CHAPTER XXVI.

Magnitude of the subterranean changes produced by earthquakes at great depths below the surface—Obscurity of geological phenomena no proof of want of uniformity in the system, because subterranean processes are but little understood—Reasons for presuming the earthquake and volcano to have a common origin—Probable analogy between the agency of steam in the Icelandic geysers, and in volcanos during eruptions—Effects of hydrostatic pressure of high columns of lava—Of the condensation of vapours in the interior of the earth—That some earthquakes may be abortive eruptions—Why all volcanos are in islands or maritime tracts—Gases evolved from volcanos—Regular discharge of heat and of gaseous and earthy matter from the subterranean regions—Cause of the wave-like motion and of the retreat of the sea during earthquakes—Difference of circumstances of heat and pressure at great depths—Inferences from the superficial changes brought about by earthquakes—In what matter the repair of land destroyed by aqueous causes takes place—Proofs that the sinking in of the earth's crust somewhat exceeds the forcing out by earthquakes—Geological consequences of this hypothesis, that there is no ground for presuming that the degree of force exerted by subterranean movements in a given time has diminished—Concluding remarks.

When we consider attentively the changes brought about by earthquakes during the last century, and reflect on the light which they already throw on the ancient history of the globe, we cannot but regret that investigations into the effects of this powerful cause have hitherto been prosecuted with so little zeal. The disregard of this important subject may be attributed to the general persuasion, that former revolutions of the earth were not brought about by causes now in operation,—a theory which, if true, would fully justify a geologist in neglecting the study of such phenomena. We may say of the superficial alterations arising from subterranean movements, as we have already declared of the visible effects of active volcanos, that, important as they are in themselves, they are still more so as indicative of far greater changes in the interior of the earth's crust. That both the chemical and mechanical changes in the subterranean regions must often be of a kind to which no counterpart can possibly be found in progress within the reach of our observation, may be confidently inferred; and speculations on these subjects ought not to be discouraged, since a great step is gained if they render us more conscious of the extent of our inability to define the amount and kind of results to which ordinary subterranean operations are now giving rise. It is no longer disputed that a great series of convulsions have carried up deposits once formed on the bottom of the ocean to the height of several miles above its level; and it is not difficult to perceive that the same movements must in numerous places have raised rocks to elevations above the level of the sea, which were once formed at the depth of several miles in the bowels of the earth. If, then, there were no spots discoverable which exhibited signs of extraordinary mechanical and chemical changes, the effects at some former period of immense pressure, intense heat, and other conditions far different from those developed on the surface, it might be urged as a triumphant argument against those who are dissatisfied with the proofs hitherto adduced in favour of the mutability of the course of Nature.

In order to set this in a clear light, let the reader suppose himself acquainted with just one-tenth part of the words of some living language, and that he is presented with several books purporting to be written in the same tongue ten centuries ago. If he should find that he comprehends a tenth part of the terms in the ancient volumes, and that he cannot divine the meaning of the other nine-tenths, would he not be strongly disposed to believe that, for a thousand years, the language has remained *unaltered?* Could he, without great labour and study, interpret the greater part of what is written in the antique documents, he must feel at once convinced that, in the interval of ten centuries, a great revolution in the language had taken place. He might, undoubtedly, by comparing the conventional signs already known to him, with those not previously acquired, and by observing the analogies and associations of terms in many of the old books, come at length to discover the true import of much of the ancient writings, and guess at the meaning of nearly all the rest; but if he is entirely shut out from all communication with those who now use the same language, he will never fully understand the value of some terms. So if a student of Nature, who, when he first examines the monuments of former changes upon our globe, is acquainted only with one-tenth part of the processes now going on upon or far below the surface, or in the depths of the sea, should still find that he comprehends at once the import of the signs of all, or even half the changes that went on in the same regions some hundred or thousand centuries ago, he might declare without hesitation that the ancient laws of nature have been subverted. Even after toiling for centuries, and learning more both of the present and former state of things, he must never expect to gain a perfect insight into all that formerly happened, so long as his acquaintance is very limited in regard to much that is now going on. So completely has the force of this line of argument been overlooked, that when any one has ventured to presume that all former changes were simply the result of causes now in operation, they have invariably been called upon to explain every obscure phenomenon in geology, and if they failed, it was considered as conclusive against their assumption. Whereas, in truth, there is no part of the evidence in favour of the uniformity of the system, more cogent than the fact, that with much that is intelligible, there is still more which is yet novel, mysterious, and inexplicable in the monuments of ancient mutations in the earth's crust.

