular structure which characterises them and is supposed to represent stratification.

* Jukes's *Manual of Geology*, 2nd edit. p. 276.

This structure is called foliation; and it may at once be understood by regarding it as a series of lárgely waved and minutely crumpled and puckered surfaces, sometimes accurately parallel, always to a certain degree conformed to one another. Something like it is occasionally seen in pasty compounds which grow stiff under irregular pressures.

DIA. 7.



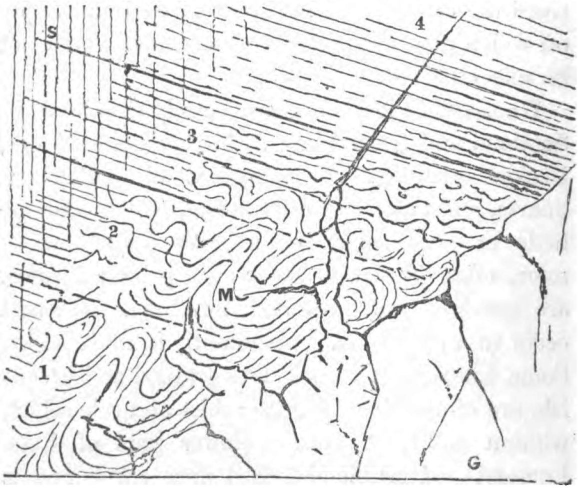
A minutely undulated character of lamination belongs to the system: it is least evident in the limestones, and most striking in the fine grained varieties of schist. Contortions in the mica schists appear most frequently along and near to the axes of anticlinals, as at the head of Loch Lomond. The laminæ are sometimes separated by small irregular cavities, lined with crystallised quartz and mica. How much of these curious laminations is due to original settling from agitated water, and how much to the metamorphic actions which have probably generated garnets, and lined the cavities already alluded to, is a subject on which new and critical observation would not be misemployed.

Gneiss and mica schist are largely developed in Scotland and Ireland, not so in England or Wales. Besides true gneiss, composed of orthoclase, quartz, and mica, and mica schist, which contains little or no felspar, but a great abundance of mica, often in silvery sheets, the principal rocks are quartzite and granular limestone. Garnets occur in all these, very abundantly in mica schist. Some kinds of this rock, fine grained and greenish, are often called chlorite schist and talc schist, without sufficient reason (lower part of Loch Lomond). Hornblende schist does occur, and is regarded as a sort of gneiss by M'Culloch.

Serpentine, chiefly in veins, is a frequent companion of these rocks, especially of the light-coloured limestones, which often also contain tremolite (Glentilt). Augite occurs in the limestone of Tiree.

It is generally found that those schists which most resemble clay slate lie in the upper part of the series; the most felspathic portions lie toward the bottom; the limestones and quartzite occur in detached masses along certain surfaces of deposition on the mica schist and gneiss.

DIA. 8.



1 Hebridean. 2 Cambrian. 3 Cambro-Silurian. 4 Silurian.
G. Granite. M. Metamorphic. S. Stratified.

The above diagram will sufficiently explain the present views of the position of these metamorphic rocks, and show clearly at what point we begin to feel ourselves in possession of a strictly successive series of stratified rocks, data for a real history and a scale of chronology, though not capable of expression in years or centuries, or other terms depending on the motion of the earth round the sun.

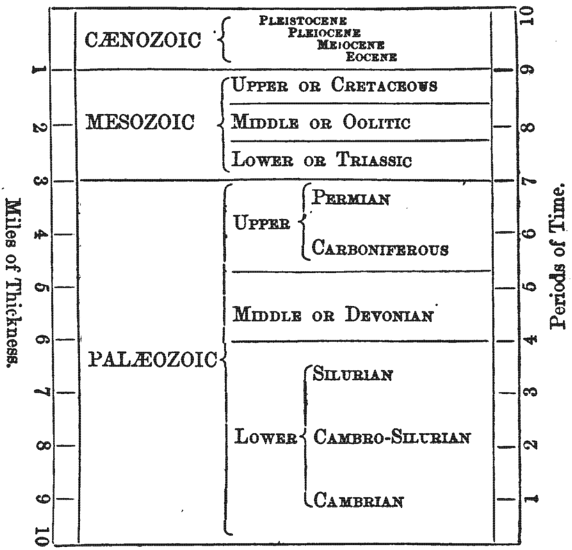
In this diagram G is granite, situated under all the deposited rocks of the district, and yielding veins into the lowest (No. 1), which may be taken to represent the hornblendic gneiss of the Hebrides, which has undergone change by heat, but in what state it was originally aggregated is not known.

No. 2 may represent the lowest rocks in Anglesea, which are rude quartzose and micaceous masses, presumed to belong to the Cambrian system of strata. The strata marked 3 are the Upper Cambrian of Sedgwick, Lower Silurian of Murchison: they are altered near the granite of Wicklow, but retain much of their original character at a distance from it. No. 4, Upper Silurian strata of Malvern, not metamorphic.

From this it will be evident that gneiss and mica schist, with their accompaniments, are, like granite, characteristic effects of particular physical conditions, not products of one definite period. Some appear older than any known strata, as, in the mountain border of Bohemia, earlier than any known forms of life; others are the result of actions which happened at different epochs in the geological history which is founded on the series of unchanged deposits from water.

In the following diagram the series of deposits from water is classed in three grand divisions, which are again subdivided, according to the nomenclature employed in this treatise. A scale of ten parts (which may be regarded as miles) placed by the side will enable the reader to judge of their relative thicknesses, but it is not easy, even in the British Islands, to assign a fair average thickness to each. The maximum thickness given by Prof. Ramsay is about fourteen miles. The same scale read upwards may be supposed to represent the lapse of time, but the unit of value is unknown.

DIA. 9.



The following table of British fossiliferous strata, subdivided so as to show the groups usually referred to by name, has been drawn up as a convenient index to the descriptions of the several rocks which follow:—

Cænozoic strata, containing some recent species and many recent genera of plants and animals. Pachydermatous mammals frequent. Remains of man confined to the latest period.

PLEISTOCENE . .	Postglacial [1]
	Glacial
	Preglacial [2]
PLEIOCENE . . .	Crag, upper
	,, lower
MEIOCENE (?) . .	(Mull. and Bovey)
EOCENE . . .	Vectian [3]
	Bagshot
	London
	Plastic

Mesozoic strata, containing no living species of plant or animal,* but many living genera of invertebrate animals, marine reptiles, and Marsupial mammalia.

UPPER MESOZOIC	CHALK	Chalk, upper
		,, lower
	GREENSAND	Upper green
		Gault
		Lower green

[1] [2] Terms proposed in my work on the rivers, mountains, and sea-coast of Yorkshire, 1853.

[3] Name now proposed for the Fluvio-marine beds of the Isle of Wight.

* Foraminifera must be excepted. Possibly also one brachiopod (Tereb. striatula of the chalk) may be undistinguishable from a recent form.

MIDDLE MESOZOIC	WEALDEN *	Weald
		Hastings
		Purbeck
	UPPER OOLITE	Portland
		Kimmeridge
	MIDDLE OOLITE	Calc grit, upper
		Coralline oolite
		Calc grit, lower
		Oxford clay
		Kelloway rock
	LOWER OOLITE	Cornbrash
		Forest marble
		Great oolite
		Fuller's earth
		Inferior oolite
		Sand
	LIAS	Lias shale, upper
		Marlstone
		Lias shale, middle
		Lias limestone
		Lias shale, lower
LOWER MESOZOIC	TRIAS	Red marls
		Red sandstones
		Conglomerates

Palæozoic strata, containing very few living genera. Trilobites are limited to these strata: no fishes have occurred below the Ludlow rocks; no reptiles below the carboniferous; no mammalia in any part of the Palæozoic series.

UPPER PALÆOZOIC	PERMIAN	Limestone
		Red clays
		Limestone
		Marl slate
		Red sandstone
	CARBONIFEROUS	Coal
		Millstone grit
		Yoredale rocks
		Scar limestone
		Alternations
MIDDLE PALÆOZOIC	DEVONIAN	Middle
		Lower

* By several writers the Wealden beds are regarded as a cretaceous group; and Purbeck beds are classed with the oolites.

- LOWER PALÆOZOIC
  - SILURIAN
    - UPPER
      - Ledbury
      - Ludlow
      - Wenlock
      - Mayhill
    - LOWER
      - Llandovery
      - Caradoc
      - Llandeilo
  - CAMBRIAN
    - Tremadoc
    - Ffestiniog
    - Barmouth

Metamorphic rocks and granites in some cases derived from the Lower Palæozoics.

LOWER PALÆOZOIC STRATA.

The classification of these rocks, which enclose the most ancient remains of life yet discovered, has been completed for many parts of the world on the pattern set by Sedgwick and Murchison, whose labours date from 1831. So many additions have been made to the first catalogues of Silurian fossils given by Murchison, that all the palæontologists of Europe and America have been fully tasked to keep pace with the discoveries. Among them all no one is so eminent as M. Barrande, the great investigator of the Bohemian basin.

These investigations have established three main zones of life; which are distinct enough on a comparison of them in full, but graduate into one another by many analogies, and several generic affinities.

These three main zones are most fully exhibited in the far separated Tremadoc, Caradoc, and Wenlock formations, to each of which some strata both above and below may be joined with convenience, though sometimes in one district and sometimes in another nature refuses to be bound by the chain of classification.

The three general groups here employed have been already adopted. The upper and middle divisions constitute the original 'Silurian system' of Murchison; the middle and lower are included in the 'Cambrian' series of Sedgwick; the lower one nearly corresponds to the primordial zone of Barrande, with the addition of part of the Tremadoc beds above and the Barmouth beds below.

Murchison now includes the Tremadoc and Ffestiniog beds in the Lower Silurian. The whole, however, is one great natural system of associated strata and successive life, across which no lines of division can be drawn which are very satisfactory except for small tracts of country. By help of the organic remains, however, the classification above given may be made to fit the sections in other parts of the British Islands, in Bohemia, Scandinavia, and North America.

The thickness of these strata varies from district to district. In the following diagram an attempt is made to give something like an average to each, on the supposition that the whole series may be taken at four miles—that being, however, in the opinion of the government surveyors actually exceeded in the Longmynd by the lowest group alone.

LOWER PALÆOZOIC PERIOD.

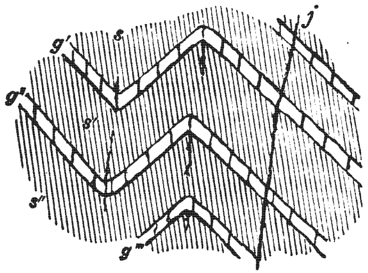
				Average thickness in Feet
SILURIAN	Upper	Ledbury	Arenaceous	250
		Ludlow	Arenaceous, Calcareous, Argillaceous	1,000
		Wenlock	Calcareous, Argillaceous	1,250
		Mayhill	Arenaceous	1,250
	Lower	Llandovery	Arenaceous	
		Caradoc	Arenaceous, Calcareous	2,500
		Llandeilo	Calcareous, Argillaceous	2,500
CAMBRIAN		Tremadoc	Argillaceous	1,500
		Ffestiniog	Argillaceous	2,500
		Barmouth	Argillaceous and Arenaceous	7,500

Mineral Characters. The rocks of this, the most ancient series of strata which has escaped metamorphosis, have much analogy with ordinary sandstones, limestones, and indurated clays. They contain no coal, and but very slight traces of ironstone or pyrites, except in metalliferous veins, or near thermogenous rocks. Gypsum, flint, and red oxide of iron are but rarely and locally met with.

The sandstones are remarkably hard, and approach to quartzite in the Barmouth series; at St. David's and some other places they are of a purple tint. Most of the Lower Silurian sandstones are occasionally conglomeritic — those of the Upper Silurians are softer and pass into arenaceous shales and flagstones.

The argillaceous rocks usually hold arenaceous and calcareous particles, and are seldom to be regarded as clays. Shales of a decided character occur in the Malvern Hills, of the same age probably as the laminated beds of the Ffestiniog and Tremadoc series, which, however, exhibit also slaty cleavage. This characteristic structure, common in the Cambrian and also in the Lower Silurian rocks, may be described as a natural fissility, parallel to one certain plane, which almost always differs from the laminæ of deposition. Cleavage is most perfect in thick masses of fine-grained argillaceous rock; but even very coarse-grained rocks in the region of Snowdonia are rudely fissile. The cleavage through great part of North Wales is limited in direction between N. 28° E. and N. 35° E. Where the beds of argillaceous rocks are thin and dissimilar (as at Aberystwith), the cleavage structure pervades the fine-grained beds only; in other cases cleavage may be seen to traverse coarser and finer beds, the former more transversely, the latter more obliquely; the two sets of cleavage planes often gradually passing into one another by a short curvature.

DIA. 10.



A case of cleavage planes occurring in fine-grained beds of argillaceous rock, s, s', s'', but not in the sandstone beds g, g', g'', g'''. The cleavage planes dip 85° from the horizontal, and all in the same direction, though the beds are contorted. A joint, j, crosses the fine-grained beds s, s', s'', at an angle of 57°, and the coarse-grained beds at 77°, which is the angle of inclination of many lesser joints in g, g', on the plane of the bed; these lesser joints never entering the beds s, s', s'', as the cleavage of these beds never enters g, g', g''. This interesting case occurs at Aberystwith.

It is frequently observed that the planes of cleavage and great axes of stratification have the same strike (i. e. coincide in a horizontal line), but the cleavage is often more highly inclined than the strata, so as generally to approach a vertical position. If strata are vertical, cleavage may be inclined. If the strata are curved, cleavage may be in planes. The effect of lateral pressure as a concomitant of cleavage, and directed across its planes, is evident in many ways; by the folding of the surfaces of deposition, in wrinkles parallel to the edges of the cleavage laminæ, and by the distortion of the figures of organic remains. Pressure, heat, and electrical currents have been cited as the causes of cleavage. One thing is certain — the particles of the slate have undergone displacement with respect to their *mutual distances*, and their *mutual angular positions*, and they have become fixed in these new relations. Many rocks associated with slates do not admit of cleavage; but throughout all these ancient deposits the joints present a great degree of local symmetry, and, when they have been sufficiently studied, will probably combine, with the constancy of the direction of cleavage, to indicate some general geometrical relations of great importance in physical geology. Wales, Cumberland, Yorkshire, Charnwood Forest, Wicklow, Wexford, the Lammermuir Hills and Highlands, exhibit these slaty rocks very fully.

The limestones which occur in the Ludlow rocks (dividing that series into upper and lower), and in the Wenlock, Caradoc, and Llandeilo beds, are for the most part not only filled with zoophytes, crinoids, shells, and trilobites, but are almost wholly composed of these remains, in all cases except the thin-bedded and somewhat argillaceous varieties of Llandeilo. Pisolitic structure is rarely met with in Wenlock limestone at Malvern. It has been found almost impracticable to obtain a slab of Silurian limestone large enough and compact enough to be polished for a marble shaft.

Thermogenous rocks are associated with the strata of the Cambrian and Silurian series, both by interposed masses, and by intrusive dykes. Interposed porphyritic and greenstone masses occur in Cader Idris, Aran Mowddy, Arenig, and Snowdon—chiefly in Cambrian and Lower Silurian strata; and the same strata are divided by dykes, sometimes of great magnitude. In the Malvern Hills syenite and granite are in contact both with the Lower and Upper Silurians. In Cumberland and Westmoreland, thermogenous rocks abound, both parallel to and across the strata, which are greatly altered near them.

Mineral veins, some yielding argentiferous lead ore, others gold, others oxide of iron, others sulphide of copper, occur in the lower parts of the series in Wales and Cumberland.

Organic remains. The life of this period, perhaps the earliest life on the globe, begins with a very few forms in the Barmouth group. They consist of tracks of an annellid and part of a trilobite from the Longmynd in Shropshire; and of a marine plant (Oldhamia) and burrowing annellid (Histioderma) from Brayhead in the county of Wicklow. In the Ffestiniog beds above, more trilobites and other crustacea appear, and the earliest brachiopod, lingula. The series of trilobites is merely enlarged in the Tremadoc beds—orthis is added to the brachiopoda—polyzoa and pteropoda appear.

The full series of Cambrian life, including the fossils of Bray, the Primordial zone of Barrande, and the Tremadoc groups, stands thus*:—

	Lowest Zone	Middle Zone	Upper Zone
Marine plants	*	*	*
(Actinozoa) none	—	—	—
Echinodermata	—	*	*
Annellida	*	*	*
Crustacea	*	*	*
Polyzoa	—	*	*
Brachiopoda	—	*	*
(Monomyaria) none . . .	—	—	—
(Dimyaria) none . . .	—	—	—
Pteropoda	—	*	*
Gasteropoda	—	*	—
(Heteropoda) none . . .	—	—	—
Cephalopoda	—	*	*

* In the Primordial zone of Bohemia, believed to correspond with this division of the Cambrians, Barrande finds crinoidea, but no pteropod and no lingula, while in the north-west of Spain a gasteropod genus is met with, which also occurs in beds of equal age in North America, according to Marcou.

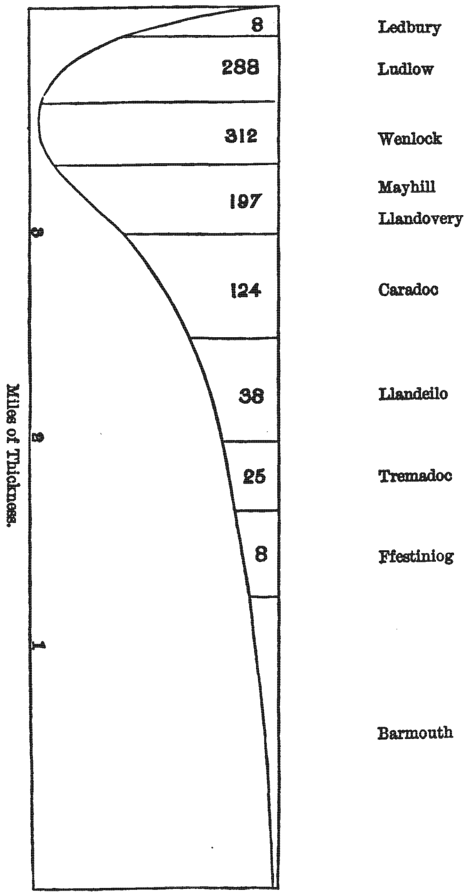
The absence of amorphozoa, foraminifera, actinozoa, monomyaria, dimyaria, and heteropoda is remarkable. These classes are added in the great group of Lower Silurians, next in order of time, and thus, excepting insecta and some other articulata, the whole series of invertebral classes is complete in the Lower Palæozoic strata. But no vertebrata appear until we reach the upper divisions of the Upper Silurians, and there only fishes of small size have been recognised.

In respect of number the fossils are distributed in the Lower Palæozoic strata in a remarkable and systematic manner, which the diagram (p. 158) will explain.

The stratified masses being represented of their relative thickness, in succession vertically, the relative richness in variety of life in the several deposits is expressed by the numerals placed on the left, and by the distance of the curve from the vertical.

If 312 species could be collected from 500 feet of Wenlock rocks in a certain space of country, 124 could be collected from the Caradoc, under the same conditions. But as the Caradoc is, on the average, twice as thick as the Wenlock, it is found to yield, in fact, quite as many species when all parts of its thickness are equally searched. The numbers given appear, however, to represent fairly the relative richness of life of the deposits, and they show the remarkable growth of this

DIA. 11.


8
Ledbury
288
Ludlow
312
Wenlock
197
Mayhill
Llandovery
3
124
Caradoc
38
Llandeilo
2
25
Tremadoc
8
Ffestiniog
1
Barmouth
Miles of Thickness.

richness from a minimum in the Barmouth beds, to maximum in Wenlock rocks, after which the whole series rapidly dies out (at least on the border of Wales), and is extinct in the uppermost Silurians of Ledbury.

The following general summary of the organic remains of the Lower Palæozoic strata is compiled from the large table of species given in Murchison's 'Siluria.'

Plants, 13; species mostly marine.

Amorphozoa, 6; in the middle parts of the series of strata from Caradoc to Wenlock.

Actinozoa, 91; chiefly in Caradoc, Llandovery, and Wenlock beds—a few in Llandeilo and Ludlow beds.

Echinodermata, 76; from Caradoc to Ludlow beds.

Annellida, 34; distributed through the whole series.

Crustacea, 185; distributed through the series, but specially abundant in Caradoc beds. We may specify as characteristic of some of the divisions the following genera:

Eurypterus and Pterygotus belong mostly to the Ludlow beds; Calymene and Phacops are frequent in Wenlock rocks; Encrinurus in Mayhill rocks; Trinucleus in Caradoc; Ogygia in Llandeilo; Angelina in Tremadoc; and Olenus in Ffestiniog; only one imperfect trilobite yet found in the Barmouth group.

Polyzoa, 65; from Llandeilo to Ludlow rocks, but most abundant in Caradoc.

Brachiopoda, 177; which are distributed as follows:—

Ledbury beds, none; Ludlow, 30; Wenlock, 79; Mayhill and Llandovery, 69; Caradoc, 67; Llandeilo, 18; beds below, 3; a remarkable illustration of the growth to a maximum, and decline to extinction, which has been shown to affect all the fossils of this ancient series of strata.

Monomyaria, 30; chiefly in Upper Silurians; rare below Caradoc; none above Ludlow.

Dimyaria, 86; rare below Caradoc, none above Ludlow beds.

Gasteropoda, 84; rare below Caradoc, none above Ludlow beds.

Heteropoda, 14; rare below Caradoc, none above Ludlow beds.

Pteropoda, 18; rare below Caradoc, none above Ludlow beds.

Cephalopoda, 69; rare below Caradoc, none above Ludlow beds.

Thus in a general sense the Mollusca seem to have been plentiful only in the middle part of the Lower Silurian period, and to have died out before its close, about the time when fishes came in; of which 12 small species occur in the Upper Ludlow rocks, but not below them.

Of the fossils in this series of strata few acquire great size, except the crustacea, as isotelus, eurypterus, and pterygotus. Bellerophon, orthoceras, and lituites, are of full, but not inordinate size. Regarded as polyzoa, some graptolites are large, and so are a few of the actinozoa and echinodermata.

Localities. The best district for studying the lower groups of these rocks is about Barmouth and Tremadoc; the Middle or Lower Silurian groups are well seen about Snowdon, Bala, Church Stretton, Builth, Llandovery, and Llandeilo; the pper groups in the Malvern and Abberley Hills, Usk, Woolhope Forest, and Ludlow. For the upper groups, Dudley and Kirkby Lonsdale in

England, and Ferriter's Cove in the SW. of Ireland, may be quoted; in Ireland, Tyrone, in Scotland the Lammermuir Hills, and in England the head of Windermere may be examined for the middle group.

We have now passed through the Lower Palæozoic series. Before entering another great division of the old strata, it may be well to call attention to a few main points in their history. First, it may be observed that they are all of marine origin; hitherto no freshwater remains, few land-plants, no land animals have been found in the series. Secondly, the forms of life, viewed on a large scale, at first extremely few and rare, become more numerous as we ascend, and appear specially plentiful and varied in the parallel of Bala and Llandeilo, and in that of Wenlock and Dudley; the lower development constituting the grand Cambro-Silurian type, the upper one being truly and exclusively Silurian: very strong analogies, however, unite these groups into one great series of life. Thirdly, vertebral life appears in the upper part of the Silurians. Looking at the whole series of rocks, we remark above the micaceous systems which rest on the granitic skeleton, a vast thickness of sediments, mostly tinted by protoxide of iron, some deposited in tranquillity, others with local disturbance; alternately with these, thick aggregates of limestone, the fruit of chemical reagencies and vital secretions in sea-water; and bands of porphyry and greenstone, which were poured from submarine volcanic vents, and spread out on the old sea bed. (Snowdonia, Sca fell, &c.) In conformity with this indication of the extensive effects of internal heat, we find the metamorphism of the slaty rocks, and the general induration of the entire series,—qualities which are, on the whole, reduced as we ascend in the strata.

During the deposition of these rocks some cases of nonconformity appear, as pointed out by the geological survey of Wales, proofs of local disturbance of the sea-bed, through volcanic excitement, of which the porphyries and greenstones are indications. After the completion of the whole series, more general movements happened, especially in the districts of the English lakes, the Isle of Man, and the South of Scotland. For here the Silurian sea-bed was elevated into mountainous ranges; land was apparent; its shores were worn by the breakers; valleys were formed in it, and in these valleys, at a later time, were deposited the red sandstones and marls of the next great group of strata, to which we at once proceed.

MIDDLE PALÆOZOIC STRATA.

Which have only taken this name in the scale of English rocks since the investigations of Lonsdale, and the field-work of Murchison, Sedgwick, and others, have demonstrated in Devonshire the true place of a large series of slaty, sandy, conglomeritic, and calcareous rocks, locally rich in fossils, to be, in a general sense, the same as that of the old red sandstone of Wales. Entirely different physical conditions must have accompanied the formation of these two very different types —the Devonian being by far the most developed, representing, probably, *a longer series of geological time,* and presenting no small amount of analogies, on the one hand, to the Silurians below, and on the other, still stronger relationship to the mountain limestone, with which its strata are usually conformed, and to which it was formerly joined by Conybeare.

