(5.) *Cones of Tuff and Lava.*—These are by far the most frequent. They may be taken, indeed, as the typical form of volcanoes. Around the central vent the successive showers of scoriæ and ashes gather, with occasional streams of lava, which from time to time descend different sides of the growing cone. The component strata have thus the usual inclination outwards, though, when seen in section along the crater-walls, they look approximately horizontal. By continued explosions fissures are formed in the sides of the cone. These are injected with lava, producing a network of dykes which strengthen the cone, or they serve as channels of escape for lava, and give rise to lateral eruptions and minor or parasitic cones. As the main cone increases in diameter by the accumulation of fragmentary and molten ejections, it rises also in height, until at last few or no eruptions take place from its summit, but only from openings on its flanks.

(6.) *Submarine Volcanoes.*—It is not only on the surface of the land that volcanic action shows itself. It takes place likewise under the sea, and as the geological records of the earth's past history are chiefly marine formations, the characteristics of submarine volcanic action have no small interest to the geologist. Unfortunately, the phenomena of recent volcanic eruptions under the sea are for the most part inaccessible. Here and there, as among the islands of the Greek Archipelago and at Tahiti, elevation of the sea-bed has taken place, and brought to the surface beds of lava, which had been erupted and had consolidated under water. There does not appear to be any appreciable difference either in external aspect or in internal structure between such submarine lavas and those erupted on the land. Some of them are highly scoriaceous. There is no reason indeed why slaggy lava and loose scoriæ should not accumulate under the pressure of a deep column of the ocean. At the Hawaii Islands, on 25th February 1877, masses of pumice, during a submarine volcanic explosion, were ejected to the surface, one of which struck the bottom of a boat with considerable violence and then floated. At the same time, when we reflect to what a considerable extent the bottom of the great ocean basins is dotted over with volcanic cones, rising often solitary from profound depths, we can understand how large a proportion of the actual eruptions may take place under the sea. The foundations of these volcanic islands doubtless consist of submarine lavas and fragmentary materials, which, in each case, continued to accumulate to a height of two or three miles, until the pile reached the surface of the water and the phenomena became subaerial. The immense abundance and wide diffusion of volcanic detritus over the bottom of the Pacific and Atlantic Oceans, even at distances remote from land, as has been made known by the voyage of the "Challenger," may indicate the prevalence and persistence of submarine volcanic action, though, at the same time, it must be admitted that an extensive diffusion of volcanic debris from the islands is effected by winds and ocean-currents.

4. *Geographical Distribution of Volcanoes.*

The chief facts under this head may thus be summarized. (1.) Volcanoes occur along the margins of the ocean basins, particularly along lines of dominant mountain ranges. The vast hollow of the Pacific is girdled with a wide ring of volcanic foci. (2.) They rise as a striking feature in the heart of the ocean basins. Most of the oceanic islands are volcanic. Even the coral islands have in all likelihood been built upon the tops of submarine volcanic cones. (3.) Volcanoes are thus situated, as a rule, close to the sea. When they occur inland they sometimes appear in the neighbourhood of a large sheet of water. Yet so many instances have been observed where volcanoes have appeared at great distances from any sheet of water that the proximity of a lake or of the sea cannot be regarded as necessary for the evolution of volcanic phenomena. (4.) The dominant arrangement of volcanoes is in lines along subterranean lines of weakness, as in the chain of the Andes, the Aleutian Islands, and the Malay Archipelago. (5.) Where the linear arrangement does not hold, it gives place to one in groups, as in Italy, Iceland, and the volcanic islands of the great oceans.