Before the immense depth of the sources of volcanic fire was generally admitted, the causes of subterranean movements were sought in peculiar states of the atmosphere. These were imagined to afford not only prognostics of the convulsions, but to have considerable influence in their production. But the supposed signs of approaching earthquakes were of a most uncertain and contradictory character. Aristotle, Pliny, and Seneca, taught that earthquakes were preceded by a serene state of the air; whereas several modern writers have been of opinion that a cloudy sky and sudden storms are the forerunners of these commotions. That there is an intimate connexion between subterranean convulsions and particular states of the weather is unquestionable; but as Michell truly remarked, "it is more probable that the air should be affected by the causes of earthquakes, than that the earth should be affected in so extraordinary a manner, and to so great a depth, by a cause residing in the air."

After violent earthquakes the regular drainage of a country is obstructed; lakes and pools are caused by local subsidences or landslips, and the evaporation of an extensive surface of shallow water produces unseasonable rains. Fogs proceed from the damp soil which is traversed by numerous rents and crevices filled with water. In addition to these circumstances, the electrical effect produced by the movement and friction of great masses of rock against each other may cause lightning, gusts of wind, luminous exhalations, and other atmospheric phenomena. Rains, moreover, are sometimes derived from volcanic eruptions accompanying earthquakes; for eruptions, as we before stated, are attended with a copious discharge of aqueous vapour.

Before we attempt to enquire farther into the true causes of earthquakes, we shall briefly recapitulate our reasons for considering them as originating from the same sources as volcanic phenomena. In the first place, the regions convulsed by violent earthquakes include within them the site of all the active volcanos. Earthquakes, sometimes local, sometimes extending over vast areas, precede volcanic eruptions. Both the subterranean movement and the eruption return again and again, at unequal intervals of time, and with unequal degrees of force, to the same places. The duration of both may continue for a few hours, or for several consecutive years. Paroxysmal convulsions of both kinds are usually followed by long periods of tranquillity. Thermal springs, and those containing abundance of mineral matter in solution, are characteristic of countries where active volcanos or earthquakes are frequent. In districts considerably distant from volcanic vents, the temperature of hot springs has been sometimes raised by subterranean movements. In addition to these signs of relation and analogy, we may observe, that it is not very easy to conceive how columns of melted matter can be raised to such great heights, as we know them to attain in volcanos, without exerting an hydrostatic pressure capable of moving enormous masses of land; nor can we be surprised that elastic fluids capable of forcing up so great a weight of rock in fusion, and of projecting large stones to immense heights in the air, should also cause tremors, vibrations, and violent movements in the solid crust of the earth. The volcano of Cotopaxi has thrown a mass of rock, about one hundred cubic yards in volume, to the distance of eight or nine miles, and we may well conceive that the slightest obstruction to the escape of such an expansive force may convulse a considerable tract in South America. "If these vapours," says Michell, "when they find a vent are capable of shaking a country to the distance of ten or twenty miles round the volcano, what may we not expect from them when they are confined?" As there is no doubt that aqueous vapour constitutes the most abundant of the aëriform products of volcanic eruptions, it may be well to consider attentively a case in which steam is exclusively the moving power—the Geysers of Iceland. These intermittent hot springs rise from a large tract, covered to a considerable depth by a stream of lava; and where thermal waters, and apertures evolving steam, are very common. The great Geyser rises out of a spacious basin at the summit of a circular mound, composed of siliceous incrustations deposited from the spray of its waters. The diameter of the basin or crater, in one direction, is fifty-six feet, and forty-six in another.

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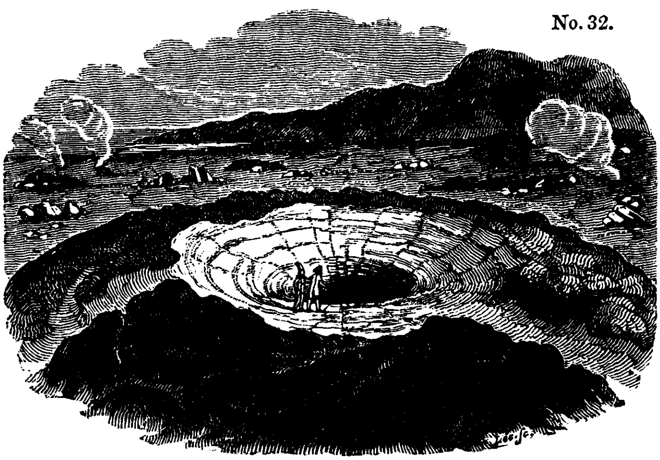

*View of the Crater of the great Geyser in Iceland**.

