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was illustrated by Werner, after the model of the Saxon mountains, is found to include, perhaps, the largest class of inquiries which has ever been ranked under one head. For, in the attempt which it makes to decipher the history of the past, and to prognosticate the future changes of our planet, it requires the aid of all the gathered knowledge of nature, interpreted by the profoundest researches of abstract science. It is not even enough to know the actual state of the earth, we must further learn the measure of momentary changes in this state; and thus inquiries of a new order are suggested to naturalists, who are seldom aware, while investigating the problems before them, that these include dynamical as well as statical determinations, and that the former are necessary to the right understanding of the latter.

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

earth showed "no traces of a beginning, no prospect of an end"; because, on that matter, other evidence might have been brought to bear.

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

Geology, or the natural history of the earth, as a planet revolving in space round a central orb of light and heat, surrounded by an atmosphere, and partially or wholly begirt by water, includes all the phenomena produced on the land, in the sea, and within the mass of the globe, by the operation of those mechanical, chemical, electrical, and vital forces, which are termed natural agencies, from the earliest epoch of which monuments remain, down to the present hour. All variations in the proportions of land and water; all variations of level; all changes in the combination and distribution of masses or molecules of matter, whether above, upon, or below the surface; all changes in the

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

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

In geology, however, the physical conditions are *not known*, but are to be *inferred*, for any particular epoch in the history of the globe, from the facts collected concerning the organic and inorganic bodies which belonged to that era, and are indicative of the physical influences then operating: and hence arise both the difficulties and the charms of geological reasoning. The difficulties are unavoidably very great; for, even in the acquisition of the data concerning organic and inorganic bodies, geology is often forced to be satisfied with less

exactness than is attainable in modern natural history. Certain shells, fishes, &c., are recognised by the geologist, but he may not find them of all ages; cannot know correctly what were the limits of variation, of their magnitude, forms, habits, &c. In some important cases, he can hardly know whether particular mollusca and fishes lived in lakes, rivers, or the sea; whether certain plants grew on land or in water. Now, as it is only on a correct knowledge of the affinities which the fossil remains of life bear to existing races, that any just inference can be founded concerning the contemporaneous physical conditions, we see how fertile are the sources of error, and with what justice men of philosophic minds have endeavoured to restrain that propensity to speculation which imperceptibly gets possession of the human mind, and has particularly luxuriated among the enthusiastic votaries of geology. There is less difficulty with respect to inorganic bodies, because the laws of their aggregation are such as, in many instances, can be tested by experiments which apply with equal exactness to the ancient and modern mineral kingdoms.

Scale of Geological Time.

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

known, the problem of the history of the successive conditions of the globe becomes almost desperate.

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

Series of Stratified Rocks.

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

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

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

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

The historic records of man's residence on the earth are, for most parts of the globe, utterly incomplete; so that, but for the Jewish Scriptures and other documents of eastern nations, we should be in danger of attributing to the human race an origin too recent by thousands of years. Now, as all historic records end, for each country, with the surface, — terminate at some point of man's history posterior to the preparation of that tract for his residence, we see how far more ancient than the historic date of the human race is the series of productions which lie below the surface. The limit of least antiquity of the scale of geological time is in every country

beyond the date of the present surface. The series of strata is so ancient, that even its uppermost and newest term in every country is older than the race of man now existing there ; though we are not entitled to say, without further examination, that it is older than the human species generally, for it is supposable that a former race of men might have existed over an older surface of the same part of the spherical area, under older physical conditions.

Antiquity of the Surface.

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

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

Nature of the Scale of Time.

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

Terms of the Scale of Geological Time.

The different strata which are terms of the series or spaces on the scale of geological time are of various mineral qualities — arenaceous, argillaceous, calcareous, or composed of mixtures of these in unequal proportions. In the substance of many of them, peculiar minerals, as mica, red oxide of iron, silicate of iron, &c., are diffused; they differ in hardness, granulation, crystalline structure, and many other circumstances. Every

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

Series of Terms on the Scale of Geological Time.

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

Moreover, an additional fact of great interest here comes to fortify all our inferences — the organic remains of plants and animals which abound in the earth are not those of the tribes that now live, but of many wholly extinct, and often quite different, races — different in form and structure, and, consequently, in function and habits of life, though certainly belonging to a general system of nature founded on analogous principal conditions. Further, it is not sufficient nor correct to say, there is one living and one extinct creation: the plants and animals buried in the earth belong to many distinct and successive creations, which differ among one another no less than they almost all differ from the actual forms of life. These distinct creations of former date are found buried in different parts of the series of strata; one series of organic forms belongs to

the lower and older strata, another to those of middle, another to those of later date. The different groups of strata, deposited in successive periods, are thus filled with distinct races of plants and animals, which lived at successive periods, and thus it is proved that in every region the land and the sea were covered and filled at successive times with new creations suited to the new physical conditions of the altered planet.

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

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

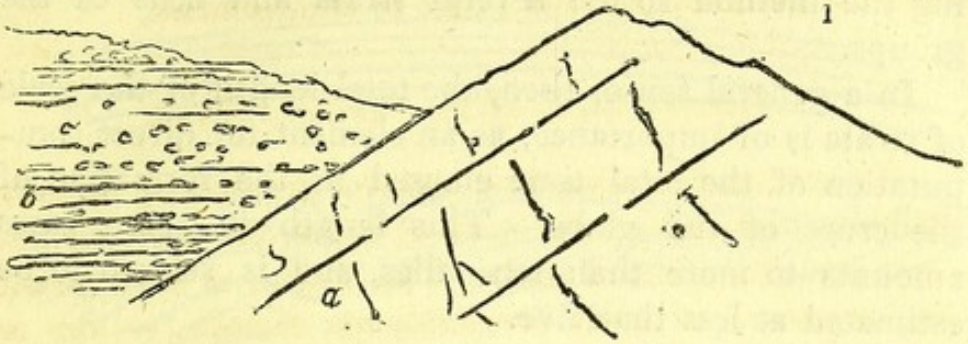
violent revolutions, capable of so influencing organic life (if probable at all), require, according to what is known of the earth and planetary system, periods or intervals too great for the mind to comprehend.