The old *Red Sandstone* type may be first noticed, having a thickness of three to eight thousand feet on the course of the Wye, the Usk, and the Towy, which may be regarded as typical districts. Here the series consists of three parts; viz., quartzose conglomerates, and sandstones above; concretionary limestones in red and blue clays in the middle; and similar clays, sandstones, and flagstones below. The limestones of this series are little known in the North of England and in Scotland. Around the Cumbrian, Lammermuir, and Grampian mountains red conglomerates abound, and contain fragments of the neighbouring older rocks. In the south-west of Ireland this group of rocks is extensive.

Organic Remains. In the lowest beds round Woolhope Forest and May Hill some traces of land plants occurred to the author.* Animal remains are nowhere numerous in England; but at Gamrie, and some other localities in Morayshire and Cromarty, and in Caithness and the Orkneys, in grey beds, fishes of singular forms—Cephalaspis, Pterichthys, Coccosteus, &c.—have been described by Agassiz, Miller,† and others. Only a few of these fishes have been found in Herefordshire and Caermarthenshire by Murchison, Symonds, and others. In Kilkenny, Ireland, bivalve shells, resembling the fresh-water genus Anodon, occur with Ferns and other land plants.

In strong contrast with this peroxidated group and poor fauna is the *Devonian type*, which was not formed round detached ridges of lofty Silurian land, but rather in oceanic valleys subject to varying currents.

In North Devon, De la Beche describes a series several thousand feet thick, of various rocks, mostly subject to slaty cleavage, which lie in the following order, dipping mostly to the south.

* Mem. Geol. Survey, vol. ii. pt. i. See also Strickland, in Geol. Proceedings, 1852.

† The Old Red Sandstone.

Upper or Pilton Group. Flaggy, shaly, and calcareous beds, yielding land plants, marine shells, corals, trilobites, &c.

Morthoe Group. Fine gray or green slates, with red and variously coloured sandstones—neither fossiliferous.

Ilfracombe Group. Gray argillaceous slates and limestone bands, with some plants, several corals, and a few Brachiopoda.

Martinhoe Group. Red, brown, gray, and claret-coloured grits and slates, without fossils.

Linton Group. Gray slaty rocks, perhaps 1,000 feet thick; in most parts rich in corals and Brachiopoda, and containing a few Gasteropoda and Cephalopoda.

Lowest or Foreland Group. Red and gray grit rocks, without fossils.

In South Devon the series is of great thickness, and may be observed near Plymouth, with a great southward dip, as under.

Upper group of Boveysand Bay. Blue and gray shales, with thin calcareous bands, partly fossiliferous.

Red and gray grits and purple schists, with fossils in bands, and ironstone layers and quartz laminæ, crumpled by cleavage.

Carbonaceous and gritty beds, and schists with fossils, and some nodules of limestone.

Blue and gray schists, and nodular limestones, with layers of fossils.

Laminated schists, and layers of "ash," or trappean fragments.

The Plymouth limestone—a thick but very variable mass, so rich in corals of the greatest beauty as to be almost a reef. Many Brachiopoda, some Gasteropoda and Cephalopoda.

Lower group—thick purple slaty rocks, without fossils.

Organic Remains. In these Devonian groups we have *land plants* in and above the limestone of Ilfracombe; Actinozoa in the gray parts of nearly the whole series, and specially abundant in the Plymouth limestones; their affinity to the Silurian life is indicated by Heliopora, Cyathophyllum and Favosites. The *Crinoidea*, which occur in the same limestone, and in higher beds, belong to Platycrinus, Pentremites, Cyathocrinus, Actinocrinus, &c., and are more allied to the forms of the mountain limestone. The *Brachiopoda* are numerous, and, for the most part, peculiar; but a rather considerable proportion of those in the upper part are the same as, or very similar to, Upper Palæozoic races. The *Lamellifera* are few, including Cucullææ, Modiolæ, Pterineæ, Pleurorhynchi. The *Gasteropoda* are numerous, more similar on the whole to Upper than Lower Palæozoic forms; and the same is the case with the *Cephalopoda*.* The Crustacea are all trilobites. *Fishes* are rare in the Devonian type of these middle Palæozoic strata, except in Russia, where Murchison had the good fortune to *find together* the *Devonian shells* and the *old red fishes*.

Characteristic Fossils. Calceola sandalina. Cyr-

* Palæozoic Fossils of Devon and Cornwall, 1841.

toceras sexdecimale. Brontes flabellifer. Holoptychius nobilissimus.

The Devonian type has been studied by several geologists on the Rhine and Moselle (Nieder Lahnstein), in the region of the Meuse, by Dumont, in the Boulonnais by Austen, Forbes, and Sharpe. In Ireland the peculiar characters of the series have been exhibited by Griffith, Portlock, Kelly and Jukes.

Part of the slaty killas of Cornwall, in which are situated the famous mines of tin, copper, lead, iron, &c., belongs to the Devonian series. In it occur porphyry, greenstone, serpentine; under it and sending veins through it, are granites of various quality, often rich in tourmaline.

We now pass, by an easy gradation, to the

UPPER PALÆOZOIC STRATA.

The thick varied and valuable rocks and minerals of this series may be grouped in two great systems; viz., the Permian above, the Carboniferous below; which have to one another a real affinity in the forms and combinations of life, but offer a considerable contrast in regard to mineral aspect. In this respect the analogy of the Permian series to the Mesozoic group next above is so considerable as to have allowed of their being formerly joined together in the Saliferous System;* a classification still of use in some problems of physical geology. We begin with the lower or

CARBONIFEROUS SYSTEM.

UPPER DIVISION.	Coal formation—Sandstones, shales, ironstone, and twenty or more beds of coal in many alternations (rarely any limestone), with land plants, shells, crustacea, fishes, and reptiles, mostly of estuarine habits.† 2,000 to 11,000 feet thick. Millstone grit—Coarse sandstones and shales alternating with some coal and ironstone beds, and a smaller series of fossils. 1,000 feet thick at the utmost.
LOWER DIVISION.	Yoredale rocks—Five alternations of limestone, chert, shale, sandstone, ironstone, and thin coal beds, with many marine fossils, and some land plants. 1,000 feet thick at the utmost. Scar limestone—A calcareous mass of corals, crinoids, polyzoa and shells, with crustacea and fishes—divided by thermogenous rocks (toadstone) in Derbyshire, and by greenstone, shale, sandstone, and coal in Northumberland and Scotland. 500 to 2,500 feet. Caldy limestones, shales, and sandstones, with abundance of polyzoa, corals, crinoids, and fishes. 500 feet.

* Guide to Geology, first edition, 1834.

† In Coalbrookdale the shells are mostly marine.

Such is a general view; but the sections are rarely complete. One of the best is on the Avon, but it hardly exhibits the Yoredale series, which is best seen in Yorkshire; but there and in all the north of England, as in Scotland, the Caldy series is not well made out. So of the millstone grit; it is conspicuous in Northumberland, Yorkshire, and Derbyshire; but contracts to the Farewell Rock in Wales. Similar variations occur in Ireland, where yellow sandstone, like the upper Devonian group (p. 165), occupies the lowest place.

The Coal formation is extremely variable. In Derbyshire it does not exceed 2,000 feet in thickness, with 6 feet for the thickest bed of coal; in Yorkshire 3,000 or 4,000 feet, with a 10 foot bed of coal; in South Wales, 11,000 feet, with 120 feet of coal, in many mostly thin beds; in South Staffordshire, about 1,000 feet, with one bed—or rather an aggregation of beds—27, 30, or even 45 feet thick. In Shropshire, Cheshire, and Lancashire, a thin limestone lies near the top: in Yorkshire, Lancashire, and Derbyshire, a series of calcareous nodules and a remarkable hard gritstone ('ganister') lie near the bottom.

The limestones are of many tints, nearly white, yellowish, red, gray, blue, black, and mottled; yielding excellent marble, either compact, oolitic, or crinoidal. They are almost wholly composed of organic reliquiæ. The chert is often nodular, and lies in the limestone like flint in chalk. The pebbly conglomerates of the millstone grit consist of quartz, felspar, and mica, with, occasionally, garnets and other minerals, derived from granite and gneiss. The sandstones are often finely and truly laminated, constituting excellent flagstone. The shales are occasionally quite dark and richly carbonaceous. The ironstones, hydrocarbonates, are of nodular shapes, mostly lying in layers, but sometimes extended in beds.

The coal exhibits every variety of composition between anthracite, which is nearly pure carbon, and a bright substance like jet, and equally rich in hydrogen. Anthracitic beds are rarely seen except in districts of much disturbed stratification (e. g. Pembrokeshire). Neither in this nor in the compact 'Cannel' coal is the laminar structure, or symmetrical jointing, so distinct as in 'common' coal.

Coal is nothing else than a compressed and chemically altered mass of vegetables. The tissue of some of the trees remains in the substance and may be detected by fracture, burning, and thin sections. In some cases trees appear rooted in attitude of growth, their stems above, their roots in or below the coal. The accumulation of coal in so many parallel beds can be explained by no hypothesis, unless it includes gradual and long-continued subsidence of limited tracts of the old sea-bed and the adjoining lands.

Dykes of greenstone, in Durham and Northumberland, and larger overlying masses of this rock in Shropshire and Scotland, transform the coal near them to a kind of cinder.

The organic remains of this carboniferous series are very numerous, and of marine, estuarine and terrestrial origin. The British groups, as collected in Morris's Catalogue (2nd edition), give nearly the following members, which may be usefully compared with the corresponding list for the Lower Palæozoic series, p. 159.

Plants (chiefly in the coal formation)	286	Brachiopoda	191
Amorphozoa	1	Monomyaria	116
Foraminifera	3	Dimyaria	166
Actinozoa	114	Pteropoda	1
Echinodermata	127	Gasteropoda	179
Annellida	16	Heteropoda	27
Crustacea	36	Cephalopoda	137
Insecta	3	Fishes	174
Polyzoa	53	Reptilia	1

The most striking differences are occasioned by the abundance of plants and fishes; the augmentation of all the molluscous divisions except Pteropoda, and the reduction of the Crustacea. Insects now make their appearance in England, and Myriopoda in Nova Scotia, where also, and in Germany, other species of reptiles occur. Nearly all the invertebrate fossils are distinct specifically from those of the Lower Palæozoic strata, but many exhibit affinity both to the Devonian and to the Permian fauna. Among plants, Asterophyllites, Calamites, Lepidodendron, Sigillaria, Neuropteris, Pecopteris, and Sphenopteris are most frequent. Among Actinozoa, Cyathophyllum, Lithodendron, Lithostrotion, Syringopora, and Zaphrentis are prevalent. Pentremites, Platycrinus, Poteriocrinus and Archæocidaris represent Echinodermata. Dithyrocaris, Griffithsia, and Phillipsia are the most common Crustacea. Fenestella is the ordinary Polyzoon; Chonetes, Producta, and Spirifera very frequent among Brachiopoda; Aviculopecten includes half the Monomyaria; while Pleurorhynchus, Edmondia, Modiola, Nucula, and Sanguinolites show how much the Dimyaria are augmented in number, without very great changes of form. Euomphalus, Loxonema, Macrocheilus, and Pleurotomaria give the same evidence for Gasteropoda, Bellerophon for Heteropoda, and Orthoceras for Cephalopoda. But in this latter group Nautilus and Goniatites are now conspicuous and numerous.

The fishes, mostly known by teeth and spine-rays, have many agreements with Devonian forms.

PERMIAN SYSTEM.

Under this title Murchison, in 1844, classed the magnesian limestone series of England, and a portion of the sandstones above and below it.

The series in descending order in the north of England stands thus:

Upper Group . .	[f] Red sandstones and clays.
Middle Group . .	[e] Limestone of Knottingley. [d] Gypsiferous clays. [c] Magnesian limestone. [b] Marly beds.
Lower Group . .	[a] Red sandstones and clay.

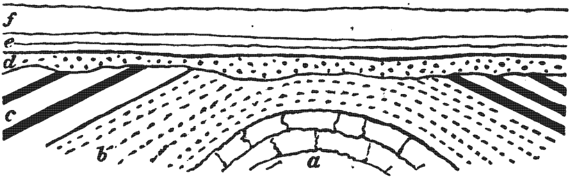
The whole group, perhaps, but certainly the upper and middle groups, are unconformed to the carboniferous strata below, in most parts of the north of England, the magnesian or middle group being only fully developed in that region. This circumstance is very conspicuous in Yorkshire at Aberford, and in Durham, near Bishop Auckland, coal being in both cases worked under the magnesian rock.

The limestones of the Permian system are magnesian through most parts of the section; the thick rocks (*c*) are often nearly exact double carbonates of lime and magnesia, but the upper beds (*e*) contain only a small percentage of magnesia; they vary much in texture and hardness.

The Houses of Parliament are built of a hard crystalline variety from near Bolsover.

The lower sandstones are generally pebbly, and in the vicinity of Harrogate much resemble red varieties of soft millstone grit; the upper sandstones and clays are of red colours, and not very

DIA. 12.



In this diagram, *a* represents the Yoredale limestone series, below *b*, the millstone grit, and *c*, the coal formation; all which beds are placed with contrary slopes under nearly level strata of *d*, red and yellow sandstone, *e*, marly beds, and *f*, magnesian limestone.

conspicuous in Yorkshire and Nottinghamshire. Sandstones of this system surround the Midland coalfields. The clays are red and greenish; containing gypsum in several places, especially the beds marked *d*. Copper ore, both sulphide and green carbonate, occurs in Yorkshire in small quantity; also oxide of iron and sulphate of baryta.

The organic remains, fewer in England than in Germany, have on the whole a decided resemblance to those of the carboniferous limestone, and several species are identical. The sandstones of Lochmaben, with footprints, are referred to this system.

Mr. King's catalogue of the fossils of the English rocks includes: —

Plants . . .	7	Polyzoa . . .	5
Amorphozoa . .	5	Brachiopoda . .	23
Foraminifera . .	6	Monomyaria . .	5
Actinozoa . .	6	Dimyaria . .	25
Echinodermata .	2	Gasteropoda . .	20
Annellida . .	5	Cephalopoda . .	2
Crustacea . .	11	Fishes . . .	16

From this catalogue the Saurian fossils from Bristol are omitted, as not really of this period.

Producta calva, Spirifera undulata, Monotis speluncaria, Axinus obscurus, Mytilus squamosus may be quoted as characteristic shells. No trilobites known in the English rocks.*

Looking back on the long series of Palæozoic stratifications, we find some facts established which are of primary importance in the physical history of the earth.

This series of rocks composes by far the greatest part of the thickness of the crust of the earth, as may be in some degree illustrated by the sectional diagram which accompanies the map (Pl. I.).

Previous to their formation, granitic, and, during their deposition, other igneous compounds were formed, and in the latter case effused on the old sea-bed of the time. (Snowdonia.)

* For the German fossils, see Geinitz's work, entitled 'Dyas.'

There were displacements of the old sea-bed during the Palæozoic period, especially after the deposition and *consolidation* of the Lower Palæozoics, so that later strata cover unconformably the earlier displaced formations. (Westmoreland.)

In the case just mentioned, and others in Scotland, the Lower Palæozoic rocks had been uplifted from the sea; washed and worn away by its waves; so that on the worn surface the later palæozoics were deposited. The shores of the sea thus become partially known: and from other phenomena we infer valleys, descending into arms of the sea, from ranges of mountainous land—from land which is still mountainous. Thus some of the grand features of physical geography were fixed in the early periods now under consideration, and some of the ranges of mountains may be justly called 'palæozoic.'

Previous to the close of this system, after the deposition of the coal, a great disturbance happened, by which the sea bed was broken up, and the land in many places thrown into new forms.

Of the marine life of the Palæozoic ages we have abundant remains, which upon the whole grow more varied as we ascend. In the earliest period as yet only Brachiopoda and Crustacea; till the close of the Lower Palæozoic ages no fishes have been found; at the same point of time we discover traces of land plants. In the later part of the

Palæozoic period land plants abound, and may be seen erect as they were growing; fresh waters and estuaries contribute to the catalogue of life; fishes are numerous; and reptiles have left a few traces. But as a whole this is the age of Trilobites and Orthoceratites. From the land plants and marine corals, equally, we infer that a higher temperature prevailed generally over the northern zones, during the Palæozoic ages, than can be accounted for by any variations in the arrangement of sea and land, or any fluctuations in the other surface elements of climate.

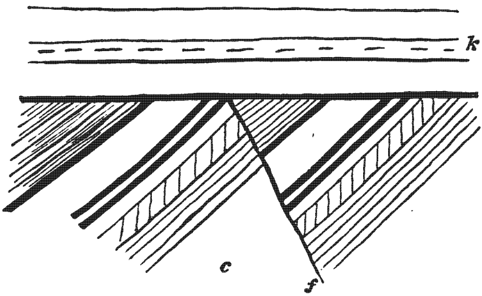
It has been conjectured that the atmosphere was then more loaded with carbonic acid; a condition which Brongniart thought favourable, and Daubeny has proved to be at least not unfriendly, to the growth of ferns and other cryptogamic plants, which make up so large a part of the Palæozoic flora of the world.

THE LOWER MESOZOIC STRATA,

composed of red, greenish, bluish and white layers of sandstone, clay, gypsum, salt (and limestone in France and Germany) constitute but one great natural system, in three formations, to which the Germans give the name of Trias. From its various colours the system has been called Poikilitic, and parts of it Bunter and Marnes irisées.

It is the Saliferous system of England, occupying large spaces in the drainage of the Severn, Trent, and Mersey, and often covering coal unconformably, as in the annexed diagram (No. 13).

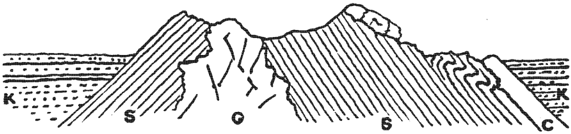
DIA. 13.



c, inclined coal formation, broken by fault *f*, which does not pass into the superior undisturbed bed *k*. The coal strata were displaced and broken, and worn to nearly a level top, before the Keuper was deposited horizontally over their uplifted edges.

By observation of the manner in which the Lower Mesozoic strata meet the Palæozoic ridges of high ground in Europe, it appears generally to have been the case that all the principal masses

DIA. 14.



of the older strata, now visible, had been elevated by subterranean movements, and formed dry land, before the thick and varied sediments of the trias were laid against them. The section across Charnwood Forest (Diag. No. 14) may serve to show the way in which the older rocks are met and covered; S, being Silurian, C, Carboniferous, K, Keuper, and G, a granitic mass.

The complete system, including the calcareous middle term, which is not yet ascertained in Britain, but excluding the 'bone bed,' which is commonly referred to the Lias, stands thus in the German nomenclature:—

KEUPER.—Red and green clays, marls, and thin sandstones, with plants, shells, and vertebrata.

MUSCHELKALK.—A series of gray fossiliferous limestones, shales, and sandstones, with many fossils.

BUNTER.—White and red sandstones, and coloured marls, resting on red and white sandstones and conglomerates.

Total thickness, 1,000 to 2,500 feet.

The Sandstones, the prevalent members of this system, are usually composed of quartz grains, coloured by an external thin adherent layer of red oxide of iron; in other cases, they are white or greenish. By additions of pebbles of quartz, highly indurated sandstone, and various other rolled masses derived from older rocks, the sandstones become conglomeritic; and when reduced to fine grains, they pass into the coloured clays which alternate with them.

These clays are occasionally divided by thin laminated sandstones, beds of gypsum, and rock salt.

These substances also accompany the lower series of limestone bands called Muschelkalk, which are of a gray tint, and are associated with gray shales and some sandstone, all very fossiliferous.

Copper ore occurs in the conglomerate of Alderley Edge; manganese ores are another product of the Bunter.

Organic remains are rare in this system in England, except in the sandstones and clays, which are of a blue, green, or gray colour, and lie in the midst of the Keuper. These contain plants, bivalve shells, with fish teeth and spines. The reptilian remains of Labyrinthodon, Cladyodon, and Rhynchosaurus belong to the Keuper and Bunter in England; and, probably, the Stagonolepis and Hyperodapedon of Elgin are of the same age.

In France and Germany, organic remains occur more plentifully in the Keuper, both in argillaceous and sandy beds (Westphalia), and in the Muschelkalk, with its many subordinate bands (Luneville). In general these fossils are very distinct from those of the Palæozoic ages; but at St. Cassian and Hallstadt, on the flanks of the Tyrol, there occur beds of the Keuper age, which contain Cyrtoceras, Orthoceras, and Goniatites, genera which are common in Palæozoic rocks; as well as Ceratites, which is almost confined to the Triassic strata, and Ammonites and Belemnites, universally found in the Jurassic deposits. This remarkable case seems to furnish proof of the long duration of some races, and of the early appearance of others, in situations which enjoyed immunity from disturbance. Thus the forms of ancient life are in some degree connected into a continuous series, uniting the Palæozoic and Mesozoic periods of time. Similar facts have been observed in India.

The catalogue of Triassic life is, however, at present very incomplete, and can only be collected in the following general manner:

Plants, of Cryptogamic, Cycadeous, Coniferous, and other terrestrial groups; chiefly from Keuper and Bunter.
Amorphozoa. (Not recorded.)
Actinozoa. (Not recorded.)
Foraminifera. (Not recorded.)
Echinodermata, as Encrinus, Asterias.
Annellida, as Serpula.
Crustacea, as Palinurus Suerii.
Brachiopoda, rare; including Terebratula and Spirifera.
Monomyaria, especially Avicula, Lima, and Ostrea.
Dimyaria, including Trigonia and Myophoria.
Gasteropoda, as Nerinæa, Platystoma.
Heteropoda. Porcellia in St. Cassian beds.
Pteropoda. (Not recorded.)
Cephalopoda. Ceratites: also Orthoceras, Goniatites, and Cyrtoceras, with Ammonites and Belemnites in the St. Cassian beds.
Fishes, of the Ganoid and Placoid orders, as Gyrolepis, Hybodus.

Reptiles, numerous, as Nothosaurus, Rhynchosaurus, Dicynodon, Labyrinthodon, Cladyodon, Simosaurus, Placodus, Palæosaurus and Thecodontosaurus.

Birds, only footprints in Connecticut.

Mammalia, probably marsupial, as Microlestes, of which teeth have been found in Würtemberg, and near Frome, Somerset (Moore).

THE MIDDLE MESOZOIC STRATA,

to which the terms Oolitic and Jurassic are commonly given, contain altogether about 4,000 feet of argillaceous, arenaceous, and calcareous rocks, varied by partial admixtures of ironstone and coal. Five natural groups may be formed, the upper one only known as fluviatile or estuarine, the others wholly marine or partially mixed with fresh-water deposits.

THE LIAS FORMATION,

which in Yorkshire is about 1,000 feet thick, consists principally of laminated blue clay, or shale, with ironstone courses, and septaria. In it are beds of sandstone, and balls and strata of blue and white limestone. It contains many subdivisions, which taken in descending order may be thus described:—

(*h*) Sandy and micaceous layers gradually becoming more argillaceous below.

(*g*) Upper lias clay or shale, with balls of argillaceous limestone and ironstone.

(*f*) Hard lias shale, with jet bands at Whitby.

(*e*) Shales and ironstone bands, 2, 4, 6, 8, 12, and even 16 feet thick in Cleveland.

(*d*) Marlstone, a series of calcareous and arenaceous bands, yielding ironstone in Oxfordshire.

(*c*) Middle lias shales, with balls of limestone, 500 feet.

(*b*) Lias limestones, blue and white.

(*a*) Lower shales, thin sandstones, and limestones, and the bone beds of Aust and Westbury.

The lower beds (*a*) of this series are often classed with the Keuper, and are acquiring the name of 'Rhœtic beds.' The higher beds (*h*) gradually change upwards to resemble the inferior oolite group. Several of the strata are useful in the arts. The blue limestone beds yield lime which sets in water, and some of the nodules are burnt for cement, others smelted for iron; the white limestone has been used for lithography, the upper shale for alum, the bone bed has been recommended for manure, and jet obtained in Yorkshire is the basis of a flourishing trade. Pyrites, blende, and petroleum occur in connection with the Ammonites and other fossils of the lias.

This characteristic feature of English geology runs in a long, connected course of hill slopes and low plains beneath the escarpment of the lower oolites, from the Tees to the Exe. Through a great part of this course it has tempted trials for coal. It is discovered in the Hebrides, and extends to the east and centre of France, Switzerland, and Germany. It may be well studied on the coasts of Yorkshire and Dorsetshire, and in the vicinity of Cheltenham and Bath. The lias limestones are well seen at Barrow-on-Soar, near Shipston, near Bath, and at Lyme Regis. Beneath the basalt of Antrim, it is of a metamorphic character, but its fossils are distinct.

The *organic remains* of the British lias are about 450 in number, and except a few Coniferous plants, and Insects, all marine. Owing to the argillaceous character of the deposits, Corals and Echinida are scarce, and Gasteropoda not numerous. Most of the other classes of animals are fully represented, and Cephalopoda, Fishes, and Reptiles abound. Insects occur in the lower layers, and also in the upper lias shales.