§ 5. *Distribution of Volcanic Action in Time.*

Besides the existence of what are called extinct volcanoes, the geologist can adduce proofs of the former presence of active volcanoes in many countries where cones and craters and all ordinary aspects of volcanic mountains have long disappeared. Sheets of lava, beds of tuff, dykes, and necks representing the sites of volcanic vents have been recognized abundantly. These manifestations of volcanic action, moreover, have as wide a range in geological time as they have in geographical area. Every great geological period, back at least as far as the Lower Silurian, has had its volcanoes. In Britain, for instance, there were active volcanic vents in the Lower Silurian period, whence the lavas and tuffs of Snowdon, Aran Mowddwy, and Cader Idris were ejected. The Lower Old Red Sandstone epoch was one of prolonged volcanic activity in central Scotland. The earlier half of the Carboniferous period likewise witnessed the outburst of innumerable small volcanoes over the same region. During the Permian period a few scattered vents existed in the south-west of Scotland, and in the time of the New Red Sandstone some similar points of eruption appeared in the south of England. The older Tertiary ages were distinguished by the outpouring of the enormous basaltic plateaus of Antrim and the Inner Hebrides.

Thus it can be shown that, within the same comparatively limited geographical space, volcanic action has been rife at intervals during a long succession of geological ages. The existing active volcanoes of Iceland rise from amid Tertiary lavas and tuffs, which form part of a great volcanic ridge, extending down through the Faroe Islands into the west of Britain. Volcanic action, which now manifests itself so conspicuously along certain lines, seems to have continued in that linear development for protracted periods of time. The actual vents have changed, dying in one place and breaking out in another, yet keeping on the whole along the same lines.

§ 6. *Causes of Volcanic Action.*

Volcanoes depend, of course, upon the internal heat of the planet as their prime source of energy. But the *modus operandi* whereby that internal heat manifests itself in volcanic action is a problem by no means of easy solution. Were this action merely an expression of the intensity of the heat, we might expect it to have manifested itself in a far more powerful manner in former periods, and to exhibit a regularity and continuity commensurate with the exceedingly slow diminution of the earth's temperature. But there is no geological evidence in favour of greater volcanic intensity in ancient times than in more recent periods; on the contrary, it may be doubted whether any of the Palæozoic volcanoes equalled in magnitude those of the Tertiary period, or whether any of the latter ever produced such stupendous changes as have been effected by modern volcanoes still active. On the other hand, no feature of volcanic action is more conspicuous than its spasmodic fitfulness.

The mere presence of a high internal temperature, therefore, would probably not of itself produce the phenomena of volcanoes, at least in the present condition of the planet. There can be no doubt that one essential exciting cause of volcanic action is the descent of water from the surface. It has already been pointed out how invariably steam plays a chief part in volcanic eruptions, how it issues in vast clouds from the crater, and continues to rise copiously from the lava even after the molten rock has travelled for some miles, and has assumed a solid surface. The quantity of water which descends into the interior must be enormous. The floor of the sea, the beds of rivers and lakes, are all leaky. Of the annual rain which sinks beneath the surface of the land, we cannot tell what proportion is detained and prevented from rising again in springs. Not only does this subterranean water percolate down cracks and joints, it infiltrates through the very pores of the rocks, and can do so even against the pressure of steam on the further side.

Accordingly, there has arisen a very prevalent belief among geologists, that it is to the enormous expansive force of perhaps white-hot water finding access to, and imprisoned in, some of the heated empty spaces at the roots of volcanoes that the explosions of a crater and the subsequent rise of a lava-column are due. It has been supposed that, somewhat like the reservoirs in which the hot water and steam accumulate under the Icelandic geysers, these volcanic spaces receive a constant influx of water from the surface, which cannot escape by other channels, but is in great part converted into vapour or retained in the fluid state at an enormously high temperature and under vast pressure. In the course of time, the materials filling up the chimney are unable to withstand the upward expansion of this imprisoned vapour and water, so that, after some premonitory rumblings, the whole opposing mass is blown out, and the vapour rushes up in the well-known masses of cloud. Meanwhile, the removal of the overlying column relieves some of the pressure from the water-charged lava, which therefore begins to rise in the funnel until it forces its way through some weak part of the cone, or pours over the top of the crater. After a time the vapour is expended, the energy of the volcano ceases, and there comes a variable period of repose, until a renewal of the same phenomena brings on another eruption. By such successive paroxysms it is supposed that the form of the internal reservoirs and tunnels become changed; new spaces for the accumulation of superheated water are formed, whence in time new volcanic vents issue, while the old ones gradually die out.