Interruptions of the Series of Time.

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

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

beds *a* of limestone were exposed to watery action, and broken up in part, so that fragments and pebbles of



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

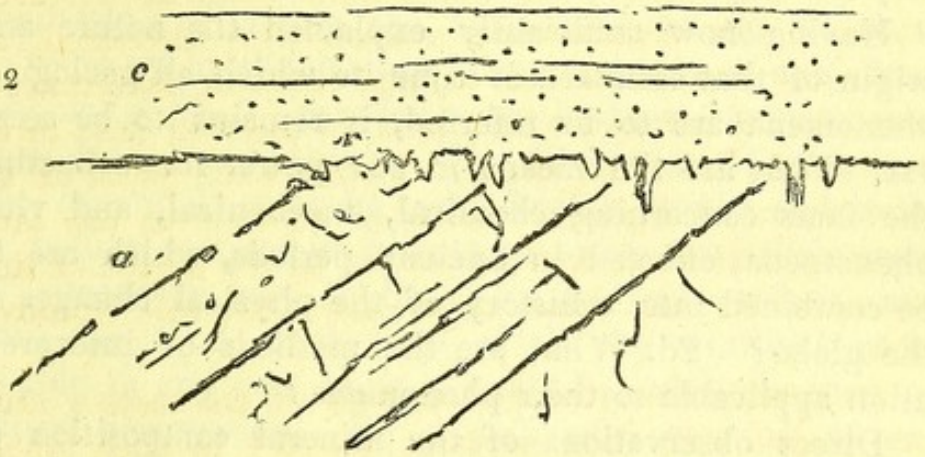


fig. 2. the same inclined limestone beds *a* are covered by horizontal oolitic strata *c*; and are worn and polished on the face of junction, and penetrated into holes by boring shells, which lived in the oolitiferous sea, long after the elevation of the older rocks.

Length of the Scale of Time.

The scale of geological time given by the series of stratified rocks is one of unequal parts: for it is almost certain that the deposition of a given thickness of sandstone, was accomplished in a different time from that consumed in the production of an equal thickness of clay, limestone, coal, &c. Yet as many of the *groups* of strata contain both sandy, argillaceous, and calcareous members, there is less error in estimating the re-

lative periods which elapsed in the production of such groups by their proportionate thickness, than in applying the method to the several strata and beds of the groups.

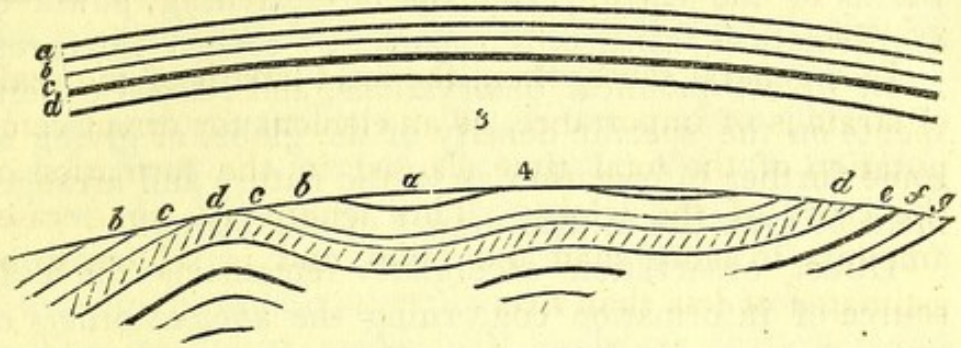
In a general sense, then, the total length of the scale of strata is of importance, as an element for direct computation of the total time elapsed in the formation of the crust of the globe. This length in some cases amounts to more than ten miles, and is seldom to be estimated at less than five.

Means of Investigation of Facts.

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

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

sentation of the arrangement of strata, in a part of the crust of the earth.



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

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

Here, then, is the limit of our knowledge, from actual inspection and exact induction of facts concern-

through the knowledge of the conditions or agencies concerned in the phenomena of existing nature, that we must approach with caution to the solution of the similar problems offered by the phenomena of ancient times: the common relations are found by comparison of the analogous effects; but if the modern effects are merely known as laws of phenomena, and not reduced, to use Mr. Whewell's expressive language, to laws of causation, the corresponding phenomena of geology must remain equally unexplained.

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

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

Geology thus presents itself in an aspect which may surprise those who have not studied the philosophy of the subject: though it gathers the most striking and beautiful facts, it depends for their interpretation entirely upon the progress of collateral science, and puts forth no speculation or hypothesis, except in conformity with the known laws of nature, and as a means of ex-

exception of mercury, which is both liquid and solid within the range of terrestrial temperature at the surface, all solid.

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

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

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

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

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

* Guide to Geology.

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

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

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

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

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

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

* See on the Chemical Constitution of Rocks, De la Beche's Geological Manual, 2d edit.
† Guide to Geology, 3d edit.