Most of the species of fossils in the lias are characteristic of it, either by exclusive occurrence or remarkable abundance. The following may be taken as examples: — Pentacrinus Briareus, Gryphæa incurva, Plagiostoma giganteum, Trochus anglicus, Belemnites paxillosus, Ammonites Bucklandi, Dapedius politus, Ichthyosaurus communis, Plesiosaurus dolichodeirus. The several stages of the lias from *a* to *h* may also be distinguished by fossils, especially by Ammonites and Belemnites. The Ammonites planorbis, near the bottom, is succeeded by A. Conybeari in the limestone, and this by A. bifrons in the upper lias.

THE LOWER OR BATH OOLITE FORMATION.

One of the most characteristic of the stratified rocks of England exhibits in its range from Dorsetshire to Yorkshire marine, estuarine, and freshwater deposits. Near Bath it is mostly of marine origin; at Stonesfield it includes drifted land plants and land reptiles; near Scarborough it is principally a mass of river-drifted sands and shales, with freshwater shells, land plants, coal, and ironstone. Near Bath and Cheltenham the thickness where greatest is above 600 feet: in Yorkshire it somewhat exceeds that amount.

In the following diagram the two contrasted types at Bath and in Yorkshire are placed side by side, the total thickness being supposed the same in each case:—

Bath.	*Yorkshire.*
Cornbrash . .	Cornbrash.
Hinton sands . .	Sands and clays.
Forest marble . .	Two bands of oolitic lime-
Bradford clay . .	stone, separated by clays,
Great oolite . .	ironstone, and coal.
Fuller's earth rocks .	Sands, clays, and coal.
Inferior oolite . .	Inferior oolite.
Sand	Sands.

The Bath type occurs in Normandy, the Jura, and Franconia.

The sandstones of the series are never conglomeritic and rarely micaceous, except in the river deposits on the Yorkshire coast; the clays are nowhere shaly except in the same district; the limestones are mostly oolitic, except the cornbrash. The coal is mostly composed of equiseta and ferns. The inferior oolite becomes highly ferruginous in Yorkshire; and perhaps it is the same bed which yields the greater part of the Northamptonshire ores. The oolitic beds were quarried by the Romans at Ancaster in Lincolnshire, and at Bath. Some of the finest and most desirable sorts of this rock are found near Stamford; one bed yields a pretty marble full of Nerinæa.

From the Dorsetshire coast to the Humber, these oolitic rocks constitute an almost continuous range of elevated terrace-like hills, inclined to the east and overlooking the country on the west. The greatest elevation is near Cheltenham, 1,134 feet. North of the Humber, the highest point is 1,485 feet above the sea.

The *organic remains* are very numerous, and offer probably a more complete series of the inhabitants of the land and sea than can be gathered from any other period, not excepting even the earlier Cænozoic ages. Land plants abound at Stonesfield and in Yorkshire, including Ferns, Lycopodiaceæ, Equisetaceæ, Zamiæ, and Conifers, Sponges, Actinozoa, Foraminifera, Echinodermata of all orders; Annellida, Crustacea, Insecta, Polyzoa, Brachiopoda, Monomyaria, Dimyaria, Gasteropoda (no Heteropoda, no Pteropoda), Cephalopoda, all are plentiful, and of varied structure. Fishes of ganoid and placoid genera; Reptiles, marine (Ichthyosaurus), fluviatile (Teleosaurus), terrestrial (Megalosaurus), and aerial (Pterodactylus), and Mammalia of insectivorous and artiodactylous orders, probably marsupial, complete the rich catalogue; the whole yielding above one thousand species in the British Isles.

As characteristic of this lower oolitic stage, we may name Equisetum columnare, Apiocrinus rotundus, Terebratula maxillata, Trigonia striata, Pholadomya acuticosta, Belemnites giganteus, Ammonites Blagdeni. The stages of the oolite are marked by ammonites, as A. Murchisonæ near the bottom, A. Parkinsoni toward the middle, A. macrocephalus toward the top.

The subdivisions may be thus stated:—

THE MIDDLE OR OXFORD OOLITE FORMATION.

Blue or yellow oolite, occasionally of a pisolitic character, locally full of coral; enclosed in a mass of cherty or calcareous shelly sandstones; beneath these a thick blue clay with shelly sandstone near its base. The total thickness in Yorkshire is about 300 feet, in Oxfordshire and Wiltshire 600 to 800 feet.

(*f*) Upper calcareous grit.
(*e*) Coraline oolite.
(*d*) Lower calcareous grit.
(*c*) Oxford clay.
(*b*) Kelloway rock.
(*a*) Clay.

The upper portion forms a range of dry hills of moderate elevation through England; the lower portion spreads in broad vales near Oxford, Calne, and Weymouth.

Organic remains, chiefly of marine kinds, abound in these strata to the extent of 266 species. Land-plants occur chiefly in the oolitic and arenaceous beds. The classes of animals which occur are the same as in the Bath series, Corals and Echinida being equally plentiful. Among Reptiles, Megalosaurus occurs. No Mammalia yet discovered, but the extraordinary fossil bird from Solenhofen, now in the British Museum, belongs to this period.

Characteristic Fossils. Stylina tubulifera, Hemicidaris intermedia, Nucleolites dimidiatus, Plagiostoma rigidum, Gryphæa dilatata, Ammonites Calloviensis, Belemnites tornatilis. Ammonites Calloviensis lies near the base of the Oxford clay; A. vertebralis near its top and in the whole range of the Oxford oolites above.

THE UPPER OR PORTLAND OOLITE FORMATION consists of a mass of limestone, partly oolitic, partly compact or cretaceous, including nodules and ramifications of chert; green sandy and nodular beds below, resting on a thick blue clay, with lignite and layers of Septaria, and one or two thin calcareous and arenaceous bands. Only three subdivisions are commonly used; viz.,

(*c*) Portland oolite.
(*b*) Portland sands.
(*a*) Kimmeridge clay.

This series is very discontinuous in the upper portions; but the lower is traced from Dorsetshire, where it is 600 feet thick, to Oxfordshire, where it is sometimes less than 100 feet thick, and thence into Cambridgeshire and Yorkshire, everywhere marked by one bed of flat oysters (O. deltoïdea).

Organic remains, not so plentiful in these upper oolites as in the middle and lower ones, amount to eighty species. Corals, Echinodermata, Polyzoa and Brachiopoda are not frequent. Monomyaria, Diomyaria, Gasteropoda, and Cephalopoda occur, often of unusual magnitude. Among the Ammonites, A. biplex belongs to the upper part of the Kimmeridge clay, and acquires large size in the rocks above, being however there surpassed by A. giganteus, which is sometimes thirty inches across. Cardium dissimile and Trigonia gibbosa belong to the oolite; Ostrea deltoïdea and Thracia depressa to the Kimmeridge clay.

THE WEALDEN FORMATION

is composed of variously coloured sands and clays, with interspersed lignites, conglomerates, and calcareous portions in the former, and limestone and ironstone in the latter. The organic remains indicate that it was principally a freshwater and estuarine deposit, extending across the English Channel to Boulogne and Beauvais.

The subdivisions are very numerous, but may be collected under three heads; viz.,

(*c*) Weald clay, alternating below with
(*b*) Hastings sands, which rest on
(*a*) Purbeck clays and limestones.

The Purbeck beds, composed of thin limestones and clays, with freshwater and estuarine shells, Insects, Fishes, Reptiles and Mammalia, rest on the Portland oolite in the Isle of Purbeck, near Weymouth, in the vale of Wardour, and near Swindon and Oxford. Near their base in the cliffs of Dorsetshire occur one or two 'dirt-beds,' with roots and stems of Cycadaceous and Coniferous trees, situated as though they grew on an ancient surface of land and soil, which was afterwards sunk under fresh waters and covered by numerous thin lacustrine deposits, 200 or 300 feet thick, varied by occasional irruptions of salt or brackish water.

In these layers occur no marine forms, except one echinoderm, and an oyster, probably littoral species; but abundance of freshwater bivalves (Cyrena), and univalves (Physa, Paludina), which are very like the corresponding forms of the present day. Ganoid fishes (Aspidorhynchus), Crocodilian and other Reptiles, and Mammalia of several genera (Spalacotherium, Plagiaulax, &c.), probably marsupial.

The Hastings deposits, several hundred feet thick, consist mainly of sandstones and clays, more or less frequently alternating; the former sometimes containing pebbles, ferns, fragments of wood, bones of reptiles, and bivalve shells of freshwater origin; probably drifted by some ancient river. In these beds occur the huge remains of Hylæosaurus, Iguanodon, Megalosaurus, and Pelorosaurus. They form the central elevation of Kent and Surrey, rising to 805 feet.

The Weald clay, with sandy partings and subordinate beds of ironstone and shelly marble, about 600 feet thick, sweeps round the Hastings sands in a broad woody vale. The marble beds are composed of Cyrena, or else of Paludinæ of one or two species, the most celebrated being found at Petworth in Sussex, and Bethersden in Kent.

The marine equivalents of these thick fluviatile estuarine, and lacustrine strata are not known (unless a part of the neocomian strata of Switzerland be of this age); they separate the unlike fauna of the oolites and the green sands; the two upper parts being joined by some geologists to the cretaceous rocks.

The organic remains of the Middle Mesozoic strata may be thus summarized; the numbers being nearly as given in Morris's Catalogue:—

Plants	153	Brachiopoda	98
Amorphozoa	8	Monomyaria	169
Foraminifera	16	Dimyaria	323
Zoophyta	74	Pteropoda	none
Echinodermata	109	Gasteropoda	284
Annellida	26	Cephalopoda	255
Cirripedia	3	Fishes	207
Crustacea	21	Reptilia	68
Insecta	111	Birds	1
Polyzoa	24	Mammalia	10

UPPER MESOZOIC STRATA.

They rest unconformably on the oolitic formations, or on the lias, in Yorkshire and Dorsetshire, the oolitiferous sea-bed having been previously displaced very extensively.

THE GREENSAND FORMATION.

A stratified mass of sands, occasionally pebbly, often cherty, almost always slightly calcareous, and characterised by abundance of green grains in some or all of the beds. In many tracts, the lower sands are very irony. In the midst of the series is a sandy and calcareous fossiliferous clay. The green grains are silicate of iron, possibly derived from some old augitic rock.

c. Upper greensand, passing below into
b. Gault, which sometimes alternates with
a. Lower green or iron-sand, enclosing limestone in Kent, and fullers' earth at Nutfield in Surrey.

In England, it generally forms the base of the chalk hills, but in Blackdown, Surrey, and Kent, it rises into separate ranges of hills. In the north-east of Ireland, it is covered by basalt. On the Continent, it extends with the chalk, and is found separate from that rock in Saxony, along the Alps, and Carpathians.

Organic remains are plentiful in the greensand and gault strata. A few marine plants occur; sponges for the first time become numerous, especially in the upper greensand. Echinida are very frequent, and of many genera. Brachiopoda Monomyaria, Dimyaria, Gasteropoda, and Cephalopoda abound. Decapod Crustacea occur, and at Cambridge in upper greensand Pterodactylus and other reptiles.

Among *Characteristic Fossils* may be mentioned Siphoniæ, Cyclocyathus Kœnigi, Galerites subuculus, Terebratula biplicata, Exogyra sinuata, Pecten quinquecostatus, Inoceramus sulcatus, Trigonia aliformis, Cardium Hillanum, Ammonites splendens, Belemnites minimus, Hamites intermedius. Ammonites are found to be considerably different in the different groups. A. Deshaysii belongs to the lower, A. auritus to the middle, A. varians to the upper beds.

THE CHALK FORMATION

consists principally of carbonate of lime in a finely granular state (sometimes full of minute Rotaliæ and other Foraminifera), imperfectly indurated, and white. The stratification is rendered evident chiefly by layers of flint nodules, which occur at regular intervals, mostly in the upper part, but sometimes in other parts, or through nearly the whole of the mass.

The main subdivisions of the chalk, including the beds of Maestricht, not recognised in England are four:

(*d*) Maestricht, granular beds.
(*c*) Norwich, beds soft, with flints.
(*b*) Wiltshire, beds hard, without flints.
(*a*) Chalk marl, soft, without flints.

The flints are formed mostly round sponges, and lie in parallel surfaces, at four or more feet apart. Continuous layers of flint are also known.

In Yorkshire, the chalk is hard, and the beds marked *b* contain most of the flints. The beds *a* are sometimes hardly distinguishable from the upper greensand, which is often more intimately united to the chalk than to the series below. The lowest part of the Yorkshire and Lincolnshire chalk is of a red colour, rich in Foraminifera. The same occurs at Hunstanton in Norfolk, resting on lower greensand.

The chalk occupies generally a district of connected green (not woody) hills, with dry valleys; very strong springs at their base; surface excavated in pits and grooves, and often covered with flints. It forms the Wolds of York and Lincoln, the Downs of Berks, Wilts, Dorset, Hants, Isle of Wight, Sussex, Surrey, Kent. It sweeps round the tertiary basin of Paris, and appears in the south-east of France, Belgium, Poland, and Isle of Rugen.

Organic Remains are very numerous, mostly marine, but including Cycadeæ and other *plants* drifted from the land. *Amorphozoa* abundant, often enclosed in flint, which, likewise, as well as the chalk, contains *Foraminifera*. *Actinozoa* are less frequent. *Echinida* are numerous; among them genera unknown in older strata, as Ananchytes.

Asteroïdea of several species, and *Crinoïdea*, as Apiocrinus, Marsupites, are common.

Brachiopoda are frequent, and *Conchifera* plentiful, including Gryphæa and Inoceramus. *Gasteropoda* are less abundant, but *Cephalopoda*, numerous, including Ammonites, peculiar groups of Belemnites, Scaphites, Turrilites, Baculites, &c.

Crustacea are not common. *Fishes*, many, including (in the chalk) Cycloid and Ctenoid genera.

Reptiles, of large size, as Ichthyosaurus and Mosasaurus, complete the catalogue, which amounts to about 1,350 species.

Characteristic Fossils. Marsupites ornatus, Ananchytes ovatus, Galerites albogalerus, Inoceramus Cuvieri, Lima spinosa, Terebratula plicatilis, Belemnites mucronatus, Mosasaurus Hoffmanni.

The following is a summary of the fossils of the Cretaceous System — the numbers nearly as in Morris's Catalogue; —

Plants . . .	14	Brachiopoda . .	67
Amorphozoa . .	127	Monomyaria . .	139
Foraminifera . .	130	Dimyaria . . .	168
Zoophyta . . .	29	Pteropoda . .	none
Echinodermata . .	136	Gasteropoda . .	105
Annellida . . .	81	Cephalopoda . .	141
Cirripedia . . .	21	Fishes . . .	94
Crustacea . . .	44	Reptiles . . .	23
Polyzoa . . .	81		

On a review of the Mesozoic strata, we find that the alternations of limestone, sandstone, clay, coal, ironstone, which they contain, are generally distinguishable lithologically from the rocks bearing the same names in the Palæozoic series.

The forms of life, whether terrestrial, fluviatile, or marine, are in general very different from those of earlier date, often referable to different genera, always distinct specifically, more numerous and more varied. This is the Age of Reptiles. Though in Yorkshire and Dorsetshire unconformity appears among these strata, by the over extension of the chalk and greensand, to the Lias, they have rarely been exposed to igneous action; and, except in the cases of lias near the Whindyke in Yorkshire, and the Antrim Basalt, they have seldom suffered metamorphism.

At the close of this period, through great part of Europe, the strata were again disturbed, new hills were added to the land, new outlines were imparted to the sea, and very different conditions of life began.

CÆNOZOIC STRATA.

The last great group of stratified deposits in which lie the latest of the extinct races of plants and animals, have been formed since the ocean became much divided into arms and gulfs, and have so much of local character and independent origin, as to render it almost impossible, by direct comparisons of stratification, to refer these dissociated and interrupted strata to one general series. It is only by employing intermediate analogies, and the evidence of organic remains, that we can form to ourselves a proper general view of the order of antiquity of the deposits in different districts. On this account it is always best to describe the tertiary strata according to the natural regions in which they were formed: the English tertiaries are one series; the Parisian another, and very analogous one; the Subapennine a third; the Danubian a fourth. There are many others in Europe, Asia, and America.

The notices in the text will be confined to the English tertiaries, for though these are, indeed, of small extent compared to the Cænozoic rocks which range parallel to the Alps and Apennines, the Caucasus and the Himalaya, they are highly instructive, and have been very carefully studied, so as to offer an excellent basis for wider enquiries. According to Deshayes and Lyell, the tertiary series of Europe may admit of being ranked in three leading groups, according to the numerical relation of the organic remains with existing species of shells. The upper group, with from 40 to 95 per cent of living species (Pleiocene), includes the Sicilian tertiaries, the crag, and Subapennine marls: the middle group, with about 20 per cent (Meiocene), the tertiaries of the Danube, Rhine, Loire, and Garonne: the lower group, with about 5 per cent (Eocene), is typified by the Calcaire grossier of France, the Barton clay, the London clay, and the Plastic clays of England. • It is convenient to add a fourth group, the Pleistocene in which most of the Invertebrata and many of the Vertebrata are of species still living. It therefore includes what has been called the 'recent' period.

EOCENE STRATA.

The series fills the northern half of the Isle of Wight, and exhibits the following general terms, the upper one being by some writers transferred to the Meiocene period.

Vectian Beds: of freshwater and estuarine origin, 500 to 600 feet, in four groups:

Hempstead beds.
Bembridge beds.
Osborne beds.
Headon beds.

Bagshot Beds: of sands, clays, pebbles variously coloured, and lignites, in four groups, 1,200 to 1,300 feet:

Upper Bagshot beds.
Bracklesham beds.
Barton clay.
Lower Bagshot.

London Clay: clay, Septaria, and basement beds of sand and pebbles, corresponding to the Bognor Rocks, 300 to 500 feet.

Plastic Clay: sands, and pebbles of different tints, with lignite, and oyster beds, 100 to 200 feet:

Woolwich clays, &c.
Thanet sands.

Organic Remains. Those in the Bagshot group, the London clay, and some of the clays below, and in greensands which are near the base of the whole series, are for the most part marine, and consist of an immense number of shells, among which are the Voluta, Rostellaria, Fusus, Cassidaria, Ancilla, Buccinum, and other existing genera: no Belemnites or Ammonites; very few Terebratulæ or Echinida. A few species of these (not exceeding 5 per cent.) are still in existence. Most of them are characteristic of the formation.

The Limnææ, Planorbes, and Gyrogonites, in the freshwater marls, are associated with Palæotheria and Anoplotheria at Binstead in the Isle of Wight.

At Kyson, near Woodbridge, the London clay has yielded mammals (Hyracotherium and Didelphys).*

* The calcaire grossier of the Paris basin corresponds in age to the Bracklesham and Barton beds, and is even more rich in fossils. The subjacent coloured sands and

The *organic remains* of the British Eocene deposits amount to about 1,100 species.

Plants	113	Dimyaria	205
Foraminifera	41	Pteropoda	none
Zoophyta	24	Gasteropoda	431
Echinodermata	21	Cephalopoda	12
Annellida	9	Fishes	117
Cirripedia	4	Reptiles	31
Crustacea	10	Birds	14
Polyzoa	5	Mammalia	24
Monomyaria	38		

MEIOCENE Strata are represented in the British Isles by the Plant beds of the Isle of Mull, and the Lignitic beds of Bovey Tracey: no shells are known in them.

PLEIOCENE STRATA.

These are in England referable to two or three groups of no great thickness or extent, confined to the low parts of England east of the chalk (Essex,

clays have been generally referred to the plastic clay group of England.

The freshwater deposits in the Paris basin consist of upper and lower; the former characterised by silicious millstone, the lower composed of marls locally gypseous. In the gypsum lie bones of Palæotheria, Anoplotheria, Didelphys, and many other quadrupeds. The intermediate marine beds are chiefly sands. It is difficult to determine the relative age of the detached tertiary freshwater deposits in other parts of France, Germany, Hungary, &c. Some of them are of much more recent date.

Suffolk, Norfolk, Yorkshire). The upper portion *immediately* precedes in time what are here called preglacial deposits, and is partly of estuarine character; the lower portions are littoral and marine.

Norfolk Crag, with 15* per cent. of extinct species of shells, the others having, on the whole, a decided affinity to the existing fauna of the British seas; but affording some evidence of lower temperature, and no affinity with southern forms.

Red Crag, with 43 per cent. of extinct shells; the others mostly living in British seas, but manifesting somewhat greater affinities with the shells of southern seas than with those of the north.

Coralline Crag, with 49 per cent. of extinct shells, the others mostly living in British seas, but showing much greater affinity with the southern than northern types.

It is evident that the upper portion is not so intimately connected with the lower parts as to preclude the expectation that it may hereafter be found more convenient to remove it to the Pleistocene division, as a preglacial bed.

The Norfolk or 'Mammaliferous' crag contains abundance of littoral shells, as Mya, Cardium, Littorina.

* These numerical relations of the Crag shells to existing species are taken from Mr. Woodward's contribution to Lyell's Antiquity of Man, p. 209; Mr. Searles Wood being the authority.

'The Coralline Crag,' seldom completely exposed, is light in colour and nearly uniform in composition, and appears to have been deposited with more tranquillity; it is a coralline limestone at Orford, and contains abundance of shells, *not at all worn*, and not ochraceous, at Ramsholt and other places. Bones are rarely found in it.

The 'Red Crag' of Suffolk resembles almost exactly a shingle or pebble-beach, with layers of sand and shells, being composed of pebbles of various sorts, rolled and worn fish-teeth and bones, a few bones of extinct large quadrupeds, also worn; many shells, sometimes worn, sometimes not; parts of Crustacea, Actinozoa, &c. The whole has an ochreous aspect, from the admixture of oxide of iron. At or near the base, the bones, teeth, and phosphatic nodules are in sufficient quantity to be extracted for agriculture. Among the bones are those of Mastodon, Hippopotamus, Physeter, Cervus, but as yet no Palæotheria or elephants.

Organic Remains. These are very plentiful: there are above five hundred species of Actinozoa, Polyzoa, Conchifera and Mollusca in the Crag. Of these about 60 per cent., on the whole, belong to species which still exist, mostly in the neighbouring seas, but, as already observed, some of the earlier are of southern types, and some of the later belong to northern seas. Fusus contrarius and Buccinum Dalei abound in Red Crag.

The following is a numerical summary of the Pleiocene fossils of Britain: —

Plants (only marine)	1	Monomyaria	25
Amorphozoa	1	Dimyaria	190
Foraminifera	60	Pteropoda	1
Zoophyta	5	Gasteropoda	231
Echinodermata	20	Cephalopoda	none
Annellida	10	Fishes	2
Cirripedia	13	Reptiles	none
Crustacea (some drifted)	5	Birds	none
Polyzoa	52	Mammalia	10
Brachiopoda	6		

PLEISTOCENE DEPOSITS.

Following immediately the Pleistocene Strata is an extremely varied series of marine, littoral, estuarine, fluviatile, and lacustrine deposits, produced by causes still in action, and in some cases acting under very similar conditions to those of the earlier date. Thus the 'recent' period is inseparably united with the earlier pleistocene, or, if distinguishable by a strong line, it must be drawn where the human race makes its appearance; viz., in the latter part of the pleistocene period.

PREGLACIAL DEPOSITS.

Deposits which are of later date than the Norfolk Crag, and of earlier date than the 'boulder clay,' with its fragments of rocks brought from great distances, are now ranked under this title. The best example is on the Norfolk coast, where estuarine sands, pebbles, and clays, and clays of freshwater origin with lignite, are seen above the Norfolk Crag, west of Cromer, and even with tree-stems *in situ*, alder and pine, under the boulder clay near Happisburgh.

The series may be thus expressed :—

(*Boulder clay above.*)

Marine sands, silts, and gravel, mostly in thin laminæ, with occasional layers of marine shells.

Lignitic clays, with fresh-water shells, mostly of living British species. Pebbly and argillaceous bed, sometimes bearing tree-stems above, and containing bones of Elephas meridionalis, E. antiquus, and E. primigenius; Rhinoceros etruscus, and other quadrupeds allied to the fossils of Val d'Arno.

(*Norfolk Crag below.*)

Here there is plain proof of a terrestrial surface occupied by plants and a great variety of animals, before the advent of the glacial crisis which is specially marked by the marine deposit of the boulder clay. Many of the animals, especially the Invertebrata, belong to species still living; others, especially the large Pachydermata, are extinct.

GLACIAL ACCUMULATIONS.

It is not so much the presence of any particular earthy materials, such as boulders, gravel, &c., but the mode of their geographical distribution, and the occurrence in them of the remains of certain tribes of extinct Mammalia, which define the glacial products. The relation of the deposits to the physical geography of the region marks the condition of the watery or icy action concerned; and the natural history of the organic remains determines the relative date of the operations.