In the centre is a pipe seventy-eight feet in perpendicular depth, and from eight to ten feet in diameter, but gradually widening as it opens into the basin. The inside of the basin

* Reduced from a sketch given by W. J. Hooker, M.D., in his "Tour in Iceland," vol. i., p. 149.

is whitish, consisting of a siliceous incrustation, and perfectly smooth, as are two small channels on the sides of the mound, down which the water makes its escape when filled to the margin. The circular basin is sometimes empty, as represented in the above sketch, but is usually filled with beautifully transparent water in a state of ebullition. During the rise of the boiling water up the pipe, especially when the ebullition is most violent, and when the water flows over or is thrown up in jets, subterranean noises are heard, like the distant firing of cannon, and the earth is slightly shaken. The sound then increases and the motion becomes more violent, until at length a column of water is thrown up perpendicularly with loud explosions, to the height of one or two hundred feet. After playing for a time like an artificial fountain, and giving off great clouds of vapour, the pipe is evacuated, and a column of steam then rushes up with amazing force and a thundering noise, after which the eruption terminates. If stones are thrown into the crater they are instantly ejected, and such is the explosive force, that very hard rocks are sometimes shivered into small pieces. Henderson found that by throwing a great quantity of large stones into the pipe of Strockr, one of the Geysers, he could bring on an eruption in a few minutes*. The fragments of stone as well as the boiling water were thrown in that case to a much greater height than usual. After the water had been ejected, a column of steam continued to rush up with a deafening roar for nearly an hour; but the Geyser, as if exhausted by this effort, did not give symptoms of a fresh eruption when its usual interval of rest had elapsed.

In the different explanations offered of this singular phenomenon, all writers agree in supposing a subterranean cavity where water and steam collect, and where the free escape of the steam is intercepted at intervals, until it acquires sufficient force to discharge the water. Suppose water percolating from the surface of the earth to penetrate into the subterranean cavity A D by the fissures F F, while at the same time, steam, at an extremely high temperature, such as is commonly given out from the rents of lava-currents during congelation, emanates from the fissures CC. A portion of the steam is at first condensed into

* Journal of a Residence in Iceland, p. 74.

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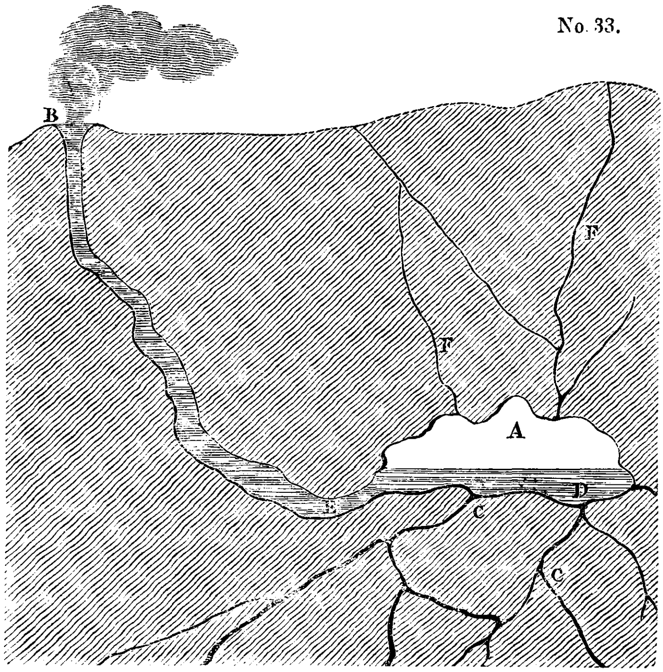

Supposed section of the subterranean reservoir and pipe of a Geyser in Iceland.

water, and the temperature of the water is raised by the latent heat evolved, until, at last, the lower part of the cavity is filled with boiling water and the upper with steam under high pressure. The expansive force of the steam becomes, at length, so great, that the boiling water is forced up the fissure or pipe E B, and a considerable quantity runs over the rim of the basin. When the pressure is thus diminished, the steam in the upper part of the cavity A expands until all the water D is driven to E, when this happens, the steam, being the lighter of the two fluids, rushes up with great velocity, as on the opening of the valve of a steam-boiler. If the pipe be choked up artificially with stones, even for a few minutes, a great increase of heat must take place, for it is prevented from escaping in a latent form in steam, so that the water is made to boil up in a few minutes, and this brings on an eruption.