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

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

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

Free relative motion to the extent here required,

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

sions, like the nebulæ and comets; speculations which appear to be gradually changing into probable *inferences* by the progress of modern astronomy. For the examination of these obscure bodies, with powerful telescopes, has shown them to be of extremely various characters, so as to offer many points in illustration of the supposed process of condensation and arrangement.

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

CHAP. III.

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

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

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

Structure of the external Parts of the Globe.

Soil, the external investment of the land, though it somewhat veil from geologists the objects of their peculiar research, merits attention; for this thin covering varies in some real relation to the rocks beneath, and appears, in many instances, to be nothing else than the substance of those rocks decomposed by time, and altered by vegetable admixtures. The depth of soil is extremely irregular, — some feet thick over certain sandy rocks, a foot thick over clays, only a few inches

continually from the mountains toward the plains, and in the middle of these is sometimes evanescent. Near London, for example, and on the coast of England generally, strata, though not level, dip moderately (1° or 2°) toward the east; but on the line to North Wales the dip augments; on the border of the Principality it measures 5°, 10°, 15°, and in the range of the Berwyn mountains, 30° and 40°, or still higher angles.

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

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

If we suppose the unstratified rocks to have been

ornamental parts are made up by a diffusion of the other forms of Linnæan madrepores, viz. fungia, pavonia, agaricia, monticularia, echinophora, pocillopora, seriatopora, and oculina, together with gorgonia, isis, corallium, melitea, corallina, spongia, alcyonium, actinia, &c., independent of the locomotive asteriæ, echini, testacea.

The coral islands are classed by Mr. Stutchbury as circular, flat, long narrow, and encircling high land.

The coral islands of the Dangerous Archipelago (lat. S. 12° to 27°, long. W. 130° to 155°) are all of the first kind, and consist of strips or belts of coral of an annulate or circular form, from 400 or 500 yards to one mile across the ring which always incloses a lagoon; seldom raised above the water more than from 4 or 5 feet; abrupt towards the ocean, which rapidly deepens to more than 120 fathoms. The islands vary from 2 or 3 to 150 miles round; the ring, being often divided across by a fissure, admits vessels to enter the lagoon. The depth at which the coralligenous zoophyta commence their labours is said not to exceed 15 or 20 fathoms (Quoy and Gaimard say 20 or 30 feet, Mr. Darwin has recently given the same estimate as Mr. Stutchbury). The bottom of the lagoons is seen in calm weather at a depth of 100 feet or more, strewed over with *dead shells and broken fragments of coral, rarely showing any living specimen below sixteen or seventeen fathoms;* at which depth, smaller reefs rise within the lagoon; and beyond which depth, broken masses of rock may be seen without any living portion attached.

It would appear that, during the formation of a reef, portions of it become compact, and as dense as any limestone rock; a circumstance indicative of the partial dissolution and re-precipitation of the coral masses, and apparently analogous to the process whereby coral shells, &c. have been imbedded in the compact limestone of ancient stratified rocks. Extensive beds of particular shells appear among the islands.

Islands often occur of a flat or tabular form, generally

oval or irregularly rounded at their circumference: of this form are the group called by Cook the Friendly Isles, consisting of numerous islands, the majority of which are tabular.

There are also many crescent-shaped reefs, with the most convex portion of their arc the highest, often denoting themselves to the mariner only by the breaking of the waves, and here and there a rock above the level of the ocean, while the horns of the crescent are depressed, and gradually lost in the greater depth: in a few instances, as at Gambier's Island, they are sufficiently raised to have become verdant and inhabited.

Of those which form long narrow strips of land, Mr. Stutchbury refers to Tehuro, a few leagues from Tahiti, and the great reef which takes the course of the north-eastern shore of New Holland, which Captain Flinders describes as being more than 1000 miles in lenth; in the course of which there is a continued portion exceeding 350 miles with scarcely a break or passage through it.

Of the last group of coral islands, or rather reefs, encircling elevated land, the Society Islands, including Tahiti, offer striking examples; being often surrounded by coral reefs, generally situated 400 or 500 yards off shore, with a deep channel between, having numerous openings, through which ships can enter and lie at anchor in perfect safety. These breaks in the coral barrier are, in most instances, opposite the mouths of freshwater rivulets.

The islands Raiatea and Tahaa (Ulietea and Otaha of Cook) are divided by a strait, by which ships can enter at the windward side of the islands, and get to sea again through the leeward channels. These two islands are entirely surrounded by one coral reef, extending throughout the circumference of both; the openings through the reefs are, in most cases, denoted by the points being rather higher and more verdant, having trees, principally cocoa nut trees, planted by the natives upon them. The passage is seldom more than 100

yards in breadth, with the depth varying from 3 to 15 fathoms.

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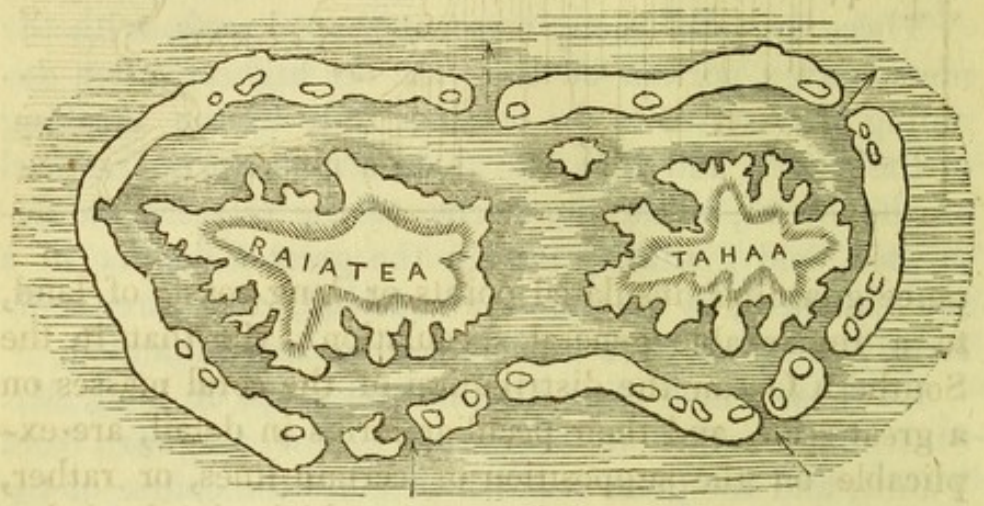

The dark part is calm water round the islands and within the coral reef. The arrows show the entrances and exits for vessels.