When deposits, like those of the glacial era, lie in valleys, we may sometimes refer them to a local origin; but when over wide plains, on hill slopes, and on ranges of high ground, we find heaps of rock fragments, and rolled but not river gravel—materials unknown *in situ* in the vicinity,—in situations to which no existing streams could carry them—where no imagined lakes could leave them—where, by no conceivable combination of conditions, consistent with the geological history of the country, either ancient streams or lakes could transport them, we are compelled to infer that some other agency has been employed. This was the course of reasoning applied by Smith, forty years ago, to some facts near Bath, and soon generalised by his extensive researches in England; by Buckland, Conybeare, and Sedgwick, to a large class of impressive phenomena in the North of England, in the midland counties, and in the valley of the Thames; by Saussure and De Luc to the scattered blocks of the Alps; by Brongniart and others to the travelled boulders of the North of Germany. A case in the North of England appears decisive of the truth of the principle.

The accompanying section (Pl. II. fig. 8) is intended to show the nature of the country along a line ESE. from Shap Fell in Cumberland, to Flamborough Head in Yorkshire, a distance, in a straight line, of 107½ miles, but by this rather bending course, of 110 miles. Shap Fells, elevated only 1,479 feet above the sea, consist of porphyritic granite, enveloped in schistose rocks. The slope from these fells, eastward, is soon stopped by a bold escarpment of the lower mountain limestone series, which rises to about 1,000 feet in height, and slopes eastward under the flat narrow valley of the Eden, running NNW., which is full of red sandstone, at the bottom of which are certain conglomerate beds. Immediately above, on the east, is an escarpment of the same lower mountain limestone, thrown up to a great height, and surmounted by other rocks of the same formation to an altitude, in Cross Fell, of 2,901 feet; in Shunnor Fell, of 2,329 feet; Water Crag, 2,186 feet, &c. The lowest part of this ridge, *which opens directly to the west*, is the pass of Stainmoor, 1,440 feet, which is almost level with Shap Fells: from hence the slope is almost uniform to the Vale of York, which runs north and south. Beyond rises the oolitic ridge of the eastern moorlands 300 to 1,485 feet; then follows the Vale of Pickering, 100 feet above the sea; and the section crosses over the chalk wolds, 500 to 800 feet, and ends at Flamborough Head, 150 feet above the sea.

It is found that blocks of the Shap granite have travelled down the slope of their native mountains, over the limestone ridge of Orton, across the Vale of Eden, over the limestone ridge of Stainmoor, down and athwart the whole Vale of York, over the oolitic ridge—not at the highest points—and over the chalk hills to Flamborough Head.*

The valley of the Eden is a submarine valley of mesozoic age, defined by elevations of the limestone and slate on either side; the Vale of York has served for the passage of vast bodies of water, which have removed much of its stratified red sandstone, so that the physical features of the country were much the same during the transport of the blocks as at present. But the level of the sea was different. Accumulations marking this level can be traced to about 1,500 feet higher than the actual mean height of the tide, and there is little doubt that after the age of the crag and other preglacial deposits a large portion of the northern hemisphere was depressed; the sea currents were altered; the temperature was lowered; and the mountains, though less conspicuous, were over-

* For details on this and many other instances, read Buckland, Reliq. Diluv.; Conyb. and Phill., Geology of England, Enclyop. Metrop.; Geology of Yorkshire.

spread with snows, which gave birth to glaciers. These, loaded with detritus and broken off at the edge of the sea, were floated away by the currents in various directions, and dropped their load in different parts of the sea.

The difficulty of distinguishing between glacial and old alluvial accumulations may, in general, be removed by attention to these points: 1st. The rock fragments, or boulders, and smaller masses in diluvial deposits, have been generally removed great distances (so that often no rocks of the same kind occur in the drainage of the district), and in directions different from those of existing streams. 2nd. The gravel of these deposits is generally somewhat different in its aspect and manner of attrition from that of old river-courses: it often lies in clay. 3rd. Bones of elephants, oxen, horses, deer, &c., are not unfrequently found in the gravel and clay.

There is good geological evidence that the glacial accumulations are not all contemporaneous—not all the result of one transient agency, but of forces varying in strength and direction, and transporting different materials—clay and pebbles, gravel and sand, in several alternations. But there is such a conformity among the organic remains associated with these deposits, that we are entitled to say these deposits mark, over large regions, first, the termination of a certain geological period, defined by the existence on the dry land of peculiar, chiefly extinct races of quadrupeds; secondly, the submersion of large tracts of this ancient land; and thirdly, the reelevation of it to nearly its present level. The glacial deposits, then, are mostly marine, formed during the descent and reelevation of tracts of land; and they separate the littoral, estuarine, and freshwater formations of the pleistocene ages into the two groups—one preglacial, the other postglacial.

POSTGLACIAL ACCUMULATIONS.

Under this head we shall rank a considerable variety of deposits which have happened on the land, at the shores, and in the sea, for the most part at a remote period; but under the same or nearly the same general conditions of land and sea as those which now prevail; the remains of life connected with them are mostly those of species now living in the same regions; corresponding phenomena are still in progress; and we find ourselves brought to the period when geological time approximates to, if it does not really pass, into historical date.

We shall first notice those lacustrine and peaty deposits, which by their contents, trees, or shells, or bones, seem to claim a comparatively high and definite antiquity, immediately following the glacial period, and then add a few remarks on fluviatile and marine deposits now in progress.

LACUSTRINE SEDIMENTS.

Deposits are formed in lakes from several causes: 1, From the growth of shells; 2, from springs containing carbonate of lime; 3, from mechanical admixtures of sand and clay, and vegetable remains derived from inundations or rivers. Some of these may be of very high geological antiquity; for we may believe lacustrine deposits to have been produced upon the land as soon as it was raised above the sea; and this has been shown to have happened at many different periods. The right way of investigating their antiquity is to study and compare the organic remains imbedded. Thus studied, it is found that all the known *superficial* lacustrine deposits in England are nearly all subsequent to the era when the mammoth existed in northern regions.

The processes connected with lacustrine sediments are various. Lyell has described the production of shell marl in Bakie Loch, Forfarshire, as depending on calcareous springs, and the growth of Limnææ, Cyclades, &c. It contains seeds of Chara, horns of stags, &c. Almost every trace of shells is sometimes obliterated. Certain springs, especially in the volcanic regions of Italy and Auvergne, deposit in lakes a great quantity of carbonate of lime. The accumulation of fine clay in ponds and lakes may be universally observed. Inclined laminæ of pebbles and sand are swept into the Lake of Geneva by the stormy waters of the Rhone, and deposited in the upper part. In some lakes all these processes go on simultaneously.

It is not easy to point out the real or even the relative antiquity of the various lacustrine deposits not associated with marine deposits now known to geologists. We may distinguish, however, among them some which are now in progress in many lakes of Italy, and some in Scotland, England, and Wales.

Others which mark the site of old lakes, nearly contemporaneous with submarine forests, containing the bones of the beaver, the wolf, the red deer, and other existing species of animals, and the extinct Irish elk. (Holderness, Berwickshire.) And probably many lakes of the mammoth era, traversed by floods or rough rivers, and containing bones of the fossil elephant, fossil urus, *Felis spelœa*, and *Ursus spelœus*. (Weighton in Yorkshire; Mundesley in Norfolk.) In the latter locality the fluvio-lacustrine deposit fills an excavation in the boulder clay, and the marine beds above and below it.

Much older are the lakes of the palæotherian period; lakes of the Cantal, &c., which enclose the extinct genera palæotherium, anoplotherium, and lophiodon.

TURF MOORS, SUBMARINE FORESTS, ETC.

In most cases, the submarine forests, as they are termed, lie along the course and near the mouths of great rivers, and are often, perhaps generally, at a level between high and low-water mark, and in a situation where the river sediment, or silt from the tide, has partially covered them. Along the Yorkshire rivers the trees lie generally in a mass of vegetable remains called turf, which occurs at all levels, from about high-water mark to a depth of thirty or more feet beneath it. This surprising spectacle of ancient oaks and firs buried in the earth, in situations where they could not now be made to vegetate, except by the aid of artificial drainage, has not often been carefully described by geological eye-witnesses, and the workmen commonly give but a very confused account of what they have seen. It is by no means certain that in all instances the trees grew where they now appear; the geological era of their growth is sometimes extremely dubious; the ancient condition of the drainage of the country, in relation to the tide-opening of the estuary, is seldom ascertainable: for these reasons the subject is yet in some obscurity.

In one case, near the Humber, the phenomena are not irreconcilable with a probable view of the ancient state of drainage of Yorkshire, without any intervention of subterranean movements: how far this mode of explanation will apply to other cases, may be a subject of further enquiry. In the meantime we may perhaps believe, from the occurrence of peat-beds in the old lakes on the Yorkshire coast, from the certainty of the drifting of peat and timber in other parts, and from the great analogy of the vegetable deposits, that some very general agency was concerned in the prostration and inhumation, and perhaps drifting, of the trees, whether accompanied by a change of level or not. The trees are oak, birch, fir, hazel, alder, yew, &c. With them lie acorns, fir-cones, hazel-nuts, bones of the horse, ox, stag, fallow deer, sheep, &c. (Phil. Mag. 1834.)

The turf-moors of the countries adjoining the Baltic have been the subject of many enquiries, which in the opinion of Danish archæologists, show them to have been accumulated in a long course of time, embracing the 'ages' of stone, bronze, and iron. The animal remains are almost without exception of living species.

VALLEY SEDIMENTS.

In all valleys through which continuous streams, or periodical or accidental inundations pass, the effects of their mechanical action remain more or less distinctly marked. The erosive power of the currents is conspicuous in all the steeper parts of the sloping valley, which, originating generally in a convulsive displacement of rocks, has received, in most cases, its peculiar character from the action of water. According to the nature of the rocks the features of the valley vary. In all the lower parts of the valley, and especially towards the meeting of the freshes and the tide, the sediment brought down from the uplands is deposited on the now level surfaces of the marshes and meadows in floods, or on the bed of the river in the ordinary state of the waters, or carried out to sea.

In many cases, the sedimentary deposits in valleys seem to have little relation to the actual stream. For instance, in the valley of the Rhine, between Strasburgh and Bingen, the deposit called *löss* is found at the height of some hundreds of feet above the river, and seems to have been a very extensive mass, through which, in some cases, the Rhine now works its way. The remarkable terrace-heaps of gravel and sand at the mouth of Glen Roy, and along many other Highland and Cumbrian valleys, is a phenomenon apparently of a similar nature. It seems to prove that these valleys are of high geological antiquity, and that water formerly stagnated in or flowed down them under different circumstances as to level, outlet, and dynamical action from the present.

In some cases the action of rivers, in accumulating sediment, is so regular as to permit the layers to be counted for terms of years. This is observed on the slopes of the Alps to depend on the periodical melting of the snows.

The organic remains in valley deposits are of such land animals and plants as, lying on the surface, were exposed to the inundation. Land shells are very abundant in the löss of the Rhine valley; along the rivers of Yorkshire, hazel-nuts and trees, bones of stags, land and freshwater shells, &c., occur, and in some instances have undergone petrifaction. (Phil. Mag. and Annals, 1828.)

In the Valley of the Somme in Picardy, and in that of the Ouse near Bedford, and in the gravel beds above some other English rivers, artificially chipped flints occur, which seem to indicate an early race of savages contemporaneous with some of the now extinct postglacial mammals, especially the Mammoth and Rhinoceros.

CAVERN DEPOSITS.

Caverns in limestone rocks are of every geological age, since those rocks were exposed to the wasting action of the sea, or of the rains, entering their fissures. They are still in progress, and often are only precursors to yawning chasms, destined afterwards to be moulded into valleys.

There seems reason, therefore, to think that a great proportion of the ossiferous caves of Europe received their interesting contents in the postglacial period, and that several of the races therein buried became extinct in the northern zone, since the arrival of man in this quarter of the globe.

From various causes some of the caverns and fissures naturally existing in thick limestone rocks have been partially filled by a mass of materials holding bones of the rhinoceros, hyæna, and other races of animals. In some cases the animals are conjectured to have entered the caves for the mere purpose of dying in quiet (bear-caves of Franconia); into others, hyænas have been the instruments of dragging the carcasses of elephant, rhinoceros, deer, &c. (Kirkdale, Kent's Hole.) Grazing quadrupeds have fallen or been drifted into others (Mendip caves, the ossiferous fissures of Nice, Gibraltar, &c.); and currents of water have contributed to carry the bones into particular repositories, or to move them along the passages of a cave. The extent of the earth's surface over which ossiferous caves and fissures have been discovered is prodigious. In the North and South of England, in Ireland, South and South-east of France, the Ardennes, the Harz, Franconia, Würtemburg, Switzerland, and along the Mediterranean shores and islands, are the most remarkable localities in Europe. Bone-caves occur in India, North America, South America, and Australia.

Upon the whole the animal remains are analogous in all these situations; but there is much local diversity. It is probable that they are nearly all of one geological period, that in which the mammoth, the woolly rhinoceros, and large hippopotamus were common on the plains and by the marshes and rivers of Europe. No doubt into a cave full of old and extinct quadrupeds others in more modern times might enter, fall, or be driven to die; and thus a mixture of existing and extinct races be occasioned. Still more probable is the event of man, in an early and uncivilised state, or in a state of war and oppression, occupying a cave formerly tenanted by wild beasts, and there leaving traces of human art. Apparently this is the right view of most of the cases of human remains found mixed among, or buried in, or lying upon the heaps of older bones. Some of the caves in the South of France and in Belgium, where human remains, rude pottery, and chipped flints occur, have been found to admit of this explanation; but in the late work of Sir C. Lyell, on the antiquity of man, it is contended that the remains of men are of contemporary date with the animal remains in the caves.

The following animals are frequent in the cavern deposits: most of them are found in the postglacial detritus of the same countries; several of them also occur in lacustrine deposits, of various antiquity.

Ursus spelæus.
—— arctoideus.
Machairodus cultridens.
Gulo spelæus.
Wolf.
Fox.
Hyæna spelæa.
Felis spelæa.
Hare.
Rabbit.
Water Rat.
Beaver.
Horse.
Boar.
Elephas primigenius.
Hippopotamus major.
Rhinoceros tichorhinus.
Megaceros hibernicus.
Cervus elaphus.
Bos primigenius.
—— priscus.
Megatherium Cuvierii.
Megalonyx Jeffersonii.

The remarkable pachydermal genus *Mastodon* occurs in the crag and other tertiaries of Europe, America, and Ava, but not in caverns.

CORAL REEFS, SHELL BEDS, ETC.

The growth of coral in the warm tropical waters, and along the Australian shores, is one of the most important agencies now at work in altering the face of the globe. Coral reefs are not formed at such enormous depths as was once imagined, but they rise from submarine mountain ridges, from the peaks of old submarine volcanos, along the coasts, and around the islands. In these accumulations the lamelliferous corals bear the largest share; but many shells, fragments of other coral, drifted sand, and many other substances lodged in the reef, are enveloped in its growing mass; and thus islands of living rock slowly emerge from the middle of the ocean, gradually become heightened by the heaping up of the materials broken from their edges or drifted by the sea, covered by trees and inhabited by birds and a few other animals. The coral reefs of the Bermudas are described as partly a mass of chalky or granular carbonate of lime, derived from comminuted and decomposed coral, and as taking a form depending partly on the currents of the sea. The elevation above the sea which some West Indian coral islands assume is ascribed to volcanic action. We have already noticed the opinion, which is gradually gaining ground among geologists, that several of the limestone strata are locally to be regarded as magnificent coral reefs.

In particular parts of the sea the currents drift shell and fishes' teeth, so as to make the seamen remark the fact in their soundings. This is analogous to many cases of the accumulation of shells and shelly fragments in particular parts of the ancient strata.

COAST SEDIMENTS.

The materials brought into the sea by rivers, and obtained from the incessant wasting of cliffs, are not all carried down to the depths, but in a great measure restored to the land, where the coastward currents cease their movements. This happens generally along some low shore, which only just rises above the gradually deepening waters, in some land-locked bay or estuary. The most rapid growths of new land certainly adjoin, or are influenced by, the mouths of great rivers; but many considerable tracts are only remotely dependent on such influence. It is not so much by the mud which descends with the Ouse, the Dun, and the Trent, that the coast of Lincolnshire has been extended, as by the materials brought from the ruined cliffs of Holderness; neither have the sluggish streams which meander through the fens of Cambridgeshire yielded that mass of matter which, since the Roman sway in Britain, has been added to the coast, to the extent of miles, beyond their line of embankment. The case is different along the shore of the Adriatic, where the torrents from the Alps bring such loads of sediment as to promise the eventual conversion of all the northern end of that sea into marsh land. The flatness of these *foreshores* corresponds with the degree of quiescence of the water, and the laminæ, which cover one another successively, are not quite horizontal, but form long inclined planes, sloping seaward.

Storms, or varying circumstances, may produce a temporary derangement of the laminæ, or spread layers of pebbles, or scatter shells over the surfaces. A variety of marine worms may leave their traces, or marine reptiles the prints of their feet; but generally, remains of such animals, of shells, and plants, are very rare in marsh lands formed under shallow waters. In this manner we may conceive some sandstones of the old strata to have originated; and account for many of their peculiar appearances. The pebble beaches along some parts of the English coast may remind us of the appearance of some conglomerates.

SANDBANKS.

The agitation of the ocean is so unequal, even on the same line of coast, that in some parts sand, in other parts fine clay, in others pebbles, are accumulated, according to the moving force of the water. Generally, the materials which fall from sea cliffs are sorted by the tide; pebbles drop quickly near their original sites; sand moves further; fine clay is transported for leagues along the coast. The sandbanks along many parts of the coast are either stationary or moving, augmenting or decreasing, according to the circumstances of the oceanic currents. Along the east coast of England especially, but everywhere more or less, the submarine sandbanks are cut through by real channels, which might be properly called tidal valleys.

This fact is perhaps analogous to the well-known irregularity of the extent and thickness of many of the ancient stratified sandstones.

Certain modern sandbanks are occupied by weeds, cockles, oysters, or fishes; others not. This is also to be compared with the very irregular distribution of organic remains in the sandstone rocks.

MODERN ELEVATIONS OF THE SEA-BED.

The geologist must on no account think it out of the bounds of his legitimate province to examine with care and interest into the history of the processes now performed in the ocean and on the land; for it is only by discrimination and generalisation of these that we can hope to draw satisfactory inferences concerning the force and direction of the agencies formerly exerted in earlier oceans, and on earlier continents.

There is, in fact, no hard line of separation between the modern sea deposits and the ancient submarine strata. In some situations the sea-bed has been laid dry, at epochs within the reach of history, as by volcanic action at Santorino, in the Grecian Seas; in other cases, in periods which ascend beyond the existence of mankind, to the earlier era of the mammoth, as in the eastern parts of Yorkshire. The deposits thus exposed to our view often present characteristics of organic life and mineral aggregation, which are distinct both from those of diurnal occurrence, and from those of the tertiary periods; but as frequently they display intermediate characters, and thus connect the actual with the past—the modern reef with the ancient coral rock—the sediments of to-day with the sandstones of immeasurable antiquity—the shell and fish banks of our shallow seas with the crag, the lias, and the mountain limestone.

The most frequent examples of such elevations of the sea-bed are called 'Raised beaches.' Such occur in Sweden extensively, as at Uddevalla; on the English coast, as near Preston in Lancashire, and near Filey in Yorkshire; on the Scottish coast, as in the vale of the Clyde, and the valley of the Forth; on the Irish coast, as about Wexford. Similar cases abound on the shores of Europe and America. In the sand or argillaceous deposits referred to, moderns hells often occur, and in great numbers, such as Turritella terebra, Cardium edule, Littorina littoralis, &c. Occasionally an extinct species appears among them. The elevation of such deposits above the sea is generally from 10 to 100, but reaches 1,400 feet on Moel Tryfane in Wales.

In judging of the upward extent of these movements of the sea-bed, we shall find the benefit conferred on geology by Professor E. Forbes's surveys of the British and Ægean seas. From his dredgings at various depths we learn that the invertebral life of the ocean may be classed in several zones of depth, and that to each zone some *characteristic* forms of plants or animals, or, in the case of shallow seas, both, may be assigned. In the Ægean we have soundings to the depth of 1,380 feet; and dividing the depth into eight zones, we find the following useful table of characters.*

1. Littoral Zone—to depth of 12 feet; the bottom variable. *Plants*, Padina pavonia. *Animals*, Littorina cærulescens, Fasciolaria tarentina, Cardium edule.
2. Zone from 12 to 60 feet; ground variable. *Plants*, Caulerpa, Zostera. *Animals*, Cerithium vulgatum, Lucina lactea, Holothuriæ.
3. Zone from 60 to 120 feet. Ground muddy or sandy. *Animals*, Aplysiæ, Cardium papillosum.
4. Zone from 120 to 210 feet; ground gravelly and weedy or muddy. *Plants*, Dictyomenia volubilis, Codium bursa. *Animals*, Ascidiæ, Nucula emarginata, Cellaria ceramoides.
5. Zone from 210 to 330 feet. Ground full of Nullipores and shelly. *Plants*, Rityphlæa tinctoria. *Animals*, Cardita aculeata, Nucula striata, Pecten opercularis, Myriopora truncata.
6. Zone from 330 to 474 feet. Ground mostly nulliporous. *Plant*, Nullipora. *Animals*,

* Reports of British Association, 1843.

Venus ovata, Turbo sanguineus, Pleurotoma maravignæ, Cidaris hystrix.

7. Zone from 474 to 630 feet. Ground mostly nulliporous. *Plant*, Nullipora. *Animals*, Brachiopoda,[1] Rissoa reticulata, Pecten similis, Echinus monilis.
8. Zone from 630 to 1,380 feet. Ground yellow mud, full of remains of Pteropoda and Foraminifera. *No Plants. Animals*, Dentalium 5-angulare, Kellia abyssicola, Ligula profundissima, Pecten Hoskynsi, Ophiura abyssicola, Idmonea Alecto.

The study of the 'ancient sea-margins,' as Mr. Chambers justly calls them, which the raised beaches, and the terrace lines of watery action often associated with them, indicate, is one of the most curious parts of modern geology. They are really of all geological ages; and by their help, conjoined with the independent data regarding depths of marine life furnished by such dredgings and such reasonings as those of Forbes in the Ægean Sea, we shall find many parts of the hydrography of the Old World come more distinctly into view, and afford standing points for those philosophical views of the ancient land and sea at successive epochs, to which man is invited by geology.

CHAPTER VIII.

LITHOLOGY.

THE composition of the stony crust of the earth has for many years, especially in England, been but lightly regarded by geologists, except in relation to the organic remains which it includes. Yet the mineral constitution of rocks offers matter of research, which must be prosecuted by mineralogists, and ought to be interesting to the geologist. It is, however, only within a few years that chemists have been able to trace a clear road through the perplexities of the silicates which form so large a portion of the rocks of fusion; and hardly a longer period has elapsed since the completion of such a system of crystallography as to render the recognition of minerals comparatively sure. In the following remarks we shall mention a few of the minerals which enter into the composition of rocks, such as appear most essential for a student to know; and shall add short descriptions, with figures, which may assist him in distinguishing them. Let him, however, obtain specimens and examine them frequently; for it is a good rule in this, as, indeed, in all parts of natural history—

Nocturnâ versare manu, versare diurnâ.

The characters by which the student of rocks will most easily recognise their mineral constituents are: 1. The crystalline form, colour, and optical peculiarities; 2. The specific gravity; 3. The degree of hardness on the following scale:—

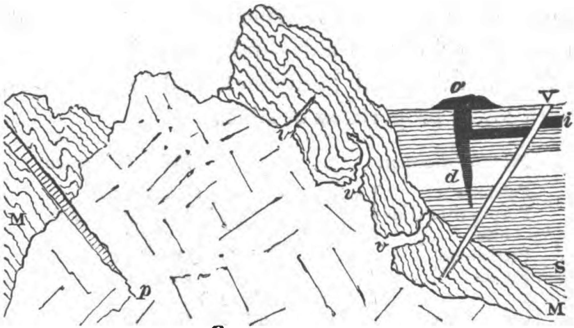
Diamond	10	Apatite	5
Corundum	9	Fluor spar	4
Topaz	8	Calcareous spar	3
Quartz	7	Selenite	2
Orthoclase	6	Talc	1

4. The action of the blowpipe, marking the degree of fusibility and the product of fusion; 5. The action of chemical reagents, especially nitric and hydrochloric acids.

PLUTONIC ROCKS.

Mostly formed under the heavy pressure of thick strata or deep sea, these silicates of the alkalies and earths appear in a variety of forms, which may be understood by help of a diagram like that annexed.

DIA. 15.



G is granite below the metamorphic strata M, into which it throws veins *v*. A dyke of porphyry, *p*, passes through the metamorphic rocks into the granite; and a mineral vein, V, traverses the strata S; greenstone is marked *d* where it is a dyke, *i* where it is interposed, and *o* where it is overlying.

The difference between these rocks and ordinary volcanic accumulations depends probably on the subaerial consolidation of the latter, which thus on the whole have less compactness of texture, more frequent cavities, and a larger proportion of ashes gathered in conical forms round centres of eruption. Could we examine the deep foundations of volcanic energy, probably the rocks there solidified from fusion might closely resemble the older gifts of subterranean heat which we call greenstones, porphyries and granites.