Now if we suppose a great number of large subterranean cavities at the depth of several miles below the surface of the earth, wherein melted lava accumulates, and that water penetrating to these is converted into steam, this steam, together with other gases generated by the decomposition of melted rocks, may press upon the lava and force it up the duct of a volcano, in the same manner as it drives a column of water up the pipe of a Geyser. But the weight of the lava being immense, the hydrostatic pressure exerted on the sides and roofs of such large cavities and fissures may well be supposed to occasion not merely slight tremors, such as agitate the ground before an eruption of the Geyser, but violent earthquakes. Sometimes the lateral pressure of the lower extremity of the high column of lava may cause the more yielding strata to give way, and to fold themselves in numerous convolutions, so as to occupy less space, and thereby give relief, for a time, to the fused and dilated matter. Sometimes, on the contrary, a weight equal to that of the vertical column of lava, pressing on every part of the roof, may heave up the superincumbent mass, and force lava into every fissure which, on consolidation, may support the arch, and cause the land above to be permanently elevated. On the other hand, subsidences may follow the condensation of vapour when cold water descends through fissures, or when heat is lost by the cooling down of lava.

That lava should often break out from the side or base, rather than from the summit of a lofty cone like Etna, has always been attributed to the immense hydrostatic pressure which the sides of the mountain undergo, before the lava can rise to the crater. This conclusion is too obvious not to have met with a general reception; yet how trifling must this pressure be when compared to that which the same column imparts to the reservoirs of aëriform fluids and melted rock, at the depth of many miles or leagues below the surface!

If earthquakes be derived from the expansion by heat of elastic fluids and melted rock, it is perfectly natural that they should terminate, either when a volcanic vent permits a portion of the pent up vapours or lava to escape, or when the earth has been so fissured that the vapour is condensed by its admission into cooler regions, or by its coming in contact with water. Or relief may be obtained when lava and gaseous fluids have, by distending the strata, made more room for themselves, so that the weight of the superincumbent mass is sufficient to repress them. If we regard earthquakes as abortive volcanic eruptions at a great depth, we must expect them to succeed each other for an indefinite number of times in the same place, for the same reason that eruptions do; and it is easy to conceive that, if the matter has failed several times to reach the surface, the consolidation of the lava first raised and congealed will strengthen the earth's crust, and become an additional obstacle to the protrusion of other fused matter during subsequent convulsions.

As most volcanos are in islands or maritime tracts, the neighbourhood of the sea seems one of the conditions necessary for the ascent of lava to great heights. Even those volcanos which lie inland form part of a chain of volcanic hills, and may be supposed to have a subterranean communication with the extremities of the chain which are in the neighbourhood of large masses of salt-water. Thus Jorullo, in Mexico, though itself no less than forty leagues from the nearest ocean, seems, nevertheless, connected with the volcano of Tuxtla on the one hand, and that of Colima on the other, the one bordering on the Atlantic, the other on the Pacific ocean. This communication is rendered the more probable by the parallelism that exists between these and several volcanic hills intermediate*. Perhaps the quantity of water which percolates from the surface of the land is sufficient to contribute to the violence of earthquakes, without producing so much steam as is required to bring on a volcanic eruption. But when the sea overlies a mass of incandescent lava, and the intermediate crust of the globe is shaken and fissured by earthquakes, it may well be supposed that a convulsion of a different kind will ensue. If an open fissure be caused like that which traversed the plain of S. Lio, on Etna, in 1669, so that the water descends at once upon a mass of melted lava, eruptions will probably burst forth along the line of this aperture, the steam rushing up, together with gaseous emanations from the lava, and carrying up scoriæ with it. But from what we know of the wave-like motion of the ground during earthquakes, there is good reason to conclude that a continuous communication will rarely be formed between the sea and a bed of lava at great depth below, because the alternate

* See Daubeny's remarks on this subject,—"Volcanos," p. 368.

rising and falling of the earth causes chasms to open and again to close in violently. In the same manner, therefore, as yawning fissures shut again after engulphing trees and houses, so great masses of water may be swallowed up, and the sea may immediately afterwards be excluded. Suppose then a volcanic vent to be once formed by a submarine eruption, all the water engulphed will, on penetrating to subterranean reservoirs of heated lava, be converted into steam, and this steam making its way through the same channels by which elastic fluids escape in the intervals between eruptions, will drive melted lava before it. Successive eruptions will have a tendency to seek the same vent, especially if the peak of a cone is raised above the water; for then there will probably be no more than the pressure of the atmosphere in a great part of the duct leading to the crater.