The form of the coral islands must very materially depend upon that of the base on which they happen to be built; hence their circular, lunulate, oval, or irregular forms give information as to the shape and even nature of the subjacent rocks. In most cases, the base of the small islands appears to be a volcanic crater, entire or broken; islands of volcanic rock, as Tahiti, are surrounded by rings of coral. The elevation of the coral islands is not owing to the mere accumulation by the rough action of the sea, but to a gradual rising of the low islands, and a violent subterranean movement of the lofty ones, like Tahiti, *which bears on the apex of one of the highest mountains a distinct and regular stratum of semi-fossil coral,* and near it, but on a lower level, a volcanic crater with two lateral gorges.

In this case, had the upward movement been gradual, why should not the coral growths have covered the edges of the crater, or rested on other points?

Mr. Darwin has recently been conducted, by a consideration of the structure of coral islands, annular and linear, whether immediately investing, or at a dis-

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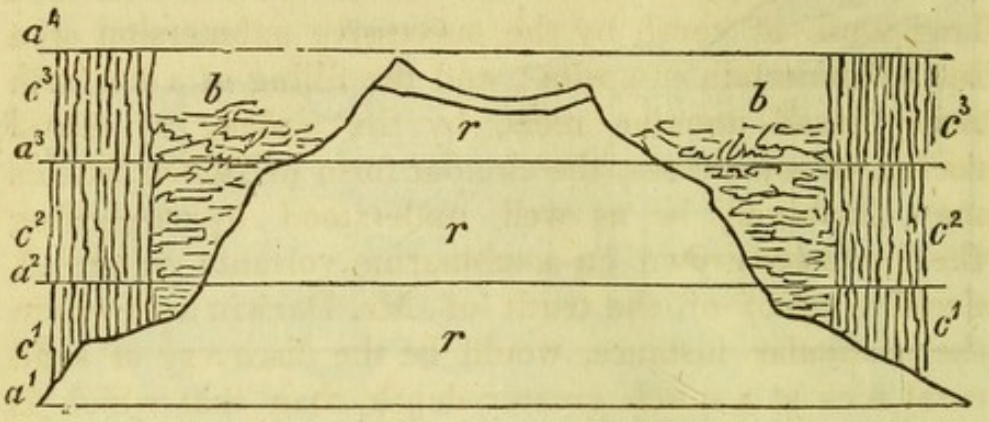

off by waves filling up the space between the reef and the rock, the whole became an annular coral reef inclosing a lagoon. The island and reef would thus present in a plan the following features successively.

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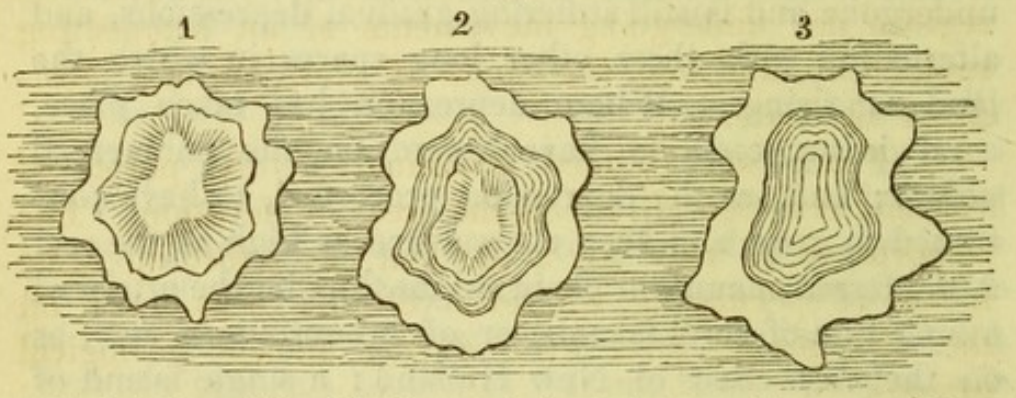


In *fig* 1. the rock is *skirted* by coral; in *fig.* 2. the rock is separated from the coral which *widely encircles* it by a channel of (deep) water; in *fig.* 3. the rock is not seen, but forms the *base* of the lagoon, and is covered by fragmented corals.

If, instead of a sinking, we next imagine a gradual rising or a stationary situation of some island, on which a circle of coral was fixed, the additional growth of this substance would be always on the outside, and the land would never be separated from a *widely encircling* reef by a channel of deep water.