The affinity of the ancient plutonic and the modern volcanic rocks may be illustrated by placing some of each division in a general scheme of classification suited to both. This scheme is founded on the predominance of one or other of two groups of minerals—felspar and its highly silicated allies, and hornblende and its associates, with lower proportions of silica.

Plutonic division.		*Volcanic division.*
Felstone Porphyritic Granite Pitchstone Eurite	Felspathic Order. Silica 60 to 80 per cent.	Clinkstone. Porphyritic Trachyte Obsidian Domite
Greenstone Whinstone	Hornblendic or Augitic Order. Silica 45 to 55 per cent.*	Dolerite Basalt

Not less clearly appear the general affinity and the special difference of these rocks if we attend to their textures, as in the subjoined comparison:—

Plutonic.	*Volcanic.*
Mostly crystallised.	Often crystallised.
Sometimes fine-grained.	Often fine-grained.
Rarely cellular.	Often cellular.
Rarely glassy.	Sometimes glassy.
Porphyry frequent.	Porphyry rare.†
Amygdaloid rare.	Amygdaloid frequent.
Ashes rare.	Ashes abundant.

* The proportions of silica are from Cotta's 'Gesteinslehre.'

† Exceptions occur where the deeper parts of the volcanic masses have been brought up to the surface; as in Mont Dor and Mexico.

By the study of modern volcanic rocks, consolidated under different degrees of pressure and different rates of cooling, by experiments under like conditions, and by observation of old plutonic rocks in large masses and small veins, it is concluded that from one given mass of fused mineral matter might be derived largely crystallised rocks like granite, or a more compact mass like porphyry or felstone, or a glassy product like pitchstone, or vesicular and fibrous masses like amygdaloid and pumice-stone. The various textures of plutonic rocks, now to be mentioned, do not then show so much original peculiarities of mineral and of chemical nature as differences of conditions under which they were consolidated.

Granite, the most abundant of the felspathic order of plutonic rocks, is worthy of even more careful and prolonged study than its conspicuous beauty has secured for it. It is a mass of felspar, quartz, and mica crystallised together. The quartz, an essential part of the compound, seems rarely to be crystallised in freedom, but to fill up spaces among the other minerals. The mica is found penetrating with its six-sided plates and short prisms both the quartz and the felspar. When cavities occur, each of these minerals may be seen freely crystallised on the walls of the cavity, sometimes with topaz and beryl. The felspar is generally of the kind called orthoclase, with three cleavages and containing potash. In other examples it is albite, with soda; and a third sort called oligoclase, with less distinct cleavage, is recognised, especially in Norwegian granites. Tourmaline is common in Cornish granites, and garnet in those of Ross-shire.

The quartz is usually gray and translucent; the mica black, or of a pearly white; the felspar red, white, or greenish, rarely translucent, except in thin flakes. Some of the most durable granites are polished at Aberdeen. The specific gravity of granite is about 2·65. The per-centage of silica in the aggregate is about 75.

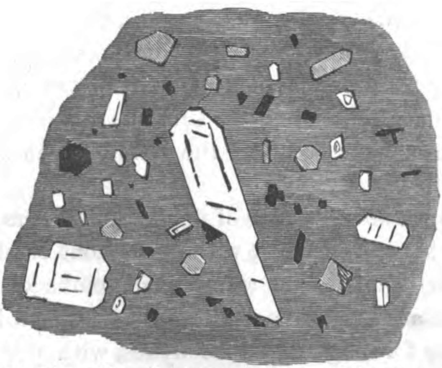
DIA. 16.

Porphyritic granite of Shap Fell. The large crystals are orthoclase, the black is mica, the gray parts quartz.

The mica sometimes becomes very scanty or entirely fails, leaving a binary granite which has been called aplite. When the quartz appears in angular masses, surrounded by largely crystallised felspar, the rock is called graphic granite or pegmatite. If, in addition to the ordinary granular mixture of the minerals, large scattered crystals of orthoclase occur, the rock is called porphyritic granite. A fine example occurs at Shap Fell, and others in Ben Nevis, Cornwall, &c. Veins pass from all varieties of granite.

Eurite, the Whitestone of Werner, is a very fine-grained granular mixture of felspar and quartz, with variable, sometimes very small, proportions of mica. It occurs in contemporaneous veins, or segregated masses, in ordinary granite, as at Dalkey. Specific gravity as granite.

DIA. 17.



Elvanite, with crystals of orthoclase, quartz, and mica.

Elvanite, a Cornish rock composed of granular or compact felspar, mixed with quartz; distinct crystals of felspar and quartz and even mica appear in the compact varieties, so that it is a sort of granite porphyry, and is probably associated with, or a ramification from, granite. An allied rock occurs red in Dufton Pike, with large crystals of mica. Specific gravity as granite.

Felstone, including the 'compact felspar' of MacCulloch, and other mixtures of quartz and felspar, not distinctly crystallised, is a very common rock, often occurring as a metamorphic product among old slaty deposits; as under Helvellyn and Cader Idris. It varies in the proportion of silica, but is usually richer in that substance than granite, sometimes containing above eighty per cent.* Imperfect crystals of felspar appear in some examples, perfect crystals in others, thus producing a true porphyry. Less common are the concretionary textures, called amygdaloidal. The more siliceous and less fusible varieties have received the name of hornstone. Specific gravity, 2·6.

Claystone has a basis of uncrystallised, granular, almost earthy felspar, with or without crystals of felspar, quartz, and rarely mica, embedded. It occurs of red, yellow, and gray tints in the Isle of Arran, forming numerous dykes, with prisms at

* Haughton in 'Jukes's Manual,' p. 71, 2nd ed.

right angles to the bounding surfaces. On the western side, the rock is porphyritic, with abundance of included felspar; amygdaloidal textures also occur. Specific gravity, 2·2 to 2.6.

Pitchstone, a glassy felspathic rock, with or without crystals of felspar, and small spherulitic concretions. This interesting rock occurs in the Isle of Arran, in dykes and interposed masses of green, reddish, or black tints, and often assumes the prismatic structure. In the island of Eigg it is largely porphyritic. It contains a notable quantity of water. Specific gravity, 2·3 to 2·6.

The three rocks named felstone, claystone, and pitchstone, each becoming porphyritic, have great natural affinity. They conduct to elvan, as this to eurite and granite; and may all be entitled 'Felspathic Traps,' to mark their frequent occurrence in dykes and interposed beds, rather than in huge amorphous masses like granite.

Porphyry, from what has been said, is usually formed by the occurrence of separate crystals in an uncrystallised base of felstone. Thus the dark red rock of Ulfdalen, with its felspar crystals; the beautiful pale red dykes of Armboth Fell, near Thirlmere, with its crystals of felspar and quartz; the fine pale stone of Bodmin, with crystals of felspar, quartz, and mica, as well as the celebrated verde antico, come within the modern notion of porphyry, though only the first might have been acknowledged by the ancients. Granites and greenstones also become porphyritic, and perhaps it will eventually be found best to employ the adjective in a scientific, and the substantive in a popular sense. We shall then have porphyritic varieties of every felspathic rock.

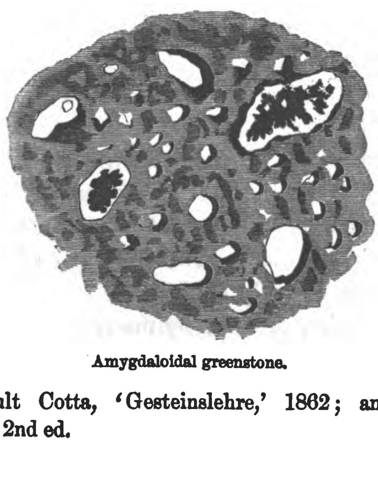
Syenite, which commences the hornblendic order, if we take the rock of Syene for type, is granite with hornblende added, the quartz and mica being reduced in amount, the latter sometimes absent. It is not a satisfactory term; too great a latitude has been allowed in the use of it; too little conformity of usage has been observed by the geologists of Germany and England. Orthoclase felspar and hornblende distinctly crystallised together, with variable admixtures of mica, quartz, epidote, titanite, and oxidulous iron, would be called syenite; the felspar is usually red or white. This occurs in the Malvern Hills, Charnwood Forest, and Carrock Fell, with various compounds of a granitic aspect, and masses of rich hornblende mixed with a small quantity of felspar. No veins pass from these hornblendic syenites into the stratified rocks of Malvern. The specific gravity of the syenite of Charnwood Forest is about 2·8. In Norway occurs the remarkable variety called Zircon syenite. The geological history of the more quartzose syenite is the same as that of granite—the syenites with larger proportions of hornblende have more affinity with greenstones.

Greenstone* follows naturally the syenitic

DIA. 18.

Greenstone, large grained.

DIA. 19.



Amygdaloidal greenstone.

* Consult Cotta, 'Gesteinslehre,' 1862; and Jukes's 'Manual,' 2nd ed.

rocks, and has a more positively basic character of its silicates, and a smaller per-centage of silica. If we regard it as a family of rocks, it may include nearly all the various mixtures of felspars distinct from orthoclase, with hornblende, and some analogous minerals. It seems convenient, however, to employ special terms for some of these mixtures, which are commonly known as trap, and occur in dykes and overlying and interposed masses.

Hypersthenite is a mixture of the felspar called labradorite with the variety of hornblende called hypersthene, in small or large crystallisation, with titanite, magnetite, iron ore, garnet, &c. In some Swedish rocks called norite, the felspar is said to be orthoclase, and in the Valteline it seems to graduate toward syenite. The specific gravity is about 3·00. The silica is about 50 per cent. The Isle of Skye is the best example in the British Isles.

Diallage Rock differs from the preceding only by the small distinction of the variety of hornblende which it contains. It occurs in the Lizard district of Cornwall. The Italians call the rock gabbro; the French, euphotide.

Serpentinite, treated by many geologists as a metamorphic rock, seems, however, by its abundantly contained diallage or bronzite, to claim a place near Diallage Rock, with which it is associated in Cornwall. It does not seem to be the talcose mineral called serpentine which encloses the diallage, but rather a soft felspathic substance often traversed by veins of steatite. In the Lizard district, no true stratification can be traced in it, nor is there any ordinary cause of metamorphism traceable. In the Pyrenees, Apennines, and Corsica it is common. The proportion of silica is about 40 per cent.

Diorite is the French term for a simple greenstone, composed of some other felspar than orthoclase, and common hornblende. The orbicular greenstone of Corsica shows a singular segregation of the minerals in concentric zones. The crystallisation so evident in this variety is much less so in other cases, but, according to our own observation, always traceable. The specific gravity is about 2·9; the per-centage of silica about 50. This is a frequent rock in the dykes and seeming beds in the Palæozoic strata; Arthur's Seat and Salisbury Craig contain it. It commonly encloses sulphide of iron.

Melaphyre is a name of Brongniart's, the application of which to hornblendic rocks is much too vague to be satisfactory. It may perhaps be employed to collect into one group many varieties of rock less crystallised than diorites, and less simple in texture. It may thus admit the rock of Fassa-thal, with its crystals of augite; the amygdaloidal traps of Scotland and Oberstein; and the less compact whinstones of Durham and Northumberland.

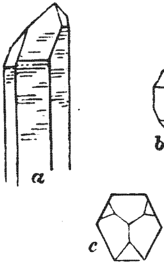
Diabase is a name given by Brongniart, to which Cotta assigns the greenstones, with a fine-grained crystalline mixture of some felspar not orthoclase, with augite, and some chlorite. The texture is sometimes porphyritic and sometimes amygdaloidal. It contains magnetic iron ore, and sulphide of iron, besides calcite and other minerals, in cavities of the amygdaloidal varieties.

Aphanite, a dark greenish rock, which appears to be of the same composition as diabase, but so very close-grained that the constituent minerals can hardly be distinguished. It occasionally contains distinct crystals, of felspar, hornblende, or augite, and encloses cavities or concretions with calcite or zeolites. It bears to the obviously crystallised greenstones the same relations as basalt to dolerite.

In the composition of Plutonic rocks the minerals most essential to be known are grouped under a few families which may now be noticed.

Quartz is a compound of one atom of silicon, and two atoms of oxygen; giving silicon 46·7 and oxygen 53·3 per cent. Its crystalline system is rhombohedral, and one of the most usual forms a six-sided prism, with pyramidal summit; colour various, but in granite transparent. Specific gravity, 2·65. Hardness, such as to scratch glass very easily. Infusible before the blowpipe. Insoluble in acids.

DIA. 20.

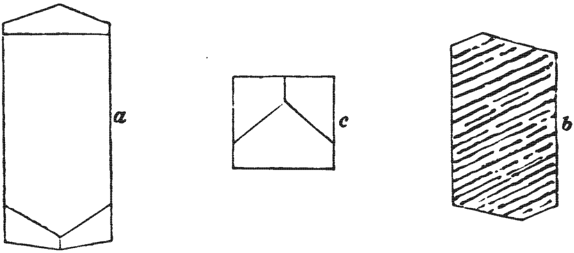


a. Crystal from the granite of Mourne mountains.
b. From Leitrim. *a* and *b* parallel to the axis.
c. Pyramidal termination of *b*.

Felspar is the family name of several minerals which contain a silicate of alumina combined with another silicate, the base of which may be potash, or soda, or lime, or two of these. The crystals always belong to the oblique, or else the doubly oblique system. Their specific gravity varies in the different species, but is always between 2·5 and 2·8. Hardness, 6. They are all fusible by the blowpipe, and insoluble in acids.

Orthoclase (ὀρθὸς, right, and κλάω, to cleave), is a compound of trisilicate of potash and monosilicate of alumina, one equivalent each, yielding silica, 65·35; potash, 16·59; and alumina, 18·06. Its crystals are of the oblique prismatic system, and show three clear cleavages. The glassy variety in volcanic rocks is called Sanidine.

DIA. 21.



a. Prismatic crystal of orthoclase from granite of Arran.
b. Glassy felspar from Drachenfels, showing the striation, on a plane perpendicular to that seen in *a*.
c. Terminal planes of *a*.

Albite, named from its frequently white colour, differs from orthoclase, chemically, by containing soda, instead of potash, and in crystallisation by its assuming the doubly oblique prism, which, however, is nearly alike to that of orthoclase.

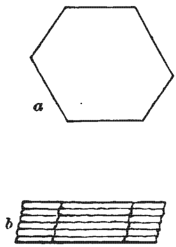
The diagrams above given, especially *a* and *c*, would suit almost equally well for albite; the difference being the want of exact rectangularity in albite, in those planes which are rectangular in orthoclase.

Oligoclase (*ολιγος*, little, and *κλαω*, to cleave), is less easily cleavable than orthoclase, and differs chemically from it and albite, by not containing a trisilicate. Its composition is—silica, 63·0; alumina, 23; soda, &c., 14. Its crystals have the same angles as those of albite.

Labradorite is a compound of silicates of alumina, lime, and soda, yielding silica, 53·69, alumina, 29·68; lime, 12·13; and soda, 4·50; thus appearing to be the poorest in silica of the felspars now described. Its crystals conform to the same oblique prism as albite. Specific gravity, 2·68—2·74. Rhyacolite has a similar composition, but belongs to the oblique system.

Mica.—Of this brilliant mineral, there are several kinds, and many colours. One of the

DIA. 22.



a. Six-sided table of Mica; *b*. the same seen edgeways.

most common in granite, now called Muscovite, is composed of trisilicate of potash, and a basic silicate of alumina — yielding about 48 silica, 37 alumina, 10 potash, and 5 oxide of iron. It crystallises in short, six-sided oblique prisms, with cleavages parallel to the terminal planes.

Specific gravity, 2·7–3·1. Hardness, 2—3. Fusible. Insoluble.

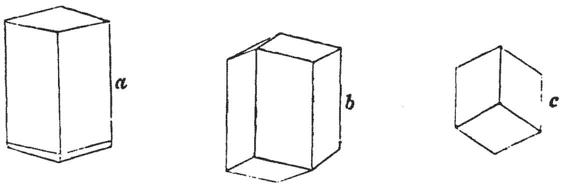
Margarodite, a white mica, occasionally found in granites, differs not much in composition from ordinary mica, but has rather less silica.

Lepidomelane, or black mica, has still less silica, contains more of oxide of iron than of alumina, and is uniaxial for light. Its specific gravity is 3·0.

Chlorite, a green mineral which occurs in tabular, six-sided crystals, is supposed to replace mica in some granites. It occurs also in metamorphic rocks and in mineral veins. It contains about 30 per cent. of silica; specific gravity, about 2·8. Hardness, 2.

Hornblende includes several compound silicates, in which magnesia, lime, iron, and alumina occur

DIA. 23.

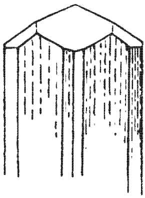


a. The oblique six-sided prism, presenting two adjacent similar faces: *b*, the same seen at right angles to *a*. *c*, the terminal faces of the prism.

as bases, in variable proportions. The silica in magnesian and calcareous silicates is quoted as high as 60 per cent.; in some others with iron and alumina for bases, as low as 40. Its crystals follow the oblique system. Their specific gravity is about 3·2; their hardness, 5·5. Easily fusible; not soluble in acids.

Tourmaline is a very compound silicate, in which the principal base is alumina, and one of the

DIA. 24.



Striated prism of Tourmaline.

common ingredients is boracic acid, which is a local product of volcanoes. Silica, 36—42; alumina, 30—44; boracic acid, 6—10; with soda, oxide of iron, manganese, &c. Crystallisation, rhombohedral; a frequent form being a six-sided prism, (often striated) with trihedral or hexahedral summit. Colour, black, and of several other tints. Specific gravity, 3—3·2. Hardness, between felspar and quartz. Acquires electricity by friction and heat. Fusible and swelling up under the blow-pipe.

Zircon is a silicate of zirconia, nearly pure, yielding silica, 33·7; and zirconia, 66·3. Crystallisation, square prismatic, or square pyramidal, with brilliant faces; colour, of a reddish-gray or

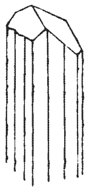
DIA. 25.

a. Square prism, with four terminal faces.
b. Octahedral crystal.

yellow; specific gravity, above 4·0. Hardness, 7·5, exceeding that of quartz. Infusible by the blowpipe. It occurs in the syenite of Norway, and the granite of Criffel, in basalt on the Rhine, and in gneiss near Stockholm.

Epidote (ἐπίδοσις, augmentation) is a double silicate of alumina and lime, with small quantities

DIA. 26.



Striated prism with two terminal faces.

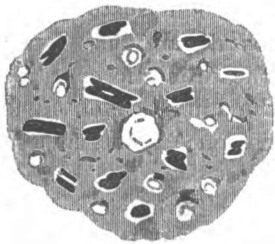
of oxide of iron, magnesia, &c.; silica about 40 per cent., alumina about 30, lime, oxide of iron, and oxide of manganese (in variable proportion), about 30 per cent.

Crystallisation, a slightly oblique rhombic prism, often much elongated, with striated sides and dihedral summit; colour often green; lustre brilliant. Specific gravity, 3·2 to 3·5. Hardness, between felspar and quartz: fusible. Prehnite differs in composition from epidote chiefly by containing water; its system of crystallisation is the right rhombic prism.

VOLCANIC ROCKS.

The lava currents (*coulées*) which issue from a burning mountain are completely fluid mineral compounds, which, according to circumstances affecting them after their eruption, solidify into glassy, cellular, compact, or crystalline rocks. Rapid cooling of lava leaves it a glass; slow cool-

DIA. 27.



Lava from Vesuvius, with crystals of leucite and augite.

ing, a crystalline rock; gaseous extrications make it a cellular mass. It is found that lava solidified under water, that is, under the *pressure* of water, is less cellular and more dense than parts of the same current which were indurated in the air. Hence we see that the *rate of cooling* and the *degree of pressure* control in a remarkable degree the condensation of lava, and determine some of its most general characters.

The chemical composition of lava is generally such as to give origin to abundance of glassy felspar, or of augite with felspar. The felspar is composed of silica, 65; alumina, 15—17; potash, 13—15. The augite, of 50 silica, 24 lime, 12 to 28 oxide of iron, &c. As an intermediate case, the compact lava of Catania and Calabria yields 51 silica, 19 alumina, 10 lime, 4 soda, 14 oxide of iron, 1 muriatic acid. Basalt is an augitic lava, generally consisting of about 46 silica, 16·5 alumina, 9 lime, 20 oxide of iron, and 3 or 4 soda. Trachyte is a felspathic rock. Between trachyte and basalt are innumerable varieties, depending on the proportions of augite and felspar, and on the admixture of olivine, oxide of iron, hornblende, quartz, and many other minerals.

Many volcanoes have yielded, as superficial products, both basalt and trachytic lava; but the far greater portion of basaltic rocks has been formed in subterranean or subaqueous sheets, and subsequently elevated with the strata; the same is supposed by some writers to be the case with the trachytes of the Mont Dor and some other localities.

SITUATIONS OF ACTIVE VOLCANOES.

In European Islands and Sea-coasts. Ætna, Vesuvius, Stromboli, Vulcano; several in Iceland; Jan Mayen, Santorino.

In African Islands. Teneriffe, Lanzerote, Cape Verd Isles, Azores, Isle of Bourbon, Madagascar.

In Asia. On the Continent: Demavend, Kamschatka. In the Islands: Zibbel Teir (Red Sea), an Island in the Sea of Azof, Aleutian Islands, Kurile Islands, Japan, Loo Choo, Formosa, Luçon, Fugo, Mindanao, Celebes, Ternate, Fidore, Sumbawa, Java, Sumatra, Barren Island, Banda, New Guinea, New Britain, New Ireland, Friendly Islands, Society Islands, Ladrone Islands.

In America. The Continent: North California, Mexico, Nicaragua, Guatemala, Colombia, Peru, Chili. West Indian Islands, Galapagos.

The principal volcanic accumulations are ashes, scoriæ, and ejected stones, forming the cone of the crater; ashes, and other ejecta, accumulated by rivers and in lakes; lava currents solidified on land, in lakes, and in the sea. These deposits may alternate.*

* Consult Daubeny on Volcanoes.

Taking these in the same order as their plutonic rivals, we have, first, those felspathic lavas, rich in silica to the extent of 60 or 70 per cent., and commence with trachyte, an abundant product of the old volcanoes of Auvergne, which derives its name from τραχὺς, signifying rough. It is a confusedly crystalline mass of oligoclase, or of glassy orthoclase, with small additions of hornblende or augite, and dark mica—and often titanite and magnetic iron ore. With large imbedded crystals of sanidine, or glassy orthoclase, it constitutes the porphyritic trachyte of the Drachenfels; in a fine equal grained oligoclastic mass, it makes the domite of Auvergne. Largely grained, it has a loose granitic aspect in the Mont Dor. Some cases occur of the formation of small spherical concretions instead of crystals in trachyte; it is occasionally compact, sometimes cellular. Silica, about 70 per cent. Specific gravity, about 2·5.

Pearlstone is of nearly the same ultimate composition as trachyte; but is full of globular, adherent, semivitreous concretions, of very minute or considerable size. Hungary gives a variety of examples.

Clinkstone, or phonolite, is a compact felspathic mass, divisible into thin laminæ, which rings when struck. It appears to contain a notable quantity of water. Silica, about 60 per cent.

Obsidian is the glass of trachytic rocks, probably cooled under conditions unfavourable to crystallisation of the constituents. Crystals of felspar do, however, appear in it occasionally. Ascension Isle yields fine dark obsidian. It occurs also green, and of a pale tint. Silica, about 70 per cent.

Pumice is volcanic glass expanded into a network of cells and filaments, by gases or steam extricated from the fused mass of obsidian.

Trachydolerite is a term employed by some writers to mark some of the varieties of lava intermediate between the highly silicated trachytes, and the basic or poorly silicated dolerites. It has no definite characters.

Proceeding now to the hornblendic and augitic division, we first notice the black or gray rocks called dolerite, composed of a granular mixture of crystallised felspar (usually labradorite), and augite, with occasional admixture of titaniferous oxide of iron, zeolites, and other materials. The texture is even, or cellular, amygdaloidal, or porphyritic. Much of the dark, cellular lava of the old volcanoes of central France is of this rock. The labradorite is sometimes replaced by nepheline, and is then called nepheline-dolerite. It is supposed to be common among plutonic, as well as volcanic rocks.

Basalt is distinguishable from dolerite only by its compact texture, and the cross jointing of its prisms. Olivine, with zeolite and other minerals, including carbonate of lime, occurs in basalt. The Isle of Staffa and the Giant's Causeway offer the best examples. The name of anamesite has been given to varieties intermediate between dolerite and basalt. A peculiar lava, more common in the old ejections of Somma than in the modern currents from Vesuvius, is called leucite rock by Abich and others. Leucite mixed with augite is the basis of the mass, which is often enriched by large separate 24-hedral crystals of leucite. It is sometimes cellular and amygdaloidal.