Volcanos exhale, during eruptions, besides aqueous vapour, the following gases: muriatic acid, sulphur combined with hydrogen or oxygen, carbonic acid and nitrogen, the greater part of which would result from the decomposition of salt-water, a fact which, when taken in conjunction with the proximity of nearly two hundred active vents to the sea, and their absence in the interior of large continents, is almost conclusive as to the co-operation of water and fire in the raising of lava to the surface.

We have before suggested the great probability that, in existing volcanic regions, there are enormous masses of matter in a constant state of fusion far below the surface: this opinion is confirmed by numerous phenomena. Perennial supplies of hot vapour and aëriform fluids rise to certain craters, as in Stromboli for example, and Nicaragua, which are in a state of ceaseless eruption. Sangay in Quito, Popocatepetl in Mexico, and the volcano of the isle of Bourbon, have continued in incessant activity for periods of sixty or one hundred and fifty years. Numerous solfataras, evolving the same gases as volcanos, serve as permanent vents of heat generated in the subterranean regions. The plentiful evolution, also, of carbonic acid, from springs and fissures throughout hundreds of square leagues, is another regular source of communication between the interior and the surface. Steam, often above the boiling temperature, is emitted for ages without intermission from "stufas," as the Italians term them. Hot springs in great numbers, especially in tracts where earthquakes are frequent, serve also as regular conductors of heat from the interior upwards. Silex, carbonate of lime, muriate of soda, and many earths, alkalies and metals are poured out in a state of solution by springs, and the solid matter which is tranquilly removed in this manner may, perhaps, exceed that which issues in the shape of lava.

It is to the efficacy of this ceaseless discharge of heat, and of solid as well as gaseous matter, that we probably owe the general tranquillity of our globe; for were it not that some kind of equilibrium is established between fresh accessions of heat and its discharge, we might expect perpetual convulsions, if we conceive the land and the ocean itself to be incumbent in many extensive districts on subterranean reservoirs of lava. If there be reason for wonder, it is, as Pliny observed, that a single day should pass without some dreadful explosion. "Excedit profectò omnia miracula, ullum diem fuisse quo non cuncta conflagrarent *." But the circulation of heat from the interior to the surface, is probably regulated like that of water from the continents to the sea, in such a manner that it is only when some obstruction occurs to the regular discharge, that the usual repose of Nature is broken. Any interruption to the regular drainage of a country causes a flood, and, if there be any obstruction in the passages by which volcanic matter continually rises, an earthquake or a paroxysmal eruption is the consequence.

Michell has observed, that the wave-like motion of the ground during earthquakes, appears less extraordinary if we call to mind the extreme elasticity of the earth, and that even the most solid materials are easily compressible. If we suppose large districts to rest upon the surface of subterranean lakes of melted matter, through which violent motions are propagated, it is easy to conceive that superincumbent solid masses may be made to vibrate or undulate. The following ingenious speculations are suggested by the above mentioned writer. "As a small quantity of vapour almost instantly generated at some considerable depth below the surface of the earth will

* Hist. Mundi, Lib. ii., c. 107.

produce a vibratory motion, so a very large quantity (whether it be generated almost instantly, or in any small portion of time) will produce a wave-like motion. The manner in which this wave-like motion will be propagated may in some measure be represented by the following experiment. Suppose a large cloth, or carpet (spread upon a floor) to be raised at one edge, and then suddenly brought down again to the floor, the air under it being by this means propelled, will pass along, till it escapes at the opposite side, raising the cloth in a wave all the way as it goes. In like manner, a large quantity of vapour may be conceived to raise the earth in a wave, as it passes along between the strata which it may easily separate in an horizontal direction, there being little or no cohesion between one stratum and another. The part of the earth that is first raised, being bent from its natural form, will endeavour to restore itself by its elasticity, and the parts next to it being to have their weight supported by the vapour, which will insinuate itself under them, will be raised in their turn, till it either finds some vent, or is again condensed by the cold into water, and by that means prevented from proceeding any farther *."

In order to account for the retreat of the ocean from the shores before or during an earthquake, the same author imagines a subsidence at the bottom of the sea, from the giving way of the roof of some cavity in consequence of a vacuum produced by the condensation of steam. For such condensation, he observes, might be the first effect of the introduction of a large body of water into fissures and cavities already filled with steam, before there has been sufficient time for the heat of the incandescent lava to turn so large a supply of water into steam, which being soon accomplished causes a greater explosion. Sometimes the rising of the coast must give rise to the retreat of the sea, and the subsequent wave may be occasioned by the subsiding of the shore to its former level; but this will not always account for the phenomena. During the Lisbon earthquake, for example, the retreat preceded the wave not only on the coast of Portugal, but also at

* On the Cause and Phenomena of Earthquakes, Phil. Trans., vol. li., § 58—1760.

the island of Madeira and several other places. If the upheaving of the coast of Portugal had caused the retreat, the motion of the waters when propagated to Madeira would have produced a wave previous to the retreat. Nor could the motion of the waters at Madeira have been caused by a different local earthquake, for the shock travelled from Lisbon to Madeira in two hours, which agrees with the time which it required to reach other places equally distant *.