As physical considerations negative the idea of a comparatively thin crust surmounting a molten interior whence volcanic energy might be derived, geologists have found themselves involved in great perplexity to explain volcanic phenomena for the production of which a source of no great depth would seem to be necessary. They have supposed the existence of pools or lakes of liquid lava lying beneath the crust, and at an inconsiderable depth from the surface. They have sometimes appealed to the influence of the contraction of the earth's mass, assuming that the contraction is greater in the outer than in the inner portions, and that the effect of this must be to squeeze out some of the internal molten matter through weak parts of the crust. Cordier, for example, calculated that a contraction of only a single millimetre (about $\frac{1}{25}$th of an inch) would suffice to force out to the surface lava enough for 500 eruptions, allowing 1 cubic kilometre (about 1300 million cubic yards) for each eruption.

The influence of contraction as the grand source of volcanic energy has recently been insisted upon on quite different grounds by Mr Mallet, who has developed the theory that all the present manifestations of hypogene action are due directly to the more rapid contraction of the hotter internal mass of the earth, and the consequent crushing in of the outer cooler shell. He points to the admitted difficulties in the way of connecting volcanic phenomena with the existence of internal lakes of liquid matter, or of a central ocean of molten rock. Observations made by him, on the effects of the earthquake shocks accompanying the volcanic eruptions of Vesuvius and of Etna, showed that the focus of disturbance could not be more than a few miles deep,—that, in relation to the general mass of the globe, it was quite superficial, and could not possibly have lain under a crust of 800 miles or upwards in thickness. The occurrence of volcanoes in lines, and especially along some of the great mountain-chains of the planet, is likewise dwelt upon by him as a fact not satisfactorily explicable on any previous hypothesis of volcanic energy. But he contends that all these difficulties disappear when once the simple idea of cooling and contraction is adequately realized. "The secular cooling of the globe," he remarks, "is always going on, though in a very slowly descending ratio. Contraction is therefore constantly providing a store of energy to be expended in crushing parts of the crust, and through that providing for the volcanic heat. But the crushing itself does not take place with uniformity; it necessarily acts *per saltum* after accumulated pressure has reached the necessary amount at a given point, where some of the pressed mass, unequally pressed as we must assume it, gives way, and is succeeded perhaps by a time of repose, or by the transfer of the crushing action elsewhere to some weaker point. Hence, though the magazine of volcanic energy is being constantly and steadily replenished by secular cooling, the effects are intermittent." He offers an experimental proof of the sufficiency of the store of heat produced by this internal crushing to cause all the phenomena of existing volcanoes. The slight comparative depth of the volcanic foci, their linear arrangement, and their occurrence along lines of dominant elevation become, he contends, intelligible under this hypothesis. For, since the crushing in of the crust may occur at any depth, the volcanic sources may vary in depth indefinitely; and as the crushing will take place chiefly along lines of weakness in the crust, it is precisely in such lines that crumpled mountain-ridges and volcanic funnels should appear. Moreover, by this explanation it is sought to harmonize the discordant observations regarding the variations in the rate of increase of temperature downward within the earth. In some parts of the crust the crushing must be much greater than in other parts; and since the heat "is directly proportionate to the local tangential pressure which produces the crushing and the resistance thereto," it may vary indefinitely up to actual fusion. So long as the crushed rock remains out of reach of a sufficient access of subterranean water, there would, of course, be no disturbance. But if, through the weaker parts, water enough should descend and be absorbed by the intensely hot crushed mass, it would be raised to a very high temperature, and, on sufficient diminution of pressure, would flash into steam and produce the commotion of a volcanic eruption.