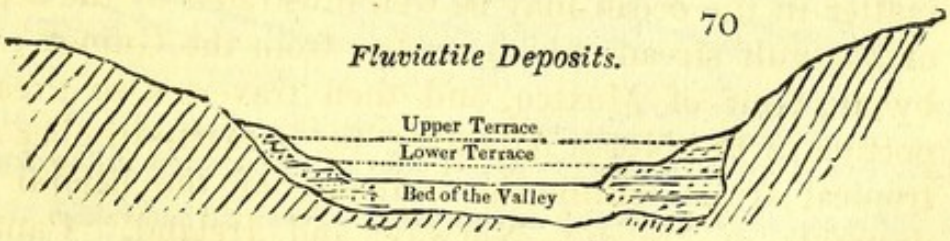
In Mr. Darwin's views, the presence of a lagoon coral island is an evidence of *depression* of the solid land there; and, on the contrary, marginal coral reefs often supply evidence of *rising*, in addition to that furnished by shelly beaches at high levels. Thus may

Ancient Valley Formations.

I have some time ago proposed this term, for the purpose of combining in one point of view a great number of remarkable ancient phenomena, attesting the former action of water *in existing valleys,* but flowing at higher levels than the actual stream, unless the land has been raised and sunk. Deposits of gravel at the mouth of a valley, in the form of terraces, abound in most mountain countries (*e. g.* foot of Glen Roy), on the sides of a valley (as in Tynedale, above Newcastle), at the head of a valley (as at the head of several Cumberland glens).

In Glen Roy, at a very high level, are two parallel lines, or terraces, which run round the mountain sides, and communicate with other drainage streams. The deposit called Löss, on the Rhine, appears of the same nature, so far, at least, as to indicate the deposition of sediments in water flowing at a level many hundred feet above the present River Rhine, and extending beyond what is now its proper valley on the north side of the range of the Ardennes.*

In some of these cases, there is sufficient proof that the water was not marine, land shells being not unfrequently found in the deposits, especially the finer sorts of sediments. The level character of the terraces, which is the most usual form of these accumulations, seems to indicate the existence of ancient lakes at a high level in the valleys where they occur.



This, however, is less certain than may be commonly imagined; for streams like the rough Arve scatter the detritus brought down from the glaciers over a surface

* Lyell, in Geol. Proc.

gently declining, as the stream runs, but nearly level in the transverse section. If, by any change of the physical conditions, the stream should cut its way to a greater depth, the banks would have that terrace form which belongs to the Lune, the Ouse, the Tees, the Tyne, and many rivers of the North of England. It not uncommonly happens, that two such terraces, at different levels, can be traced for some distance on the sides of a valley, as on the Lune ; — occasionally, in the midst of a valley, rises a low hill of gravel corresponding to the lateral terraces. In most valleys, the materials of the terraces are such as the rocks on the sides of the mountains yield ; but this is not the case on the Lune about Kirkby Lonsdale, or the Tyne above Newcastle, in both of which situations, boulders and gravel from the Cumbrian mountains constitute a considerable part of the deposit. For this reason, they would probably be called diluvial deposits by some writers, and described as raised breaches by others. The confused aggregation of the pebbles, sand, &c. is such as to imply sudden and violent inundations, which delivered a vast body of detritus in a short time, and perhaps followed the line of the valley, but deposited the coarse earthy matters near the sides when the velocity was lessened, as powerful streams are always found to do.

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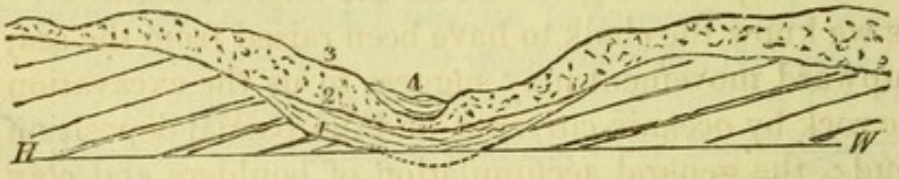


H. W. High water mark.
1. Surface of chalk excavated by water in some ancient period.
2. Surface of ancient tertiary sands, or alluvial sediment left in the chalk valley.
3. Surface of detrital (diluvial) deposit extended over hill and valley.
4. Surface of comparatively modern alluvial deposit in the valley of the diluvium, consisting of chalk and flint gravel.

Existing valleys have, then, in many cases, been traversed by floods of water which have left evidence of their volume, force, and direction. Did they excavate the

valleys? or merely follow the traces left by earlier watery violence? Perhaps we must not yet venture to propose a general answer to such questions;—there exist, however, cases which bear very decided evidence with reference to them. At a little valley in the chalk of Yorkshire (represented in the diagram, p. 318.), which opens to the sea near Bridlington, we behold, as in the above sketch, the solid, laminated, chalk, gently declining to the south, excavated in a broad undulation across the laminæ; over nearly the whole breadth of the hollow thus occasioned, rests an irregular sandy deposit very much of tertiary aspect; above this, a thick mass of diluvial clay with bouldered stones in great confusion; the whole surmounted, in places, by a widely laminated deposit of chalk and flint gravel. Finally, the channel of the existing little rill is cut, certainly by that rill, in places through the whole series of deposits, into the solid chalk beneath. What does this teach us? First, the excavation of the chalk by an agent which wholly swept away the spoils; secondly, a less turbulent agency introducing sand and gravel, so as partially to fill up the hollow, but not to cover the parts of the chalk beyond; thirdly, a violent impulse of mud and stones brought from a distance over this valley, and the surfaces for miles on each side of it; fourthly, variable but extensive deposits of local gravel; fifthly, the work of the actual stream, which gathered in the ancient hollow.

As we know the chalk to have been raised from the sea, this upward movement may suggest to us the excavation of the rock by oceanic currents, and the partial deposition of sand; the general accumulation of boulders and clay demands a general disturbance affecting other, and even remote, districts; while the mass of chalk, flint, gravel, seems the natural effect of a more local and less violent convulsion. In some instances, local gravel of this description lies both above and below the proper diluvium.