We shall not indulge at present in further speculations on the mode whereby subterranean heat may give rise to the phenomena of earthquakes and volcanos. No one, however, can fail to be convinced, if he turns his thoughts to the subject, that a great part of the reasoning of the most profound natural philosophers and chemists can be regarded as little more than mere conjecture on matters where the circumstances are so far removed from those which fall under actual observation. Many processes must be carried on in situations where the pressure exceeds as much that produced by the weight of the loftiest mountains, as the weight of the unfathomed ocean surpasses that of the atmosphere. The mechanical effects, therefore, of earthquakes at vast depths, may be such as can never be paralleled on the surface. The intensity of heat must often be so far removed from that which we can imitate by experiments, that the elements of solid rocks or fluids may enter into combinations such as can never take place within the limited range of our observations. Water at a certain depth may, as Michell boldly suggested, become incandescent without expanding, and remain at rest without any tendency to produce an earthquake. Air, if it ever penetrate to such depths, may become a fluid. Sir James Hall's experiments prove, that, under a pressure of about one thousand seven hundred feet of sea, corresponding to that of only six hundred feet of liquid lava, limestone melts without giving off its carbonic acid, so that it is only when calcareous lavas are forced up to within a slight distance of the surface, or into a sea of moderate depth, that the carbonic acid begins to assume a gaseous form, and to assist in bringing on a volcanic eruption.

But let us now turn our attention to those superficial changes

* Michell, Phil. Trans., vol. li. p. 614.

brought about by so many of the earthquakes within the last century and a half, before described. Besides the undulatory movements, and the opening of fissures, it was shewn that certain parts of the earth's crust often of considerable area, both above and below the level of the sea, have been permanently elevated or depressed; examples of elevation by single earthquakes having occurred, to the amount of from one to about twenty-five feet, and of subsidence from a few inches to about fifty feet, exclusively of those limited tracts, as the forest of Aripao, where a sinking down to the amount of three hundred feet took place. It is evident, that the force of subterranean movement does not operate at random, but the same continuous tracts are agitated again and again; and however inconsiderable may be the alterations produced during a period sufficient only for the production of ten or fifteen eruptions of an active volcano, it is obvious that, in the time required for the formation of a lofty cone, composed of thousands of lava-currents, shallow seas may be converted into lofty mountains, and low lands into deep seas. We need, therefore, cherish none of the apprehensions entertained by Buffon, that the inequalities of the earth's surface, or the height and area of our continents, will be reduced by the action of running water; nor need we participate in the wonder of Ray, that the dry land should not lose ground more rapidly. Neither need we anticipate with Hutton the waste of successive continents followed by the creation of others by paroxysmal convulsions. The renovating as well as the destroying causes are unceasingly at work, the repair of land being as constant as its decay, and the deepening of seas keeping pace with the formation of shoals. If, in the course of a century, the Ganges and other great rivers have carried down to the sea a mass of matter equal to many lofty mountains, we also find that a district in Chili, one hundred thousand square miles in area, has been uplifted to the average height of a foot or more, and the cubic contents of the granitic mass thus added in a few hours to the land, may have counterbalanced the loss effected by the aqueous action of many rivers in a century. On the other hand, if the water displaced by fluviatile sediment cause the mean level of the ocean to rise in a slight degree, such subsidences of its bed, as that of Cutch in 1819, or St. Domingo in 1751, or Jamaica in 1692, may have compensated by increasing the capacity of the great oceanic basin. No river can push forward its delta without raising the level of the whole ocean, although in an infinitesimal degree; and no lowering can take place in the bed of any part of the ocean, without a general sinking of the water, even to the antipodes.