Volcanic rocks in a decomposed earthy state have received the name of wacké. In some cases materials of this kind, or ashes, have been reaggregated, in irregularly bedded shapes, as in the Calton Hill, Edinburgh. The rock is usually traversed by strings, and filled with nodules, of calcareous spar, chalcedony, and quartz, and becomes what is ordinarily called amygdaloid.

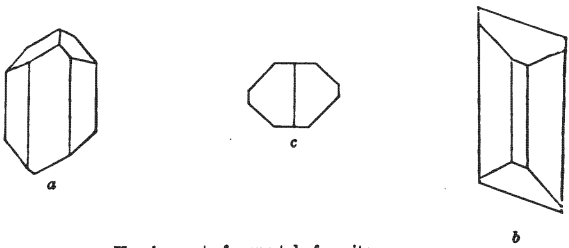
The products of volcanic action are either blown into the air by the explosive gases and vapours which accompany a volcanic eruption, and fall as dust, ashes, scoriæ, and stones; or are poured out in a stream of melted rock from the summit, or more generally the flanks, of the volcano. In consequence of the explosive force being directed nearly vertically, and the ashes falling on all sides equally round the aperture, the hills of scoriæ, ashes, &c., accumulated round a volcanic vent, are always conical. Whether lava currents issue from the apex or the side, they merely cause a slight irregularity in the figure; but a new explosive vent opening toward the base of the mountain may throw up a new hill. Thus several cones on the flanks of Ætna have been thrown up.

Heavy rains often accompany volcanic eruptions. These may sweep down the falling clouds of ashes to some plain or other repository in enormous quantities: thus, probably, the city of Herculaneum was buried, while Pompeii and Stabiæ were overwhelmed with dry ashes. The volcanic ashes deposited in lakes and hollows form what is called volcanic tuff; at Naples, puzzolana; on the Rhine, trass. The loose stones, scoriæ, ashes, &c., thrown into the air by a volcano, are generally of the same mineral composition as the lava currents, and are probably derived from the melted rocks within the crater, acted on by steam and gaseous expansion. It is evident that such ejections may happen from beneath the sea or lakes, but the depth of the ocean and other circumstances seldom permit their appearance. The short-lived island of Sciacca, on the Sicilian coast (1831), threw up a vast heap of scoriæ, &c., probably from a depth of above 100 fathoms in the sea. These loose materials, subsequently agitated in the water, and collected on the bed of the sea into irregular strata, will, probably, constitute a marine puzzolana, or volcanic sandstone, which may or may not contain marine shells.

Most of the minerals already mentioned, as of frequent occurrence in plutonic rocks, also occur in the volcanic series, with others less common in the older rocks. Among these may be mentioned nepheline, augite, leucite, olivine, several zeolites, specular iron ore.

Augite, like hornblende, is a compound silicate, the most prevalent bases being lime and magnesia. The oxides of iron and manganese and

Dia. 28.



a. Usual aspect of a crystal of augite.
b. The same seen at right angles to *a.*
c. The dihedral summit of the oblique prism.

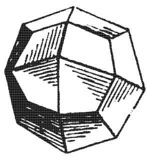
alumina also occur, and sometimes in large proportions. The proportion of silica is least when these three bases prevail, viz., 48 ; and greatest when they are absent, viz., 56. The crystalline system is oblique; the colours black, green, gray, or white. Fusible, insoluble; specific gravity, 3·2—3·5. Hardness, 5—6.

Hypersthene, diallage, and bronzite have the crystalline forms of augite, and no essential difference of chemical composition.

Olivine is essentially a double silicate of magnesia and oxide of iron, with 40 per cent. of silica; it crystallises in the rhombic system, and when transparent is called chrysolite, but is generally in uncrystallised masses. Colour, usually of a light yellowish green. Specific gravity, 3·3 to 3·5. Hardness, 6—7.

Leucite is a double silicate of alumina and potash, with 56 per cent. of silica. It crystallises in the form of a regular 24-hedron. Colour, pale gray. Specific gravity, 2·4. Hardness, 5·5

DIA. 29.



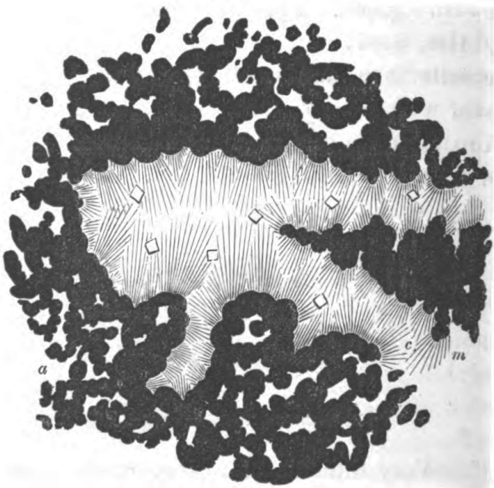
Dodecahedral crystal of leucite.

—6·0. Very difficult of fusion. Soluble in hydrochloric acid. Abundant in some Vesuvian lavas.

Zeolitic minerals are a considerable family of silicates holding water; they occur in the hornblendic division of plutonic rocks, and in the augitic division of volcanic products.

Analcime is a double silicate of alumina and soda, with water, yielding silica 55 per cent., and water, 8. It crystallises in the cubical system. Generally of light reddish tint. Specific gravity, 2·1. Hardness, 5·5. Dissolves and gelatinises in hydrochloric acid. Lines cavities in amygdaloid.

DIA. 30.



Natrolite occupying an irregular cavity in amygdaloid, with detached crystals of chabasite—Giant's Causeway.

Natrolite or mesotype is of nearly similar composition to analcime, but with only 48 parts of silica. It dissolves and gelatinises in hydrochloric acid. It forms elongated crystals of the rhombic system. Colour, pale. Specific gravity, 2·2. Hardness, 5—5·5. Occurs in cavities of rocks.

Scolezite or needlestone differs from the preceding chiefly by containing lime instead of soda. It crystallises in slightly oblique rhombic prisms. Specific gravity, 2·2. Hardness, 5—5·5. Occurs in amygdaloidal cavities, Faroë Islands, Giant's Causeway.

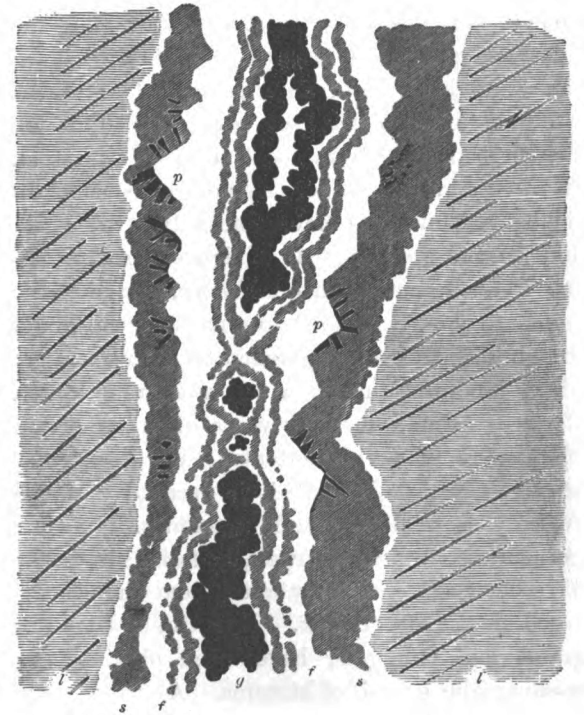
For other zeolites, as stilbite, chabasite, harmotome, Heulandite, apophyllite, Laumonite, and Thomsonite, which also occur in cavities of rocks, we must refer to treatises on Mineralogy, as also for prehnite and nepheline, which have analogy with the zeolites.

METALLIC DEPOSITS.

In particular tracts of country certain metals occur abundantly, either native, alloyed, or united with sulphur, oxygen, and acids; and singly, or in connexion with other metals. Certain associations of metallic substances are known; as of iron and copper, lead and zinc, tin and copper. It generally happens that sulphurets occur together, frequently at great depths; carbonates, phosphates, arseniates, &c. together, often in the upper parts of veins, which have undergone change by exposure to air and water. It is seldom that metallic substances occur unmixed with rock minerals: these are sometimes characteristically associated with certain metals.

Excepting ironstone, which is an aqueous deposit of carbonate of iron, red oxide of iron, which fills irregular cavities in limestone, and sulphide of copper in the copper-slate of Thuringia, metallic deposits rarely form or occur in beds. Most commonly they occur in veins which fill far-extended vertical or inclined fissures of the preconsolidated rocks, and in other veins which are contemporaneous with the rocks. In some veins (Pl. IV. fig. 12, *v.*) (called rake veins) the metallic substances mixed with various rock minerals, all crystallised more or less distinctly, form vertical plates more or less regular, the different ingredients alternating. (See Dia. 31.) In other veins (pipe veins), the metallic and rocky substances are vertical or nearly so, but restricted to narrow angular spaces, not fissures, in the rocks. The particular rock minerals associated with metallic substances in veins receive the name of matrix or veinstuff: they vary, perhaps, in some real relation to the period of their production, and to the nature of the containing rocks, but a certain independence of local character seems always to be recognised. In Cornwall, and the slate districts of Wales and Cumberland, quartz is a common matrix; in the limestone tracts of Derbyshire and Alston Moor, carbonate and sulphate of barytes and fluor spar abound;

DIA. 31.



This represents a section across a vein of lead ore *g*, enclosed between repeated vertical layers of fluor spar *f*, and sulphate of baryta *s*, the whole contained between walls of limestone *l*. At *p* are crystals of bisulphide of iron, or iron pyrites.

the metallic substances sometimes lie in soft earthy veinstuff, as at Greenhow Hill, Yorkshire, and in Cornwall.

Metallic veins are not confined to any particular tracts of country or any particular age of rocks, but yet they are by far most abundant along the lines and about the centres of mountain elevations, and in strata of high geological antiquity. No metallic vein has yet been worked in the British islands in strata above the triassic system. In almost every instance their origin is somehow related to convulsive movements within the earth, and to the development of igneous rocks. In the Pyrenees and Central France, the metallic veins are chiefly confined to a narrow zone round the granitic and other pyrogenous rocks, and are there produced in strata of various antiquity. Rock dykes and metallic veins differ chiefly in the nature of their contents; they have great analogies of origin, but it is rare to find the rock dykes yielding metallic treasures. In some granitic districts, as Cornwall, metallic substances have been aggregated by water from the decomposed masses of the rock. Thus tin, and gold in grains and 'nuggets,' have been obtained by washing the gravel of streams. As from early times in Scythia (Oural), so now in California and Australia, the ruins of quartzose and granitic hills, collected in hollows and valleys, yield vast stores of gold; nor is Cardiganshire unproductive of auriferous quartz.

There is a remarkable general fact concerning mineral veins, viz. that the most prevalent direction of those which are productive of metallic treasures is from west to east nearly. This obtains in the North of England and Derbyshire, in Wales, Cornwall, Saxony, and most parts of Europe, and in Mexico. Other directions are also characteristic, as from north to south: but veins in these lines are often less productive, and are generally supposed to be of less ancient date, because they *cut through* the east and west veins. These latter are called right-running veins, the former cross-courses.

In the mining districts of the North of England, the cross-courses are parallel to the dislocations along the Penine chain; the right-running veins are nearly parallel to the two great faults which pass from that chain to the east along the river Tyne and through Craven. This dependence of the direction of the veins upon that of the great lines of convulsion is in harmony with observations in other mining districts, and with the theoretical deductions of Mr. Hopkins.

Another problem of great interest in the reasoning on the origin of mineral veins, is their relation to the divisional planes or joints of rocks. In the vicinity of Aldstone Moor, and parts of

Yorkshire, the right-running veins and cross-courses seem to be nearly coincident with the predominant joints and fissures, one set of which runs nearly ENE., another nearly NNW. In Derbyshire the joints and principal veins form, according to Mr. Hopkins, an angle of 25°. It is desirable that this problem should be accurately examined in different districts, among rocks of different kinds and ages, and under different circumstances of position.

Metallic deposits are often found in the substance of the rocks bordering a vein, in sparry nests and cavities, and in the hollows of shells. These facts, combined with analogous results of operations still in progress, indicate a transfer of the metallic substances by electrical or other subtle agency, even through a considerable mass of rock.

Electricity, probably excited by unequal temperature or chemical action, circulates along many mineral veins. In the 'Philosophical Transactions' for 1830 are the results of Mr. Fox's experiments on this subject.

The metallic products of the British Islands amount in annual value to about sixteen millions. The most important are iron, copper, lead, tin, silver, zinc, gold.* Arsenic, manganese, cobalt, nickel, tungsten, uranium, molybdenum, titanium,

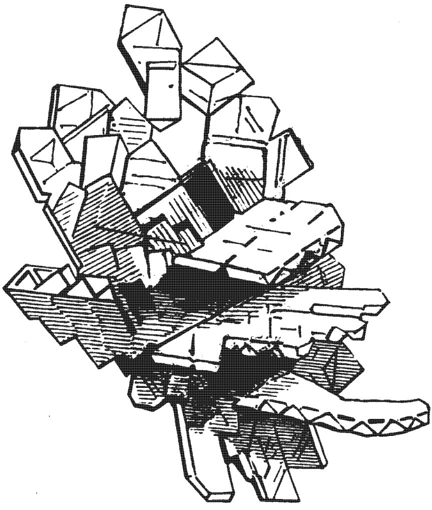
* Mining Records of Geological Survey.

bismuth, antimony, chromium, cadmium, also occur in smaller quantities, or in minerals valued only for cabinets. Platinum is also mentioned in Wicklow, Jersey, and Kirkcudbright.

GOLD.

There are no gold *ores*, properly so called, in Britain. Though the metal is widely distributed in small quantities amongst many metallic and

DIA. 32.



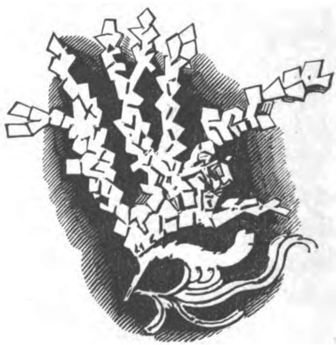
Microscopic crystals of native gold.

earthy substances, it is chiefly in quartz veins or in the alluvial deposits of countries yielding quartz veins that gold is worked to profit. The quartz veins of Gogofan were penetrated by the Romans, who crushed the quartz and separated the grains of gold. Near Dolgelli in Merionedd, the researches of Mr. Readwin, with superior mining processes, have been rewarded by more considerable results.

SILVER.

Native silver occurs in Cornwall, and several alloys, sulphurets and oxides of silver are found

DIA. 33.

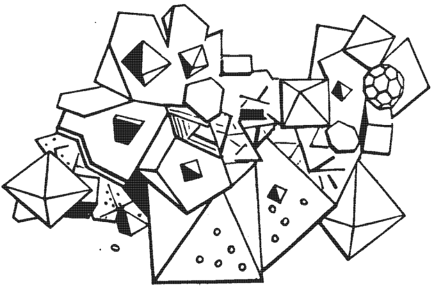


Native silver.

there in larger quantity: but the greatest quantity of silver obtained from British mines is separated from lead. The process is cheap, so that a few ounces only of silver to a ton of lead are worth the labour of extraction. The lead ores of Wales are among the richest in silver.

Copper occurs native, and combined with sulphur, oxygen, carbonic and other acids, in Palæozoic strata, especially in Cornwall and some parts of

DIA. 34.

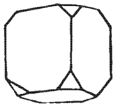


Microscopic crystals of native copper, red oxide of copper, and carbonate of copper.

Ireland, Wales, Westmoreland, Cumberland, and Scotland. It is found, as a sulphuret and carbonate, but not worked, in the magnesian limestone of Yorkshire.

Lead occurs in the state of bisulphide, oxide, carbonate, sulphate, phosphate, and other salts, in most parts of the British Isles where Palæozoic rocks occur — as Ireland, Cornwall, Devon, South and North Wales, Derbyshire, Yorkshire, Cumberland, Durham, Northumberland, Scotland, and the Isle of Man—in most parts, especially in the Silurian and Cambrian districts, yielding a notable portion of silver. It is hardly found at all in our

Dia. 35.

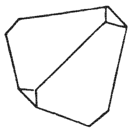


Cubo-octahedral crystal of galena.

Mesozoic or Cænozoic strata; and it is principally from the mountain limestone rocks, and from the bisulphide, called galena, that the lead market is supplied.

Zinc is found combined with sulphur (blende), oxygen, and carbonic acid, in almost every lead-bearing district of England; often making a con-

Dia. 36.

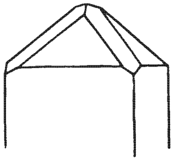


Tetrahedral crystal of blende.

siderable portion of the crystallised parts of the veins in Alston Moor, and other districts of the mountain limestone.

Tin ores constitute the most valuable products of the mines of Cornwall and Devon, but are scarcely found elsewhere in Britain. They were known before the Roman invasion. Only in a few districts in Europe (Bohemia and Gallicia),

DIA. 37.

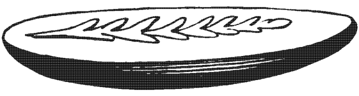


Oxide of tin—Cornwall.

is tin discovered in sufficient quantity to be worth working. It has been known from very ancient times in the East Indies.

Iron ores abound in veins in the British Isles as sulphurets, oxides, and carbonates, but the supply of our furnaces is chiefly from what may be better called 'Ironstones'—such as the earthy

DIA. 38.



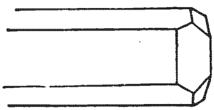
Nodule of ironstone, with fern leaf.

carbonates common in our coal districts, in the form of nodules, and the beds of calcareous stone rich in oxide and peroxide of iron, in Yorkshire and Northamptonshire. These beds vary from a few inches to as much as sixteen feet in thickness, and yield on an average about 30 per cent of iron. The bed at Rosedale in Yorkshire, lying at the base of the inferior oolite, is much richer (40 and upwards per cent.), and is magnetic with fixed polarity, though of oolitic texture and not crystallised. Another source of abundant iron ore is in the mountain limestone districts of North Lancashire and West Cumberland. Here rich and deep deposits of red peroxide of iron lie in fissures, and singular openings and hollows of the rocks, free from any impurity. The Mendip Hills and some parts of North Devon contain deposits somewhat like these, and probably of the same age.

Spathose carbonate of iron occurs in sufficient quantity in veins in Weardale to maintain the works at Towlaw, where iron of pure quality is carefully made from it, for special purposes.

The earthy minerals of most frequent occurrence in association with metallic substances in veins, besides some which have been mentioned in the rocks of fusion, as quartz and chlorite, are sulphate of baryta and fluoride of calcium.

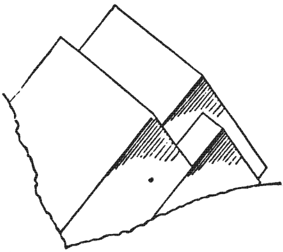
Dia. 39.



Sulphate of baryta (Dia. 39) consists of sulphuric acid, 34, and baryta, 66. Its crystalline forms are those of a right rhombic prism: they are often extended in the tabular form given above, and in more complicated shapes. Generally transparent and colourless. Specific gravity, 4·6. Hardness, 3·5. Insoluble in acids.

Fluoride of calcium—fluor spar—consists of fluorine, 48, and calcium, 52. Crystalline forms, cubical (Dia. 40.), octahedral, dodecahedral.

DIA. 40.



Colours, various, mostly transparent. Specific gravity, 3·15. Hardness, 4. Soluble in acids.

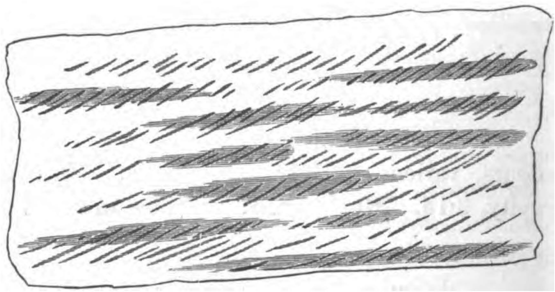
METAMORPHIC ROCKS.

These variable compounds are probably best arranged according to the analogies which they offer to one or other of the groups already mentioned. First may be placed those extensive, almost world-wide rocks often associated with granite, which suggested to M. Delesse* the idea of 'general metamorphism' with aid of heat.

Gneiss consists of laminæ either plane, undulated, or contorted (see Dia. 7, p. 142). The minerals composing it are felspar, mica, and quartz, the ingredients of granite; or felspar, hornblende, and quartz, the components of syenite; and other mixtures related to these, pass under the same name. The very ancient gneiss of the Hebrides contains much hornblende.

Mica schist is constituted of mica and quartz,

Dia. 41.



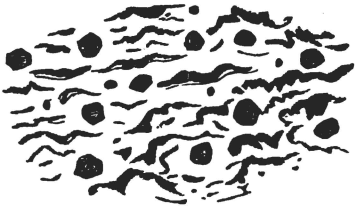
Mica schist.

in plane, or undulated, or contorted laminæ. Talc and chlorite sometimes replace the mica, but this is not so commonly the case as for the soft glistening micaceous surfaces to be mistaken for talc.

* Études sur le Métamorphisme des Roches, 1858.

Garnets, staurolite, cyanite, and magnetite occur in mica schist and talc schist.

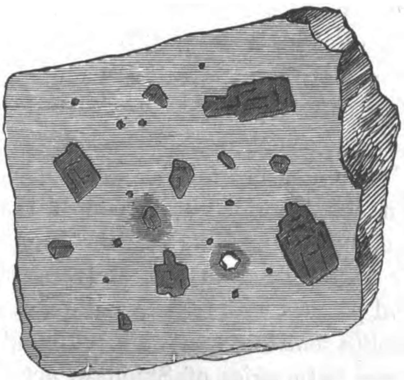
DIA. 42.



Mica schist with garnets.

Granular limestone is the altered crystalline

DIA. 43.



Tiree marble with augite, garnet, and quartz.

product of common limestone (or chalk, as in Ireland). It often shows plane, undulated, and contorted lamination, and contains garnet, crystals of quartz, and augite. Serpentine often abounds in it, and the rock then becomes 'ophiocalcite.'

Quartzite is the indurated and partially recrystallised representative of common sandstone. It often contains mica, and thus passes to a sort of mica schist. In the Wrekin this rock prevails, and illustrates 'local metamorphosis.'

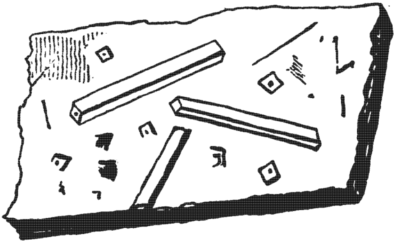
Next follow more limited groups of rock, whose origin is more easily traced to definite stratified masses, which have undergone change of texture, without obliteration of main structural features. Such are very common in the district of the English lakes, on the borders of the granitic tracts of Bootle, the Caldew Valley, and Wasdale Crag, as well as in Helvellyn, and the mountains round Scafell, far from any visible granite.

Hornblende schist, composed wholly or principally of lamellar crystals of dark hornblende, occurs in the Hebrides, as a part of the gneiss formation. It also appears near the granite of the Skiddaw region, and in the Malvern Hills, in bands and patches with felspar and quartz.

Chiastolite schist is very well exhibited in the argillaceous slate series of Skiddaw, not far from the granite — a case of local metamorphosis, by which the crystals of chiastolite have been generated.

Felstone and felstone porphyry are common products of local metamorphism, in Cumberland and Wales (see p. 234).

DIA. 44.



Chiastolite in slate—Skiddaw.

Amygdaloidal slate occurs in Borrowdale, and other valleys of the Lake district. The amygdaloidal cavities indicate the action of heat: the calcareous, chloritic, quartzose, and chalcedonic substances which fill them are marks of subsequent, probably hot, watery infiltration.

Pyritous slate owes its peculiarity to chemical actions set up along great lines of fracture (as at Ingleton in Yorkshire), or near dykes and larger masses of pyrogenous rock.

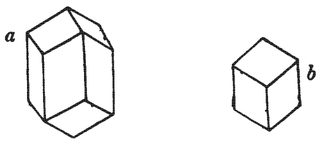
Metamorphism of the substance of portions of stratified rocks, and of the organic remains which they include, without destroying the texture of either, are common. In this operation water was the agent, sometimes warmed probably, but this appears not to be a necessary condition. Thus calcareous oolite is converted to carbonate and oxide of iron; corals and shells are silicified; the tissues of wood are changed to calcareous spar or silica, or sulphuret of iron, which also sometimes replaces the mingled carbonate and phosphate of lime in Saurian bones.

In the study of metamorphic rocks the minerals most essential to be known, in addition to those already referred to as characteristic of plutonic and volcanic rocks, are now to be mentioned.

Garnet is a double silicate, with bases of alumina, iron, and lime—the silica being about 40 per cent., the bases in variable proportions.

Crystallisation on the regular system, mostly in

Dia. 45.

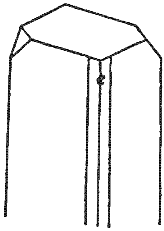


Garnet from the Simplon.
a Dodecahedron. *b* Trihedral summit.

the form of the dodecahedron, with equal rhomboidal faces, and brilliant lustre. Colour, various, in rocks usually red. Specific gravity, about 4·0. Hardness, about equal to quartz. Fusible. Common in mica schist, and gneiss, not unfrequent in metamorphic felstones, greenstones, and limestones.