The interval of time here supposed to occur between the original excavation of a hollow or valley in the rocks, and the accumulation in it of the spoils of a

violent commotion of water, is indeterminate. So, indeed, is that between the cessation of the diluvial floods (whatever they were) and the commencement of the actual stream. For if the great hollow was both excavated and afterwards filled before the chalk rose completely out of the sea water, we have no easy means of knowing when the whole became dry land, and admitted the descent of fresh water. If, however, the bones of quadupeds which occur in the diluvium be thought sufficient to prove these accumulations to have happened on dry land, the actual stream may be looked upon as a feeble but immediate successor of the devastating floods.

Rock Terraces in Valleys. — There is a peculiar class of terraces in valleys, which indicate in the same manner the successive lowering of the level of descending water (or the successive rising of the land); these terraces are formed by solid rock, with little or no trace of gravel, or other detritus. Such cases are frequent in the mining dales of the North of England, which cut deep into the "Yoredale Rocks," or upper mountain limestone series. *

In this varied series of limestone, sandstone, and shale, almost every limestone which overlies shale projects into a terrace; and this sometimes happens to strong sandstones similarly circumstanced. It is easy to see that, as this occurs in many of the branching lesser dales, as well as in the principal valley, it may plausibly be argued that the whole effect is due to atmospheric action. It is probable, however, that this is not a sufficient cause; since additional débris might thus be expected to be falling every day, or, at least, more of this accumulation should remain than we see. We must further observe, that the presumed levels of the water are only clearly marked by continuous terraces when the strata dip nearly in the plane of the valley. It appears, that just as, at this day, a mountain stream crossing the Yoredale Rocks

* Geol. of Yorkshire, vol. ii.

salient angle, — for it is always observed among the common daily effects of inundations, that such terrace-like levels are only marked on the projecting land, while the re-entering angle is excavated to vertical or steep faces.

Fluviatile Deposits.

To discuss fully the origin and history of valleys, is an object reserved for a later section; we may now proceed to consider the effects produced, in valleys already formed, and partially filled with old detritus, by the water running therein. This is a large subject; for, besides the mechanical and chemical actions of the rivers and brooks, which vary according to the hardness and nature of the rocks, there is to be examined the influence of atmospheric vicissitudes, heat and cold, moisture, dryness, frost, &c.; and all the complicated effects thus occasioned are, in relation to the valleys, further modified by the form and slope of the surface, the occurrence of lakes, and other circumstances. Streams flowing along a valley under the various conditions which we observe, are to be considered both as eroding and transporting agents; and it is not only conceivable from the admitted instability of the level of land and sea, but perfectly demonstrated by observation, that these seemingly opposite effects have been exhibited at different times by the same river, at the same points of a valley. Moreover, in the course of the changes of level of land and sea, some rivers appear to have quitted their ancient valleys entirely, and to have taken up new courses corresponding to the new conditions; and this, not merely in marshy countries, where a river's course is almost accidental, but in hilly and rocky districts like the vicinity of Ludlow or the borders of Teesdale. It will, therefore, be proper to present as full an account of the phenomena relating to the actual configuration of valleys under different circumstances, as a due regard to reasonable limits will allow. The first thing to be con-

range above the outcrop edge of the limestone beds, and act as drainage channels from the surface to the jointed calcareous rocks below. These round or irregular pits and holes are smoothed on the faces and joints of stone, as if by the action of acidulated water, the origin of which, from the air or the neighbouring vegetable substances, is not hypothetical.

Effects of Frost.

In no form is the moisture of the atmosphere inefficient in accelerating the disintegration of rocks. Collected in the joints and cavities of mountains, it loosens every thing by its expansion and relaxation; heaped into enormous glaciers on the summits and down the valleys of the Alps, it melts at its lower edges and on the lower surfaces, and thus is ever in motion downwards; augmented from above and diminished from below, its moving masses plough up the solid earth, and, by a wonderful and momentarily insensible energy, pile up, on each side of the icy valley, vast quantities of blocks of stone and heaps of earth, which slowly advance into the lower ground; and these sometimes bear trees and admit cultivation; till, in the course of changes which these rude climates experience, the whole is transported away by the river which flows beneath, and space is left for new augmentations from above. Perhaps no circumstances are so favourable to the collection of materials for rivers to sweep away, as the glacier crown and icy valleys of the Alps, accompanied by the thundering avalanche and frequent landslips, like those of the Rossberg and the Righi. What further happens to these materials, belongs to the history of the river.

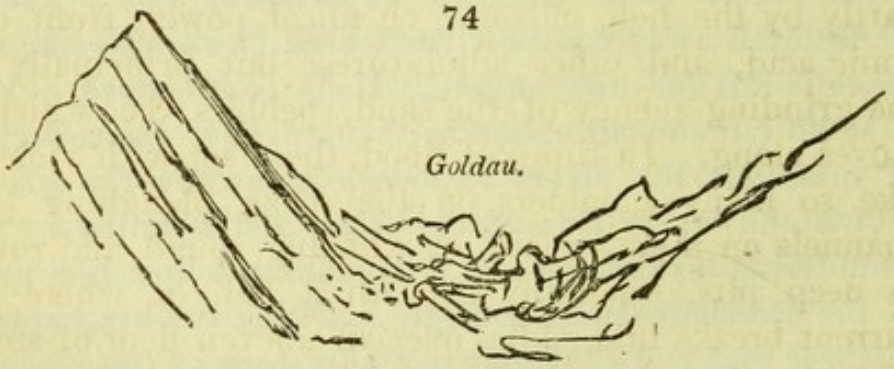
Effects of Springs.