If the separate effects of different agents, whether aqueous or igneous, are insensible, it is because they are continually counteracted by each other, and a perfect adjustment takes place before any appreciable disturbance is occasioned. How many considerable earthquakes there may be upon an average in the course of one year, throughout the whole globe, is a question that we cannot decide at present; but as we have calculated that there are about twenty volcanic eruptions annually, we shall, perhaps, not overrate the earthquakes, if we estimate their number to be equal. A large number of eruptions are attended by local earthquakes of sufficient violence to modify the surface in some slight degree, and there are many earthquakes, on the other hand, not followed by eruptions. Even if we do not assume, as many have done, that the submarine convulsions exceed in number and violence those on the land, in spaces of equal area, we must, nevertheless, reckon about three shocks exclusively submarine, for one exclusively confined to the continents.

We have said in a former chapter * that the aqueous and igneous agents may be regarded as antagonist forces, the aqueous labouring incessantly to reduce the inequalities of the earth's surface to a level, while the igneous are equally active in restoring the unevenness of the crust of the globe. But an erroneous theory appears to have been entertained by many geologists, and is indeed as old as the time of Lazzoro Moro, that the levelling power of running water was opposed rather to the *elevating* force of earthquakes than to their action generally. To such an opinion the numerous well-attested facts of subsidences must always have appeared a serious objection, but the same hypothesis would lead to other assumptions of a very arbitrary and improbable kind, inasmuch as it would be necessary to imagine the magnitude of our

* Chap. x. p. 167.

planet to be always on the increase if the elevation of the earth's surface by subterranean movements exceeded the depression. The sediment carried into the depths of the sea by rivers, tides, and currents, tends to diminish the height of the land; but, on the other hand, it tends, in a degree, to augment the height of the ocean, since water, equal in volume to the matter carried in, is displaced. The mean distance, therefore, of the surface, whether occupied by land or water from the centre of the earth, remains unchanged by the action of rivers, tides, and currents. Now suppose that while these agents are destroying islands and continents, the restoration of land should take place solely by the forcing out of the earth's envelope—it will be seen that this would imply a continual distension of the whole mass of the earth. For the greater number of earthquakes would be submarine, and they would cause the sea to rise and submerge the low lands even in a greater degree than would the influx of sediment. Two causes would, therefore, tend to destroy the land; submarine earthquakes, and the destroying and transporting power of water; and in order to counterbalance these effects, shallow seas must be upraised into continents, and low lands into mountains.

If we first consider the question simply, in regard to the manner whereby earthquakes may prevent running water from altering the relative proportion of land and sea, or the height of the land and depth of the ocean, we shall find that if the rising and sinking be equal, things would remain upon the whole in the same state: because rivers, tides, and currents, add as much to the height of lands which are rising, as they take from those which have risen.

Suppose a large river to carry down sediment into a certain part of the ocean where there is a depth of two thousand feet, and that the whole space is reduced by the fluviatile depositions to a shoal only covered by water at high tide: then let a series of two hundred earthquakes strike the shoal, each raising the ground ten feet; the result will be a mountain two thousand feet high. But suppose the same earthquakes had visited the same hollow in the bottom of the sea before the sediment of the river had filled it up, their whole force would then have been expended in converting a deep sea into a shoal, instead of changing a shoal into a mountain two thousand feet high. The superior altitude, then, of a district may often be due to the transportation of matter at a former period *to lower levels.* It would probably be more consistent with the natural course of events, if, instead of a succession of elevatory movements, we were to suppose considerable oscillations before the district attained its full height. Let there be, for example, three hundred instead of two hundred shocks, each separated from the other by intervals of about fifty years. Let the mean alteration of level produced by each earthquake be ten feet, two hundred and fifty shocks causing a rise, and the other fifty a sinking in of the ground; although more time will have been consumed by this operation than by the former, we shall still have the same result, for a tract will be raised to the height of about two thousand feet. The chief difference will consist in the superior breadth and depth of the valleys, which will be greater nearly in the proportion of one-third, in consequence of the number of landslips, floods, opening of chasms, and other effects produced by one hundred additional earthquakes. It should be borne in mind, moreover, that some of the lowering movements, happening towards the close of the period of disturbance, may have given rise to strange anomalies, should an attempt be made to reconcile the whole excavation in various hydrographical basins to the levels finally retained. Perhaps, for example, the middle portion of a valley may have sunk down, so that a deep lake may intervene between mountains and certain low plains, to which their debris had been previously carried.