Andalusite is a silicate of alumina, nearly pure, yielding silica, about 40, and alumina, about 60. Crystallisation in a right nearly square prism, with plane and dihedral summit. Of a grey or brown

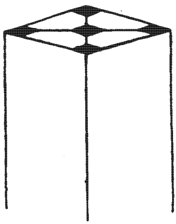
DIA. 46.



Andalusite, in four-sided prism, with pyramidal summit.

colour. Specific gravity, 3·2. Hardness, exceeding that of quartz. Infusible by the blow-pipe. This mineral is, perhaps, identical with chiastolite,

DIA. 47.



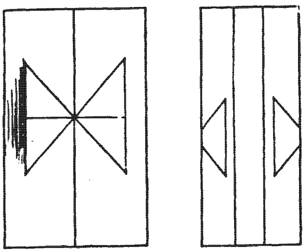
Chiastolite from Spain.

and offers close analogies of composition with cyanite, fibrolite, killinite, and staurolite, which are also found in the same metamorphic rocks, viz. mica schist, talc schist, &c.

Chiastolite is a silicate of alumina, like andalusite, and has the same crystalline forms, with the singularity of a cruciform internal structure. Occurs in those parts of the clay slates of Skiddaw which are not far removed from granite.

Staurolite (*σταυρός*, a cross), a double silicate of alumina and iron, with from 30 to 40 per cent. of

Dia. 48.



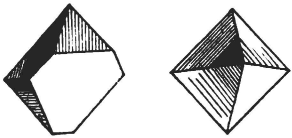
Staurolite—two aspects of the prism.

silica. Crystallisation, a right rhombic prism, with the acute edges replaced, the prisms often crossing at right angles. Colour, brown. Specific gravity, 3·5 to 3·8. Hardly fusible by the blowpipe. Occurs in mica schist.

Magnetite, a compound of oxide and peroxide of iron; about 30 of the former with 70 of the latter. It crystallises in the regular octahedron, with many variations. Colour, usually black.

Specific gravity, about 5·0 Hardness, less than felspar. Hardly fusible by the blow-pipe, losing

DIA. 49.

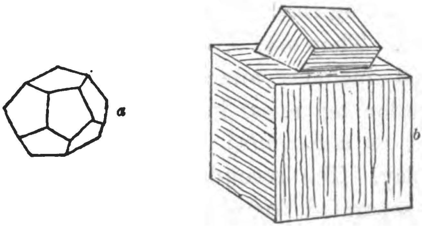


Magnetite in regular octahedral crystals—one having enlarged faces.

its magnetic property. Occurs in gneiss, mica schist, syenite, greenstone, &c.

Bisulphide of iron, or common iron pyrites, a compound of sulphur, 53, and iron, 47, nearly. Crystallisation, cubical, octahedral, dodecahedral,

DIA. 50.



a dodecahedral pyrites. *b* Cubic (striated).

with many modifications, and macles. Metallic aspect, often yellow. Specific gravity, about 5·0. Hardness, 6. Gives off sulphur before the blow-pipe.

A very common mineral in *locally* metamorphic rocks, as in shales near dykes of basalt, in slate, and in limestone; also in greenstones and in granite. It is equally common in mineral veins, and in aqueous deposits of all ages.

Graphite is carbon with variable admixtures of iron and earths. It crystallises in hexagonal prisms or plates, but is generally found in small irregular masses or in irregular veins. Occurs in Borrowdale, in slate rocks which have undergone some change, and in gneiss with garnets in Inverness-shire.

ROCKS FORMED IN WATER.

The stratified deposits, with many associated concretionary masses, offer a field of study not less interesting than that which includes the rocks of fusion. They may be ranked in three divisions. The first includes mineral substances brought by exterior agencies into water, and therein dropped as *sediments*: as conglomerate, sandstone, clay. The second division contains substances separated from *solution* in the water in a crystallised or concretionary state: as sulphate of lime, phosphate of lime, carbonate of lime, carbonate of iron, chloride of sodium. The third, of *organic* origin, may be regarded in groups: as corals, shells, and other marine exuviæ; shells of freshwater mollusks; and land plants converted to coal.

To the first division belong the rocks called breccia, derived from preconsolidated rocks, the fragments of which are cemented together. They are in general of very limited extent; formed, it is probable, on the edges of wasting cliffs, in water not much agitated. They are mostly calcareous, and have a calcareous cement, but some flint breccias occur.

Conglomerates are composed of worn fragments of preconsolidated rocks. They are of frequent occurrence in almost every considerable series of strata, and often mark the border of the ancient sea, and indicate the degree of its agitation. Perhaps the oldest conglomerate in the British Isles is that on the north-west coast of Scotland, which rests on the Hebridean gneiss. An interesting and very ancient conglomerate in the tract of the Killeries (Connemara) contains large rolled masses of granite, showing an example of that rock being crystallised at a very early period.

In the old red conglomerate of Kirkby Lonsdale, pebbles occur with veins of micaceous iron ore, showing the antiquity of that substance segregated among the older palæozoic strata. A very interesting cænozoic conglomerate is that much used by the early Britons for corn millstones; the pebbles in it are well rolled flints, derived from the chalk, and the cement is siliceous.

GRITSTONE, SANDSTONE, SAND.

Very coarse sandstones are of the nature of conglomerate. Such is the millstone grit, at the base of the coalfields of the north of England. It consists of quartz-sand, mica, and orthoclase felspar; the latter retains its internal crystalline structure; but in external figure it is worn like a pebble, though not so much as the larger quartz fragments. These materials are probably derived from granite.

Sandstones of more equal grain have a similar composition in general; but the felspar is often decomposed and serves as a cementing substance. The mica is sometimes abundant, and lies in continuous plane surfaces, making 'flagstone.' Though the colour of sandstones near the surface may be yellowish or brownish, miners find them generally blue or gray 'in the deep.' The reason seems to be, that 'in the deep' it is protoxide of iron which colours the stone, but near the surface, air and water have changed it in part to a carbonate. The same fact occurs in the paler sorts of limestone like oolite.

The green sands of the cretaceous and cænozoic series owe their colour to glauconite, a silicate of iron, perhaps derived from some augitic mineral. The red sandstones are composed of clear quartz grains invested by peroxide of iron.

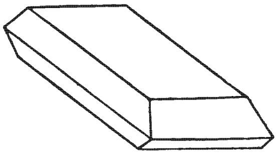
Sandstones, by disintegration, give origin to loose sands, in which, for the most part, neither mica nor felspar can be traced. They are of all colours, especially in the cænozoic strata. The quartz grains are always rounded by mutual attrition through long periods of time.

Clay, shale, and slate are equally composed of sediments derived from waste of preconsolidated rocks. Grains of quartz sand are detected in all of them, immersed, as it were, in a mass of fine-grained argillaceous matter. The coarser and laminated shales gradually pass into flagstone; so that the use of the word 'shale' is rather ambiguous. Exactly as at the present day, pebbles line the shores, sands appear in shallow water, and clay occupies the deeper anchorage grounds, so it was in the earlier periods. Clay was deposited; by the accumulations of other strata it was flattened to shale; and by a different pressure acting laterally, it was compressed to roofing-slate. In argillaceous deposits, ironstone (p. 267), selenite, and pyrites are common.

Among the masses more or less stratified, which appear to have been directly produced from solution in water, we may first notice rock-salt, which lies in short interrupted beds in Cheshire and different parts of the red marl districts of England. The beds are usually thick, the salt has a prismatic structure, and is partly very clear and partly earthy. Crystallisation, cubical, often fibrous. Specific gravity, 2·1. Hardness, 2.

Sulphate of lime occurs in many clays, but especially in the Kimmeridge clay of Shotover Hill, well crystallised in rhomboidal tables; in the coloured marls often associated with rock-

DIA. 51.



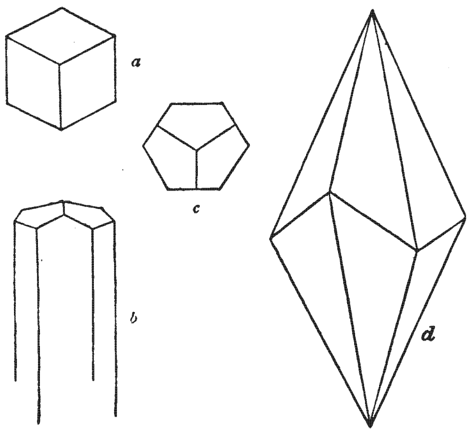
Selenite in tabular crystal.

salt it is in fibrous crystalline masses. It contains lime, 32·6; sulphuric acid, 46·5; water, 20·9. Specific gravity, 2·3. Softer than rock-salt.

Phosphate of lime forms beds in Estremadura. It is crystallised with quartz at Caldbeck Fells; in granite at Strontian and Bovey Tracey. It is discovered by analysis in the substance of most stratified rocks, being there derived from bones, shells, crusts, and other parts of animals. It is said to exist in some part or other of the substance of all plants and animals. From this it has been conjectured that the presence of phosphate of lime in rock proves the existence of life previous to the formation of that rock; merely a mistake in reasoning. On the other hand, if this substance be totally absent from a stratified rock, it may be held to prove that no organic remains are included in it, or have left their substance in it. Dr. Daubeny, by trials as to the growth of plants on soil made from the powdered slate of Llanberis, has made it probable that no phosphate of lime occurs in that rock, which is not known to contain any trace of life. Lingula, one of the very oldest genera of brachiopoda, contains much phosphate of lime in its shelly valves.

Calcite, or crystallised carbonate of lime, occurs

Dia. 52.



a. Obtuse rhombohedron.
b. Hexahedral prism.
c. Termination of the prism.
d. Acute dodecahedron.

as the cementing substance to the grains of oolite and the sandstone of Fontainebleau; it occupies innumerable cracks and cavities of the stratified rocks; fills the space once occupied by corals and shells, and composes the mass of several metamorphic limestones. Its composition is, lime, 56·2, carbonic acid, 43·8. Crystallisation, rhombohedral, in countless forms, the most frequent being six-sided prisms, with flat or three-faced summits, and acute and obtuse rhomboids. Double refraction, remarkable. Usually transparent, and colourless or white. Specific gravity, 2·7. Hardness, 3. Soluble in acids with escape of carbonic acid gas.

LIMESTONE, CHALK, MARL.

Some calcareous rocks may be certainly known to have been aggregated by the mechanical agency of water, others may be thought to have a crystalline origin from solution; but in the majority of cases the small parts of which they consist are mostly joints or fragments of the hard internal supports or exterior coverings of invertebrate animals. Thus thick beds of mountain limestone are composed of joints and stems and bodies of crinoïdea. Some oolitic beds are half made up of coral, others of shells, and some chalk is a mass of foraminifera. These elements of the rock are sometimes merely coherent, as in marl and chalk, but often firmly cemented together by crystallised calcite, as in the oolite of Ancaster. In a metamorphic state they all become crystalline.

The siliceous masses of flint and chert are generally found in limestone, chalk, or sands, formed round and within some organic bodies which have served as centres of attraction. Thus flint nodules lie in chalk in regular layers; chert occupies a similar position in the mountain limestone and Portland oolite. A remarkable flint in the Oxford Museum contains in the interior a worn fragment of a mesozoic pine, perforated by teredo: the wood and the shelly remains being silicified. In this one specimen we read a page of the history of the ancient land and sea. At some considerable height above the rather warm sea-border grew a pine forest, its branches and fragments were drifted down some river to the sea; while floating, or after it had sunk, it was perforated by teredo; then both wood and shells were overspread, on the chalky bed of the sea, by the growth of sponge, whose tissues were siliceous during life, and admitted more silica after death. Thus not only the sponge-mass was slowly filled with flint by secretion from sea-water, but the enclosed wood and shelly tubes were impregnated by the same ingredient; every single cell of the wood preserved as perfectly as in the recent close-grained pines, with which we may compare it. Thus it is that geology finds in every stone some sure memorial of its own history, and some useful evidence of the former condition of Nature.

Coal, the most important of all the strata produced from organic elements, varies in composition from the almost purely carbonaceous anthracite of Virginia, through the stone coal of Wales, the steam coal of Northumberland, and the furnace coals of Yorkshire, to the cannel coal of Lancashire, which contains about 64 per cent. of carbon, and 36 per cent. of hydrogen and oxygen, with some nitrogen. The area of visible coal in the British Isles may be reckoned at 5,000 square miles, with an average quantity of 50 or 60 feet, half of it workable, but perhaps not more than a quarter really available. The annual consumption has now reached, according to Mr. R. Hunt, 81,638,338 tons, equal to about 13 square miles of coal 10 feet thick. Much coal, doubtless, exists unseen below the triassic and oolitic parts of England; but at what depth? Let no one suppose that from this source the additional supply can greatly extend the few hundred years which may be supplied from our actual coal-fields, and that the economical or wasteful working of our collieries is a matter to be regarded with indifference by a nation whose steam power exceeds the muscular effort of all the races of mankind.

CHAPTER IX.

TABLES AND CALCULATIONS.

PHYSICAL RELATIONS OF THE GLOBE AS A PART OF THE SOLAR SYSTEM.

The Earth and the Sun.

Figure of the Earth, a spheroid of revolution, with diameters as 298 : 299.

Equatorial diameter . .	7925·648 miles	Difference commonly called the compression . . . =26·478
Polar diameter	7899·170 „	

Mean distance from the Sun, 95,365,000 miles.*

Obliquity of Ecliptic, 23° 28′.

Time in which the Sun returns to the equinox, called the Equinoctial, or Tropical, or Civil Year . . .	365^d	5^h	48^m	$51^s·6$	or	d. 365·242264
Annual precession of the equinox ∠50″·1 = in time	0	0	20	19·9		0·014119
Sidereal Year	365	6	9	11·5		365·256383
Annual precession of the apogee, ∠11″·8 = in time	0	0	4	47·3	or	0·003325
Anomalistic Year	365	6	13	58·8		365·259708

* This distance of the Earth from the Sun was computed by transits of Venus. It appears by later researches of several kinds to be in excess three or four millions of miles. Till the next transits of Venus, this correction, which involves other changes, especially in the diameters of the Sun and planets (but not in their *relative* distances), cannot be determined exactly. The computed diameter of the Sun (nearly 111½ times that of the Earth), and its mass (nearly 355,000 times that of the Earth), will require reduction, but not in equal proportions.

The Earth and the Moon.

Mean distance of the Moon from the Earth, 59·9643 equatorial radii of the Earth :

An equatorial radius = 3962·824 miles. Hence, distance of the Moon's centre from that of the Earth = 237628 miles nearly.

Diameter of the Moon	2160 miles.
The mass of the Earth being	1·0000000
That of the Moon is	0·0125172
Mean sidereal revolution of the Moon	27·321661418 days.
Mean synodical revolution of the Moon	29·530588715 days.
Excentricity of orbit	0·054844200
Mean inclination of orbit	5° 8′ 47″·9

The Earth and the other Planets.

Planets' Names	Mean distance from Sun, the Earth being 1·000	Mean Sidereal Period in Mean Days	Excentricity in parts of the Mean Distances	Inclination of the Orbit to the Ecliptic	Mass compared to the Earth	Equat. Diam. compared to that of the Earth
Mercury	0·387	87·969	0·2055	7° 0′ 9″·1	·0729	0·398
Venus .	0·723	224·700	0·0068	3 23 28·5	·9101	0·995
Earth .	1·000	365·256	0·0167	. .	1·0000	1·000
Mars .	1·523	686·979	0·0933	1 51 6·2	·1324	0·517
Jupiter .	5·202	4332·584	0·0481	1 18 51·3	338·718	10·860
Saturn .	9·538	10759·219	0·0561	2 29 35·7	101·364	9·987
Uranus .	19·182	30686·820	0·0466	0 46 21·4	14·251	4·332
Neptune	30·036	60126·170	0·0087	1 46 49	18·900	4·260

TEMPERATURE OF THE GLOBE.

LAND.—The mean temperatures near the level of the sea vary nearly as the cosines of latitude. Thus, if the equatorial mean temperature = 81°·5 Fahr., the mean temperature for any latitude = 81°·5 cos. lat. This is found to apply pretty well until we arrive near the polar circle, when several anomalies occur, which seem to indicate at least two centres of maximum cold, one in America, one in Asia.

WATER.—The oceanic temperature is not subject to the same extremes as that of the land: the sea, on the average, is warmer than the land toward the poles, and consequently permits the existence of marine animals in latitudes which are fatal to nearly all terrestrial beings.

Fresh water is heaviest at about 38°·75 Fahr., growing lighter both by heating and cooling; and consequently, in latitudes which permit of this degree of cold at the surface during the winter, there will then be a falling of cold water, and a rising of warm water, so as to counteract materially the rigour of the season. In latitudes where it is only in summer that the surface water can be heated to 38°·75, the warmed water will then sink from the surface, which at other times may freeze, and experience extreme cold, while the bottom is warm.

This does not apply to the ocean; for it is found that salt water goes on increasing in density as it cools, even to some degrees below freezing. The variations of the temperature of the sea, in relation to depth from the surface, are not yet sufficiently known. It appears, however, that the reduction of temperature in the deep parts of the tropical seas is very considerable (1° Fahr. in 25 fathoms), and that in polar regions the lowest water is warmest.

Atmosphere.—The decrease of temperature, as we ascend from the level of the sea, is subject to so many causes of fluctuation and local diversity, that it has been found very difficult to come to any general conclusion. In equatorial regions, according to Humboldt, there is a diminution of temperature = 1° Reaum. for 121 toises of ascent: at St. Bernard, 1° R. for 123½ toises = 1° Fahr. for 352 feet English. At Ventoux, near Avignon, 1° R. corresponds to 80 toises in summer, and to 100 in winter: on the Righi, 1° R. for 97 toises. In the North of England, Mr. Nixon's experience, on mountains of 1,000 to 2,000 and 3,000 fet, gives 1° F. in 230 feet. Dr. Dalton allows 1° F. to 100 yards' elevation. Generally it is found that the temperatures diminish more rapidly from the lowest stations.

The above statements apply to the air *near the ground*, where it is influenced by the heating surface of the earth. The balloon experiments by Mr. Glaisher appear to indicate a much lower rate of reduction of temperature in the higher regions of the atmosphere. At five miles only 1° for 1,000 feet of elevation.

Springs.—The unfailing springs which gush out from fissures of rock, bring with them the temperature of their shallow subterranean channels; and this temperature is generally found to be constant, and in cold regions a little higher than the mean temperature of the air. This was first noticed by Dalton, and has since been made the subject of extended enquiry by Prof. Küpffer, from whose researches it appears, that the difference of shallow subterranean mean temperature from that of the air above the surface of the ground follows a certain law, depending on the latitude and on local influences. Near the equator, the ground, at 25 metres depth, appears to have a temperature 2° R. *below* the mean temperature of the air; whilst in Lapland it is 2° *above* it. This appears to be a strong corroborative argument for the internal temperature of the earth depending on a cause distinct from solar influence. — (Forbes, in Report to the British Association, 1832.)

Subterranean Heat. — The fluctuations of superficial temperature diminish as we descend into the earth, so that at last we arrive at a point where, through the whole year, there is no change, and consequently below which the variation of solar influence is insensible. This depth is called the *invariable stratum*. From the observations in the caves at Paris, it is inferred to be nearly 30 metres, or 100 feet from the surface. Below this depth, any differences in the temperature of the earth must be ascribed to internal terrestrial peculiarities. It is found that below the invariable stratum the temperature of any point is wholly uninfluenced by seasons, and is constant; that the temperature augments regularly in proportion to the depth, at a rate, upon the average, of 1° F. for 15 or 20 English yards. It is clear, therefore, that there is a proper source of heat within the earth.

The warm and hot springs, which issue from great depths, yield another and very satisfactory proof of the existence of great heat within the earth. Some of these are closely connected with existing volcanoes, others with lines of convulsion, which open a communication to the deep parts of the earth. It is clearly to this communication that the heat is owing, and not to any local chemical actions along the channels; for the chemical composition of the waters is by no means uniform, and, perhaps generally, hot waters are as pure as others. In some places hot and cold springs rise within a few feet of each other.

Temp. of the Great Geyser	209°	Sir G. Mackenzie
La Trinchera, 3 leagues from Valencia	194·5	Humboldt
Carlsbad	165	Ure's Chemical Dictionary.
Aix-la-Chapelle	143	
Bath	116	
Buxton	82	
Hotwells (Bristol)	74	
Matlock	68	

THERMOMETRICAL SCALES.

The freezing-point of water is marked 32° on Fahrenheit's thermometer; but on Reaumur's, and Celsius's or the centigrade, it is marked 0°. The boiling-point of pure water (when the barometer is at 30·0) is marked 212° on Fahrenheit's, 80° on Reaumur's, 100° on the centigrade. Hence the relative *values* of the thermometrical unit or degree are, on Fahrenheit, 1°; on the centigrade, 1°·8; on Reaumur's, 2°·25. Hence the following rules:—

1. To reduce to Fahrenheit the observations on the other scales:—
   Multiply the number on Reaumur's by 2¼, and add 32°.
   Multiply the number on the centigrade by 1·8, and add 32°.
2. To reduce to the centigrade scale observations on the others:—
   Multiply the number on Reaumur's by 1¼.
   Diminish the number on Fahrenheit by 32°;
   And multiply the remainder by 0·555+,
   Or divide it by 1·8.

It is much to be recommended that English philosophers should adopt the centigrade scale.

Value of English Measures in French Metres.		Value of French Measures in English Inches.	
English INCH	0·0254	French Millimètre	0·03937
Foot	0·3048	Centimètre	0·39371
Yard	0·9144	Decimètre	3·93708
Fathom	1·8287	METRE	39·37079

THE BAROMETER.

A little experience in moderately elevated regions of stratified rocks will convince the geologist who values the connexion of the physical sciences, or desires to give the utmost accuracy to his results, that it is wrong to neglect the use of the portable barometer. The objections usually urged against the Englefield barometer are of little importance, if the construction of the instrument has been properly attended to. Heights of ground, thicknesses of rocks, otherwise often unascertainable, extent of dislocation, and many other useful data may be thus quickly obtained, *at the time when they are most wanted*, by the geologist. No apparatus is needed for the support of the instrument; if the observer kneel on the ground and be steady of hand and sure of eye, his observations can hardly fail to be correct. The observations are, 1. The height of the barometer, in inches, tenths, hundredths, and thousandths, at each station; 2. The degree of the thermometer *attached* to the instrument at each station; 3. The degree of this or another thermometer *detached* from the instrument, and exposed to the air in the shade, at each station.

To calculate with accuracy the difference of level corresponding to any two sets of observations, the following easy and brief processes will be sufficient, without special tables or logarithms, for altitudes under 4,000 feet, and in the latitudes of Great Britain. The geologist is recommended to copy them into his *field note book*.

1. Having written down the observations as they were made, take the mean and difference of the readings of the barometer, the difference of the attached thermometers, and the sum of the detached thermometers.

2. Correct the barometric difference for relative capacity of tube and cistern. This correction is always additive, and its value is marked on the barometer.

3. Correct for difference of attached thermometers, by multiplying that difference by $\frac{1}{10000}$th of the mean barometric pressure. The product must be subtracted from the barometric difference (2) when the upper station is colder; added to it when warmer.

4. Correct for the temperature of the air above 0° Fahr. by the following process. To the sum of the detached thermometers add 1,000; multiply together this quotient, the corrected barometric difference (3), and the constant number 24·900; divide the product by the mean barometric pressure 1,000 (1). The quotient is the height in English feet, very nearly.

Example of the whole process.

(1) Lower station, Bar. Press.	30·040	Att. Ther. 72·5	Det. Ther. 72·0
Upper Station ———	26·575	——— 63·5	——— 62·6
Mean . .	28·307	Diff. . 9	Sum . 134·6
Difference .	3·465		1806·8

(2) In this instrument the capacity is allowed for by the construction.

(3) 9 × ·00283 = ·0254 and 3·4650 − 0·254 = 3·4396.

(4) Sum of detached thermometer + 1000 = 1134·6.

$$\frac{1134{\cdot}6 \times 3{\cdot}4396 \times 24{\cdot}900}{28{\cdot}307} = 3433{\cdot}7 \text{ feet.}$$

In lat. 54°, the height by Oltmann's Tables in De la Beche's Manual, is 3432·3; height by Nixon's Tables (Phil. Mag.), 3435·9.

The fluctuations of the barometer are not necessarily productive of error in the use of the instrument. It is not requisite to have more than one barometer, provided the observer returns again, in the course of a few hours, to the point which he has chosen for his reference station; or verifies his results by including amongst his measures some point whose height, compared to that reference station, is known; or in any other way determines the hourly rate of the rising or falling of the barometer. For example:—

September 22, 1832.