Collected in the atmosphere, the rain is filtered through the sandy rocks, passes rapidly by the joints of the calcareous strata, and is stopped by the clays, and

by dykes and faults; it then issuing in springs. But it is no longer the same water: rain water is, indeed, far from being in a state of purity; it contains always carbonic acid, frequently some muriatic acid or chloride of sodium, besides other irregular admixtures. In passing through the rocks it absorbs lime, oxide of iron, &c., and on issuing in the form of springs, loses its excess of carbonic acid, and again deposits carbonate of lime, carbonate of iron, &c. From some springs the quantity of carbonate of lime deposited is enormous; with the water of others, sand, gravel, fossil shells, and zoophytic fragments issue. Thus the first operation of water in and upon the earth is the same, viz. to consume away the solid substance of the rocks, and either deposit it in new situations not far from the source, or deliver it to flowing streams to be carried further away.

Springs which have an impeded issue to the surface, are the most general cause of landslips: we may consider the great fall of the Rossberg as a case of this kind, the water entering and moistening a particular layer of strata, all inclined very highly, so as easily to acquire a descending force, if the cohesion of the parts were weakened by interposed moisture.

Rossberg.



The spring, or rather river (Arve), which issues from the foot of the mer de glace, near Mont Blanc, brings a vast quantity of detritus, which the grinding motion of the glacier on its rocky bed had broken and rolled to pebbles.

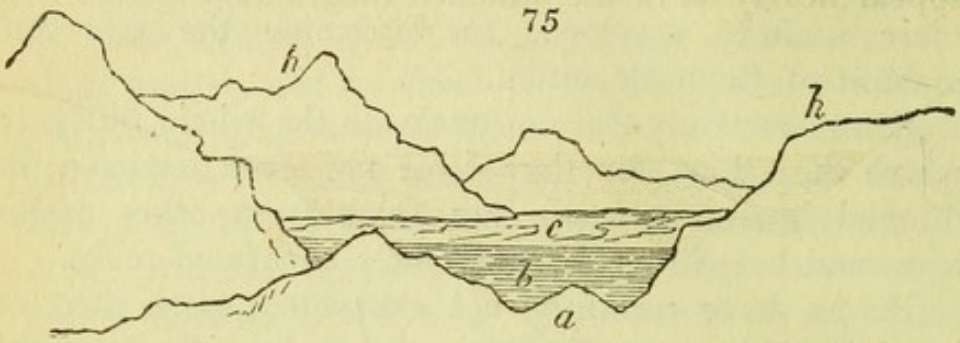
suppose, the remaining evidence of the former passage of running water, when the levels of the country were differently adjusted.

As the slopes are greatest in the upper parts of valleys (generally), and gradually flatten towards the sea, it is commonly observed, that, from all the upper parts of these valleys, rivers abstract large quantities of the finer matter, and in times of inundation, not a little of the coarser fragments of rocks; much of this is deposited in the lower ground, where the current is more tranquil, and generally (unless the river be very deep) slower. We must, indeed, suppose, that every where *some* wearing effect on its bed and sides is produced by every river, even to its mouth; but this effect grows almost insensible far from the high ground which gives birth to the streams; and long ere we approach the estuary, the wide flat meadows, which fill the whole breadth of the valley for miles in length, show what a mass of materials has been drifted away from the higher ground. Finally, where the tides and freshes meet, the sediment of both is disposed to drop; and some rivers may be viewed as sending little or no sediment to the sea.

Thus the whole effect of drainage, including all the preliminary influences of the atmosphere, rain, springs, &c., is to waste the high ground, and to raise the low; to smooth the original ruggedness of the valley in which it flows, by removing prominences and filling up hollows; and notwithstanding the length of years that rivers have flowed, they have, in general, not yet completed this work: they still continue to *add* materials to the lower ground, and, in a few instances, to carry out sediment into the sea.

The whole surface of the earth, then, is changing its level, by the mere precipitations of the atmosphere, and their subsequent effects; the high land sinks, and the low land rises; but what is the rate of this progress, we have no complete means of knowing. Few ancient measures of the height of the land which has been wasted, or the area of that which has been accumu-

or at least their surface is generally level in the direction across the valley, whatever undulations exist beneath, and however rapid may be the longitudinal declivity of the valley. This is well seen in many valleys of the Swiss Jura, the Cotswold Hills, &c.

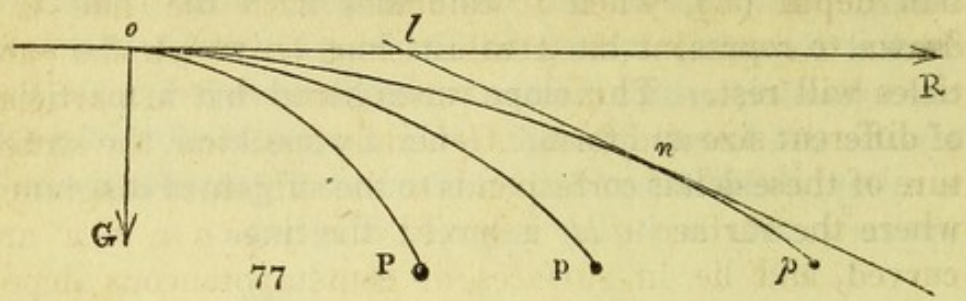


a. Irregular surface which is the original basis of the valley. *b.* The sediment left in it, with a plane surface *as if* deposited in a lake. *c.* The surface of the valley, uniformly declining among *h*, the bordering mountains.