But to return to the consideration of the proportion between the elevation and depression of the earth's crust, which may be necessary to preserve the uniformity of the general relations of land and sea, on the surface. The circumstances are in truth more complicated than those before stated, for, independently of the transfer of matter by running water from the continents to the ocean, there is a constant transportation of mineral ingredients from below upwards, by mineral springs and volcanic vents. As mountain masses are in the course of ages created by the pouring forth of successive streams of lava, so others originate from the carbonate of lime and other mineral ingredients with which springs are impregnated. The surface of the land, and parts of the bottom of the sea are thus raised, and if we conceive the dimensions of the planet to remain uniform, we must suppose these external accessions to be counteracted by some action of an opposite kind. A considerable quantity of earthy matter may sink down into fissures caused by earthquakes, but this cannot be deemed sufficient to counterbalance the addition of mountain masses by the causes before adverted to, and we must therefore suppose, that the subsidences of the earth's crust exceed the elevations caused by subterranean movements. It is to be expected, on mechanical principles, that the constant subtraction of matter from the interior will cause vacuities, so that the surface undermined will fall in during convulsions which shake the earth's crust even to great depths, and the sinking down will be occasioned partly by the hollows left when portions of the solid crust are heaved up, and partly when they are undermined by the subtraction of lava and the ingredients of decomposed rocks. The geological consequences which will follow if we embrace the theory now proposed are very important, for if there be upon the whole more subsidence than elevation, then we must consider the depth to which former surfaces have sunk down beneath their original level, to exceed the height which ancient marine strata have attained above the sea. If, for example, marine strata about the age of our chalk and green-sand have been lifted up in Europe to an extreme elevation of more than eleven thousand feet, and to a mean height of some hundreds above the level of the sea, we may conclude that certain parts of the earth's surface, which existed whether above or below the waters when those strata were deposited, have subsequently sunk down to an extreme depth of *more than* eleven thousand feet below their original level, and to a mean depth of *more than* a few hundreds.

In regard to faults, also, we must, according to the hypothesis now proposed, infer that a greater number have arisen from the sinking down than from the elevation of rocks. If we find, therefore, ancient deposits full of fresh-water remains which evidently originated in a delta or shallow estuary, covered subsequently by purely marine formations of vast thickness, we shall not be surprised; for we must expect that a greater number of existing deltas and estuary formations will sink below, than those which will rise above their present level.

Although it would be rash to attempt to confirm these speculations by reference to the scanty observations hitherto made on the effects of earthquakes, yet we cannot but remark, that the instances of subsidence on record are far more numerous than are those of elevation.

Those writers who have most strenuously contended for the analogy of the effects of earthquakes in ancient and modern times, have nevertheless declared that the energy of the force has considerably abated. But they do not appear to have been aware that, in order to adduce plausible grounds for such an hypothesis, they must possess a most extensive knowledge of the economy of the whole terrestrial system. We can only estimate the relative amount of change produced at two distinct periods, by a particular cause in a given lapse of time, when we have obtained some common standard for the measurement of equal portions of time at both periods. We have shown that, within the last one hundred and forty years, some hundred thousand square miles of territory have been upheaved to the height of several feet, and that an area of equal, if not greater extent, has been depressed. Now, they who contend, that formerly more movement was accomplished by earthquakes in the space of one hundred and forty years, must first explain the measure of time referred to, for it is obvious that they cannot in geology avail themselves of the annual revolution of our planet round the sun. Suppose they assume that the power of volcanos to emit lava, and of running water to transport sediment from one part of the globe to the other, has remained uniform from the earliest periods, they might then attempt to compare the effects of subterranean movements in ancient and modern times by reference to one common standard, and to show that, while a certain number of lava-currents were produced, or so many cubic yards of sediment accumulated, the elevation and depression of the earth's crust were once much greater than they are now. Or, if they should declare that the progressive rate of change of species in the animal and vegetable kingdoms had always been uniform, they might then endeavour to disparage the degree of energy now exerted by earthquakes, by showing that, in relation to the mutations of assemblages of organic species, earthquakes had become comparatively feeble. But our present scanty acquaintance, both with the animate and inanimate world, can by no means warrant such generalizations; nor have they who contend for the gradual decline of the activity of natural agents, attempted to support such a line of argument. That it would be most premature, in the present state of natural history, to reason on the comparative rate of fluctuation in the species of organic beings in ancient and modern times, will be more fully demonstrated when we proceed, in the next division of our subject, to consider the intimate connexion between geology, and the study of the present condition of the animal and vegetable kingdoms.

To conclude: it appears, from the views above explained, respecting the agency of subterranean movements, that the constant repair of the dry land, and the subserviency of our planet to the support of terrestrial as well as aquatic species, are secured by the elevating and depressing power of earthquakes. This cause, so often the source of death and terror to the inhabitants of the globe, which visits, in succession, every zone, and fills the earth with monuments of ruin and disorder, is, nevertheless, a conservative principle in the highest degree, and, above all others, essential to the stability of the system.