	Bar.	Time	Att. and Det. Ther.	Correction for Temp.	Corrected Pressures.
Inn at Hawes . . .	29·878	9h. 40m.	60°	·000	29·878
Gale	29·800	11 0	58	+ ·006	29·806
Summit of a hill . .	28·735	12 0	55	+ ·015	28·750
Inn at Hawes . . .	29·850	2 0	64	−·012	29·838

Hence it is seen, that in 4h. 20m. the barometer fell ·040; and by applying a correction in this proportion to all the observations,

$$\text{we have}\left\{\begin{array}{l} 29{\cdot}878+{\cdot}000=29{\cdot}878 \\ 29{\cdot}806+{\cdot}012=29{\cdot}818 \\ 28{\cdot}750+{\cdot}022=28{\cdot}772 \\ 29{\cdot}838+{\cdot}040=29{\cdot}878 \end{array}\right\}\text{true relative pressures.}$$

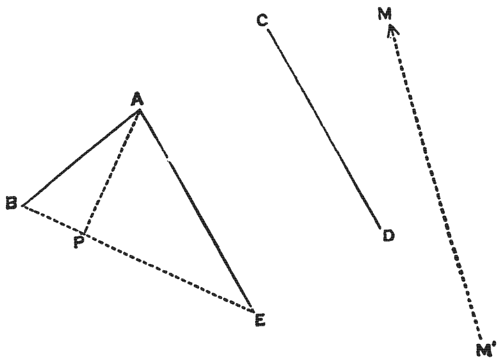
Aneroid.—This instrument may be advantageously employed, by a careful observer, for determining differences of level. The correction for the temperature of the air and the method of computation are the same as in process (4) for the barometer.

CLINOMETER AND COMPASS.

In ascertaining generally the direction and angle of the dip, and direction of the horizontal line or strike of the stratified rocks, nothing is more convenient than the pocket clinometer, fitted with a compass-needle, as usually sold in London. For accurate determination of the strike of beds, direction of joints, and bearings of objects on the surface (which the geologist will often need) better instruments than those commonly in use are necessary. Gambey's and other clinometrical compasses are (if rightly used) very satisfactory. A very ingenious instrument applicable to geological surveys, as well as ordinary clinometrical uses, was manufactured by Mr. Dunn of Edinburgh. Capt. Kater's, or any other good surveying-compass, may often be found to give curious results among certain primary rocks, along dykes of basalt, &c. The variation of the needle being marked on the circle, the geologist may record his observations in true bearings. The declination to the west is now between 21° and 25° in England: between 24° and 28° in Scotland and the Hebrides; between 25° and 28° in Ireland.

Unprovided with a clinometer, a jointed rule will suffice to those acquainted with trigonometry; and a faithful drawing or photograph will often be as good as any measure. When it happens (as in a cliff) that there are two or more lines of section exposed, neither of which passes along the line of dip, or line of strike, the amount of dip, and direction of dip and strike, can be calculated trigonometrically from the observed dips and directions of the rocks exposed in the sections. The following simple construction will furnish conveniently the required direction of strike, and amount of dip:—

DIA. 53.



Let A B and C D be the directions in reference to the magnetic meridian (M M′) of two sloping lines on the surface of a stratum; the inclination from A to B $= \delta$, that from C to D $= \delta'$. Make A B $=$ cot δ and C D $=$ cot δ'. Draw A E parallel and equal to C D. Draw B E and, perpendicular to it, A P. Then is B E the line of strike; A P is the line of dip, and its length is the cotangent of the angle of dip of the stratum.

The use of the clinometer is soon learned, and questions of the highest importance in the very first stages of physical geology can only be solved by frequent and exact observation with this instrument. For example, further information is needed on the direction of great axes of dislocation compared to the jointed structure of the rocks; and on the relation of faults, dykes, veins, and cleavage to this structure and those axes; for the evidence yet collected on this subject is by no means complete. Several problems are here presented to the observer. 1. The degree of symmetry of the jointed structure as indicated by the predominance of particular directions in it. 2. The geometrical relation of these divisional planes to faults, veins, &c., and to the centres or axes of great subterranean movements. 3. The age of the joints as compared to any neighbouring faults, veins, or axes of movement. 4. Similar inquiries as to cleavage.

The following remarks may be of use to persons who are anxious to furnish correct data for the solution of these and other questions:—

The strike and dip of the strata are always most certainly exhibited among thinbedded rocks, especially where layers of different nature alternate; thickbedded sandstones are likely to mislead a novice by their oblique lamination; thick limestone beds have often nodular surfaces; but shales, thinbedded limestones, and flagstones generally yield consistent measures of dip and strike.

On a large scale the dip and strike may be calculated from good barometrical measures of the relative elevation above the sea of three points at known distances, on any one plane of stratification. In reasoning on the relation of axes of elevation to joints, faults, and mineral veins, general results thus obtained are of great value.

The strike can always be taken with more accuracy than the direction of the dip, except when the beds are vertical. The dip being at right angles to the strike is easily measured in amount, if care be taken that during the process the plane of the clinometer is vertical. The unevenness of the surface of beds may be remedied by employing a clinometer with long radius; in using Gambey's or any other clinometric compass-box, a long straight rod, or the edge of a sketch-book, will be of service.

Divisional Planes are generally most symmetrical in those rocks where the stratification is most regularly parallel, as in the argillaceous plates of Aldstone Moor, the thin limestones of Craven and Derbyshire, and the thin beds of coarse slate at Aberystwyth. In examining the strike and dip of cracks, joints, and fissures, it is requisite to try more than one example of any set supposed to be parallel, in order to know whether they are so; or what are the limits of error. In some situations two sets of joints appear, in others (as in the oolitic rocks and carboniferous formations of Yorkshire), a diagonal set sometimes occurs. In order to state a general law of the direction of the strike or dip of the joints in any country, a great number of instances, collected at distant points having nearly the same relation to an axis of elevation, should be carefully discussed in a tabular form to obtain the mean result. To learn the nature of the geometrical relation of joints, faults, veins, &c., to centres and axes of subterranean movement, observations made *far* from such situations should be compared with others made *near* to them. It is very important to ascertain whether veins, faults, &c., *change their course*, and in what manner, at or near the centres or axes of movement;—do faults converge towards a centre of elevation, as Mr. Hopkins has observed in Nottinghamshire; do mineral veins cross at right angles an anticlinal axis or master fault, as I have found to be the case in Yorkshire? In every instance the exact strike and dip of the strata in the same situation must be recorded; for where the dip of the strata is considerable, observations of the planes of joints, faults, &c., must in most cases be submitted to calculation before their true relations to the axis of movement can be known. The object of the calculation is to ascertain what *would be* the strike and dip of any joint-plane, if the strata were *restored* to their original level position.*

The strike and dip of the cleavage in slaty rocks is a very interesting and easy subject of inquiry; and if conjoined with exact determinations of the planes of stratification, divisional joints, faults, quartzose, and mineral veins, results of great theoretical value may be deduced. It should be carefully observed whether the cleavage planes vary in their inclination from the vertical according to the different beds of slate (for the slate rocks *are* perfectly bedded), and the other coarse schistose rocks which accompany or enclose them. It is very desirable to know if there are many exceptions to the law, stated by Sedgwick, that

* In former editions of this work I presented a method of computation by which this theoretical replacement of the strata could be effected, and mentioned an instrument which I had devised for obtaining, without computation, the same result; but as I never met with a geologist who had employed either the formula or the instrument, I content myself now with repeating the scheme of observation then suggested (pp. 303, 304).

the strike of cleavage is generally coincident with that of the stratification, and under what circumstances these occur. If the planes of strata change their inclination, does the inclination of the cleavage vary in any assignable ratio? If the slate beds are contorted, do the cleavage planes retain their bearing and dip across the contortions?

What is the effect of faults, quartz veins, &c., upon the perfection and symmetry of the cleavage? What is the relation of the numerous joints in slaty rocks to the plane of cleavage, the plane of stratification, and the planes of the veins and faults? The answers to these questions which I have obtained by measurements in the slaty regions of Wales and Yorkshire, appear to contain important evidence with reference to the geological date and influential circumstances of the production of slaty cleavage and other symmetrical structures. To assist in guiding enquiries on this subject into a right channel, I propose the following general formula of observation.*

Date (   ): Locality (   ): Description of the rocks: Marks of stratification:

* These suggestions were first issued in 1836. Since that time Sharpe, Sorby, Tyndall, Haughton, Jukes, Harkness, and others, have added to our knowledge. See my Report on the Slaty Cleavage to the British Association, 1856.

Notices of contortion of the beds: Qualities of different beds of slate: Occurrence of joints, veins, &c.

Strata	strike	N. 44° E.	Dip	N. 46° W.	(45°)
Cleavage	„	N. 40° E.	„	N. 50° W.	(87½°)
Joint *a*	„	N. 86° W.	„	N. 4° E.	(76°)
„ *b*	„	N.	„	W.	(72°)
„ *c*	„	N. 45° W.	„	vertical	
„ *d*	„	Horizontal Tables			
„ *e*	„	N. 40° W.	Dip	N. 50° E.	(35°)

GLOSSARY.

THOUGH many of the technical terms employed in this Treatise may be sufficiently understood by the context, or by the figures employed in illustration, it seems useful to explain a few comprehensive words in common use, which are derived from the Greek or Latin languages.

1. Several words used for large groups of Rocks contain the Greek element ζωή, life, combined with various prefixes, as—

AZOIC, or without life (α, privative). This has been employed by Murchison for very ancient strata, supposed to be unfossiliferous.

CAINOZOIC or CÆNOZOIC. — Recent life (καινός, recent). The upper grand division of strata. The Germans write it Kainozoic. In this volume the Greek αι is changed to the ordinary Latin form æ.

HYPOZOIC. — Below life (ὑπό, below). This term was proposed by myself. It applies to the same group as Azoic, being subjacent to the Palæozoic strata.

MESOZOIC.— Middle life (μέσος, middle). The middle grand group of strata.

PALÆOZOIC.—Ancient life (παλαιός, ancient). The lower grand group of fossiliferous strata.

PROTOZOIC.—Earliest life (πρῶτος, first). The lower part of the Palæozoic series has been thus named, occasionally, by Murchison and Sedgwick. Vaguely, it corresponds to the Primordial Zone of Barrande.

2. A group of convenient terms for dividing the Cænozoic series of Strata was proposed by Lyell, in which the Greek καινός, recent, was combined with prefixes to mark the degree in which the characters of recent life appeared.

EOCENE.—The beginning of recent life (ἠώς, the dawn). The *lower* tertiaries, with only about 5 per cent. of recent shells.

MEIOCENE, or MIOCENE.—Middle Cænozoic strata with a small proportion of recent shells (μείων, less).

PLEIOCENE, or PLIOCENE.—Upper Cænozoic strata with a large proportion of recent shells (πλείων, more).

PLEISTOCENE.—Uppermost Cænozoic strata, with a very large proportion of species of recent shells (πλεῖστος, most).

3. Rocks are termed Stratified or Unstratified, from the Latin *stratum*, a layer. The term 'Stromatology' is sometimes used for the designation of this branch of study (στρῶμα, a bed).

Rocks deriving their characters from heat-action, are often called in this treatise Thermo-genous (θέρμη, heat; γεν, the radical for beginning). The terms Pyrogenous (πῦρ, fire), and Igneous are commonly used to designate these rocks. The rocks of watery origin may be called Hydrogenous (ὕδωρ, water); and finally we have Metamorphic rocks which have undergone change of condition (μεταμόρφωσις, transformation).

4. The principal divisions (classes, orders, &c.) of the Vegetable Kingdom are—

ACOTYLEDONOUS.—Without seed-lobes (ἀ privative, and κοτυληδών, lobe).

DICOTYLEDONOUS.—With two seed-lobes (δίς, twice).

MONOCOTYLEDONOUS.—With one seed-lobe (μόνος, one).

5. The principal divisions of the Animal Kingdom which occur in a fossil state are the following:—

ZOOPHYTIC division of Cuvier, including:

AMORPHOZOA. — Animals without definite form (ἀ privative; μορφή, form); as sponges.

FORAMINIFERA. — Very small, often spiral, perforated shells (*foramen*, an opening); as nummulites.

ZOOPHYTA.—Plant-like animals, with one opening to the body, and a radiated structure (ζῶον, animal; φυτόν, plant).

ARTICULATA. — A large Invertebral division (*articulus*, a joint), including:

ECHINODERMATA. — Animals allied to the Echinus, often with spinose surface (ἐχῖνος, urchin; and δέρμα, skin). Subdivisions of this group are—

Crinoïdea. — Lily-shaped animal (κρίνον, a lily; εἶδος, form).

Asteroïdea. — Star-shaped animals (ἀστήρ, a star).

Echinoïdea. — Like the Echinus (ἐχινώδης, = ἐχῖνος, εἶδος).

ANNELLIDA. — Ringed worms (*annellus*, a little ring), often written Annelida, from the French Annelides.

CIRRIPEDIA. — Curl-footed animals, a group of the Articulata (*cirrus*, a curl).

CRUSTACEA. — Animals covered with a jointed crust; as crabs, lobsters, trilobites—breathing by gills.

Entomostraca.—A group of Crustacea (ἔντομον, insect; ὄστρακον, shell).

INSECTA.—Animals with six feet in the perfect state, and breathing by tracheæ. Named from the body being as it were cut across.

Arachnida. — Spider-like animals, with eight legs (ἀράχνη, spider; εἶδος, form).

Myriopoda.—Often written Myriapoda. Animals with many feet, breathing by tracheæ (μυρίος, thousand; πούς, a foot).

MOLLUSCA.—A great Invertebral division (*mollis*, soft), including:

Polyzoa. — Many associated animals (πολύς, many; and ζῶα, animals).

Brachiopoda. — Arm-footed animals, with bivalve shells; not a good name, the so-called arms or feet being neither one nor the other (βραχίων, arm; πούς, foot). They are also called—

Palliobranchiata.—Cloak-gilled animals (*pallium*, a cloak; βράγχια, gill).

Lamellibranchiata. — Gills in layers (*lamella*, a layer), including many bivalve shells; as:

Monomyaria.—With one sub-central muscle (μόνος, one; μυών, a muscle).

Dimyaria.—With two lateral muscles (δίς, twice; μυών, muscle).

Pteropoda. — Fin-footed mollusks (πτερόν, wing or fin; πούς, foot).

Gasteropoda. — Crawling mollusks (γαστήρ, belly; πούς, foot).

Heteropoda.—With abnormal foot (ἕτερος, irregular; head; πούς, foot).

Cephalopoda. — Head surrounded by feet (κεφαλή, head; πούς, foot).

VERTEBRATA.—Vertebrated animals, the spinal nerve mass protected by a chain of jointed bones, called 'vertebræ.' The classes are:

Fishes. — Among these are the Placoïd tribes with enamelled scales (πλάξ, a plate); the Ganoïds with scales composed of bright enamel on bone (γάνος, brightness); Ctenoïds, with pectinated horny scales (κτείς, a comb); and Cycloïds, with round horny scales (κυκλός, round). Fishes with symmetrical tails are called Homocercal (ὅμοιος, similar; κέρκος, tail); and those with unsymmetrical tails, Heterocercal (ἕτερος, different).

Reptiles.—(*Repto*, to crawl). The title is too restrictive in meaning; swimming and flying reptiles were very common in the mesozoic ages. The class in its largest sense includes Amphibia or Batrachia (βάτραχος, a frog); Saurida (σαύρα, a lizard); Ophidia (ὄφις, a serpent); and Chelonida (χελώνη, a tortoise). The group of Saurida is much subdivided by Owen; the principal sections being Ichthyopterygia (ἰχθύς, fish; πτερύξ, wing or fin); including Ichthyosaurus; Sauropterygia (σαύρα, lizard; πτερύξ); including Plesiosaurus; Lacertilia (*lacerta*, lizard); Crocodilia; Deinosauria (δεινός, monstrous); and Pterosauria, flying reptiles (πτέρον and σαύρα), like Pterodactylus.

Birds.—Those most frequent in a fossil state belong to the natural orders of Cursorial and Wading birds.

Mammalia.—Viviparous quadrupeds. The earliest are thought to be principally of the Marsupial division (*marsupium*, a pouch).

REFERENCES TO THE PLATES.

PLATE I.

Fig. 1. Shows the real proportions of the height of ground above the sea level from Bridlington to Whitehaven: the lines drawn sloping from west to east mark the depth to which the systems of strata descend in that country.

2. This section shows the distinction, as to arrangement, between the superficial deposits (*d*) and the inferior strata (*c*). A dislocation, or fault, affects the latter.

3. Here the stratified rocks (*b*) are contrasted with the unstratified rocks (*a*), and the superficial deposits (*d*).

4. A Geological Map of the British Isles, to show the relative extent of the great groups of strata, and the principal masses of igneous rocks.

PLATE II.

5. From the axis of crystalline rocks (*a*) the strata (*b*, *c*, *d*, *e*, *f*) decline on both sides; those which rise highest on the mountains sink lowest under the plains.

6. Near the axis of crystalline rocks (*a*) the stratified rocks are thrown into great and almost inexplicable confusion of dip, broken by faults, and bent in violent curves. (Alps.)

7. After the occurrence of the convulsions which displaced the formation (*c*), marine strata (*d*) were deposited level on the edges and slopes of the previously disturbed rocks.

Fig. 8. Shows the course of the Shap-Fell granite boulders across three vales and three abrupt ridges of hills, a distance of 107 miles.

9. Aspect of a volcanic cone, and section of its concentric layers of scoriæ, &c.

10. Effect of local depression (*d*) and of local elevation (*e*).

PLATE III. (FRONTISPIECE.)

This geological view of the Isle of Wight, comprising a plan and elevation of the surface, the natural section of the South Cliffs, and an ideal section through the middle of it, is designed as an instructive example of the relations between the superficial and the interior or subterranean arrangement of stratified rocks. Minute topographical accuracy was not essential for this object, yet the leading physical features of this remarkable island are not ill represented by the lines which portray its geological structure. While the northern half of the island, consisting of tertiary formations, partly marine, partly lacustrine, extends into a low triangular space, the southern portion, formed of secondary strata, swells into boldly undulating ridges, which are abruptly truncated by the sea.

From the pinnacles of chalk in the west, called 'The Needles,' to 'Culver Cliff' in the east, is the line of a remarkable dislocation, which has thrown the lower tertiary beds and the chalk from a horizontal into a vertical position. In the drawing the island is supposed to be cut through by a broad channel passing nearly north and south, and exposing on one of its sides a complete section of all the strata, in their real order and arrangement. It is there seen that both to the north and the south of the line of vertical strata the rocks recover their nearly horizontal position; further, we remark the Wealden formation rising into the imaginary cliff in the form of an arch, which agrees with the appearance of that formation both in Brixton Bay to the west, and Sandown Bay to the east, in a kind of 'saddle,' parallel to the line of vertical strata before mentioned.

Drawings of this nature are peculiarly useful, and there are few interesting geological tracts to which they are inapplicable: in many instances, especially in mining and coal districts, it will be proper to construct them upon the principles of isometrical perspective, as proposed by Professor Farish, and developed with much ingenuity and practical skill in Mr. Sopwith's Treatise.

The letters *h*, *l*, *g*, &c., mark the strata.

h, HASTINGS SANDS, or Wealden formation.

l, LOWER GREENSAND, nearly horizontal in the southern cliffs, rising thence towards the north, and passing inland, over the Hastings Sands, and returning to the cliffs near Culver and the Needles, with a steep dip northward.

g, GAULT, ranging parallel to and above the Lower Greensand.

u, UPPER GREENSAND, forming the highest points of some of the southern cliffs; then ranging inland, and returning to the cliffs, and dipping north under the chalk of the Needles and Culver.

c, CHALK, in ramified and detached high masses or downs on the surface, dipping very steeply to the north at Culver, and acquiring at the Needles almost a vertical position. The flints which lie in the upper part of the chalk near the line of dislocation are in a singular condition, penetrated by secret fissures, so as to fall to fragments on being removed from the rock.

t, THE TERTIARY STRATA. Of these the London clay, and a great variety of coloured sands, with mottled clays, beds of lignite, and layers of pebbles, are placed directly vertical at Alum Bay, north of the Needles, while the upper beds of the sandy series turn under the horizontal freshwater marls and limestones of Headen Hill, which is a little farther north.

PLATE IV.

Fig. 11. Illustrates the simplest case of the sloping layers of detritus round the place where a rapid river enters a deep and quiet lake: *h*, *h′*, the surface of the water; *s*, *s′*, the slope of the layers, becoming straight in the lower parts; *b*, *b*, the bed of the lake. It is probable that the matter in these laminæ grows coarser toward the bottom, so as to give somewhat of horizontality to lines of similar ingredients.

12. This figure is proposed as an example of the relations of symmetrical structures and dislocations to the planes of stratification; *c*, cracks; *f*, fissure; *j*, joints; *v*, a vein passing through a series of different sorts of stratified rocks. Fissures and joints seldom deviate much from a plane rectangled to the strata (small joints are sometimes oblique in shales); cracks are less regular; vein-fissures are of unequal breadth, and are unequally productive in rocks of different nature. *l*, shows the relation of oblique lamination to true stratification; *p*, the pebbles of a conglomerate divided by the cracks and joints.

13. The relation of faults to planes of stratification is here shown.

14. Contorted strata: near such the rocks are usually full of cracks, and these in limestone are often sparry.

Fig. 15. Illustrates in a vertical section the meaning of unconformed stratification, the coal measures having been elevated and dislocated, so that the red marl and lias were deposited on their displaced edges.

16. A general section of the strata, showing the principal cases of unconformity in the British Islands.

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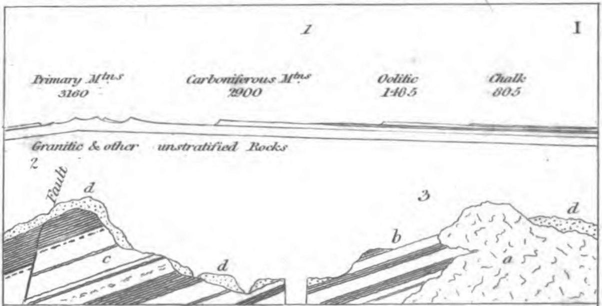

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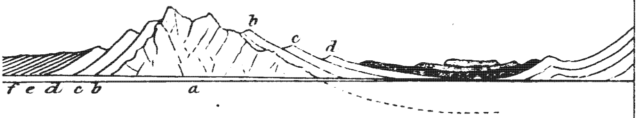

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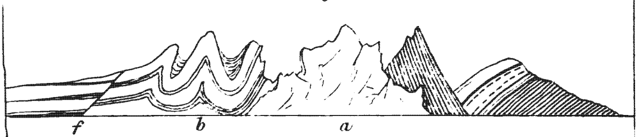

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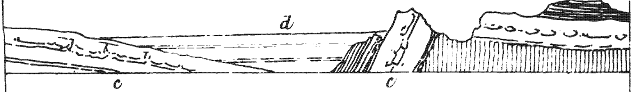

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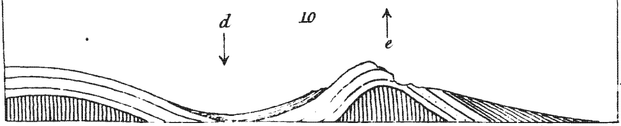

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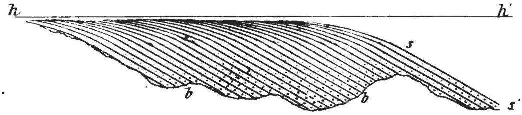
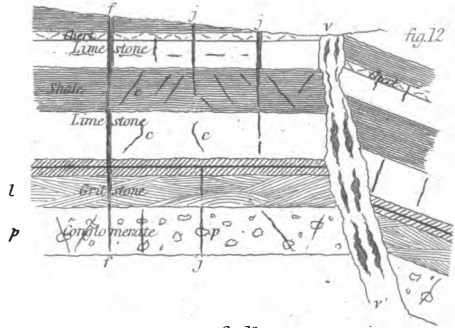
fig. 11





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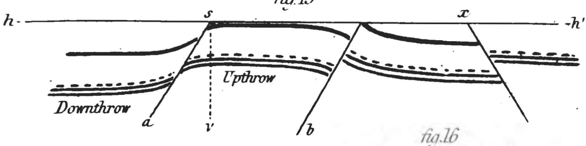

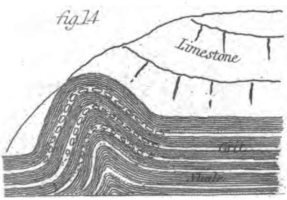

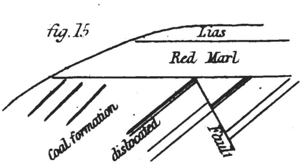

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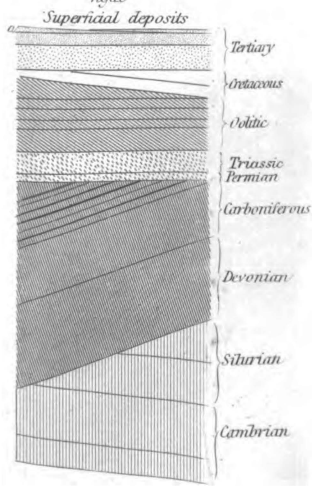

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