When the materials are gravel and coarse sand, deposited by an impetuous stream, the general surface may be level, and yet the laminæ beneath are frequently much inclined, with slopes in various directions, as Mr. Lyell has noticed with regard to the detritus left by the stormy waters of the Arve. The same thing occurs in many of the stratified rocks which appear to have been accumulated under violent agitation near the sea-shore. (See Diag. No. 20. p. 61.)

Lakes on the Course of Rivers.

Plane surfaces existing along the course of valleys, are commonly, without further question, supposed to be indicative of the site of ancient lakes, which have been slowly but completely filled: the supposition is often correct, but it is sometimes erroneous. Rapid rivers, which, in times of inundation, drift coarse materials down their rough beds, and deposit them in the expansions of their valleys, are thus partly choked in their courses, and turned into new channels. Thus they wander irregularly over a large area, every where



tude, entering together, describe curves of unequal curvature (they are all related to the same vertical axis, G); the smallest particles being transported furthest, because they have, proportionally, the largest surface, and therefore subside most slowly in the water.

On the horizontal plan (No. 78.) the courses of such deposits are shown to be concentrical, or nearly so, to the point of influx of the river. By such deposits, the Delta of the Rhone in the Lake of Geneva, as well as that of the Derwent in the Lake of Keswick, has been formed; and, in fact, in every lake a similar explanation

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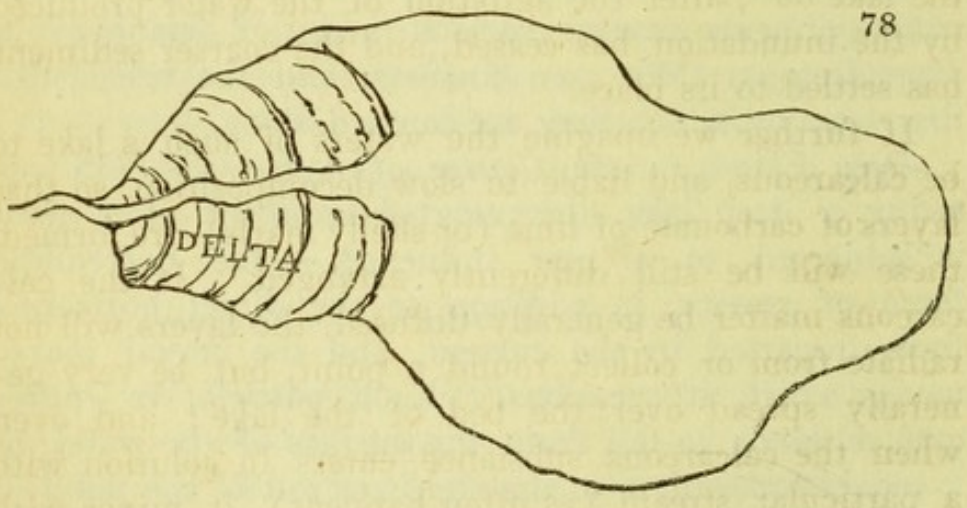
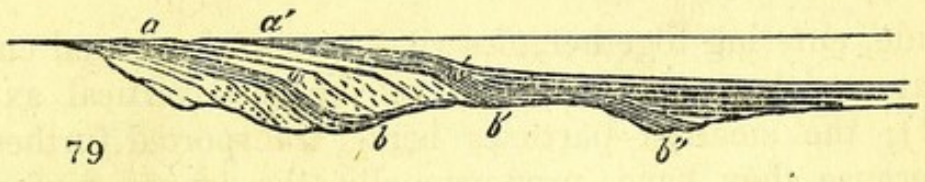


is found applicable. Returning to the vertical section (No. 77.), we may remark, that the parabolic lines there given, if considered as representing successive depositions, require to be modified above and below: above, by the shifting of (*o*) the point of influx forward; below, by the circumstance, that the curve ceases at a cer-

tain depth (n), when it coincides with the line $n\ l$ drawn to represent the greatest slope on which the particles will rest. This slope varies somewhat in particles of different size and form. Generally speaking, the structure of these deltas corresponds to the subjoined diagram; where the surface $a\ a'$ is level; the lines $a\ n$, $a'\ n'$ are curved, and lie in surfaces of contemporaneous depo-



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sitions; and the lines $n\ b$, $n\ b'$ are straight lines corresponding to the angle of rest in deep water.

We may further observe, that the unequal dispersion of the sediments in water causes another modification of the lamination of such delta. Fine clay is spread far in the water, and settles at length in a general thin deposit over the curved and sloping faces $a\ n\ b$, and on the bed of the lake $b\ b''$, after the agitation of the water produced by the inundation has ceased, and the coarser sediment has settled to its place.

If further we imagine the waters of such a lake to be calcareous, and liable to slow decomposition, so that layers of carbonate of lime (or shelly marls) are formed, these will be still differently arranged. If the calcareous matter be generally diffused, the layers will not radiate from or collect round a point, but be very generally spread over the bed of the lake; and even when the calcareous substance enters in solution with a particular stream (as often happens), it mixes with the water of the lake so extensively as to yield wider and more regular deposits than those produced by merely mechanical agency.

Shallow lakes, subject to fluctuation, produce on the deposits of coarse gravel and sand, which are brought into them by rivers, an effect intermediate between that of deep water and mere fluviatile currents. The

conoidal lamination due to the former is complicated with variation of the point of influx arising from the latter; and thus the upper ends of such lakes become irregular in outline, and are filled by insulated subaqueous banks.

END OF THE FIRST VOLUME.

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