This ingenious theory requires the operation of sudden and violent movements, or at least that the heat generated by the crushing should be more than can be immediately conducted away through the crust. Were the crushing slow and equable, the heat developed by it would doubtless be tranquilly dissipated through the crust, the temperature of which might not be sensibly affected in the process, or not to such an extent as to cause any appreciable molecular rearrangement of the particles of the rock. Moreover, as the action is general throughout the whole mass of the outer shell, there does not seem in the theory any valid reason why volcanic action should be limited to particular lines, and why it should continue so long persistently on these lines. The existence of weak parts of the crust is postulated; but the successive crushings and consequent fusions might be expected to strengthen these weaker parts and to make volcanic conditions less easy.

It cannot indeed be denied that there exists the most convincing geological evidence in favour of the secular contraction of the globe, that during the process masses of sedimentary strata, many thousands of feet in thickness, have been crumpled and crushed, and that the crumpling has often been accompanied by such an amount of heat and evolution of chemical activity as to produce a movement and rearrangement of the elements of the rocks,—this change sometimes advancing to the point of actual fusion. There is reason to believe that some at least of these periods of intense terrestrial disturbance have been followed by periods of prolonged volcanic action in the disturbed areas. Mr Mallet's theory is thus, to some extent, supported by independent geological testimony. The existence, however, of large reservoirs of fused rock, at a comparatively small depth beneath the surface, may be conceived as probable, apart altogether from the effects of the subsidence of the outer shell upon the inner nucleus. The connexion of volcanoes with lines of elevation, and consequent weakness in the earth's crust, is precisely what might have been anticipated on the view that the nucleus, though practically solid, is at such a temperature and pressure that any diminution of the pressure, by corrugation of the crust or otherwise, will cause the subjacent portion of the nucleus to melt. It is along the lines of elevation that the pressure must be relieved, and it is there that the consequent melting will take place. On these lines of tension and weakness, therefore, the conditions for volcanic excitement must be best developed. Water is there able soonest to reach the intensely-heated materials underneath the crust, and to give rise to the volcanic explosions. The periodicity of eruptions will thus depend upon the length of time required for the storing up of sufficient steam, and on the amount of resistance in the crust to be overcome. In some cases the intervals of activity, like those of the geysers, return with considerable regularity. In other cases, the shattering of the crust, or the upwelling of vast masses of lava, or the closing of subterranean passages for the descending water, or other causes may vary the conditions so much, from time to time, that the eruptions may follow each other at very unequal periods, and with very discrepant energy. Each great outburst exhausts for a while the vigour of the volcano, and an interval is needed for the renewed accumulation of vapour.

Section II.—Earthquakes.

The phenomena of earthquake-motion having been discussed in the article EARTHQUAKES, we shall notice here only those which have a marked geological importance from the way in which they affect the crust or surface of the earth, briefly describing the effects of earthquakes upon the surface of the land, and upon terrestrial and oceanic waters, the permanent changes of level occasioned by them, their distribution and geological relations, and their causes.

1. *Effects upon the Soil and General Surface of a Country.*—The earth-wave or wave of shock underneath a country may traverse a wide region and affect it violently at the time without leaving any trace of its passage. Loose objects, however, are apt to be displaced. Thus blocks of rock, already disengaged from their parent masses, may be rolled down into the valleys below. Large landslips are thus produced, and these may give rise to very considerable subsequent changes in the drainage of the localities where they take place. It has often been observed that the soil is rent by the passage of the earthquake. Fissures appear, varying in size from mere cracks, like those due to desiccation, up to deep and wide chasms. Where these cracks are numerous, and where, consequently, the ground has been much disturbed, permanent modifications of the landscape may be produced. Trees are thrown down and buried, wholly or in part, in the rents. These superficial effects may, in a few years, be effaced by the gradual levelling power of the atmosphere. Where, however, the chasms are wide and deep enough to intercept any rivulets, or to serve as channels for heavy rain-torrents, they are sometimes further excavated, so as to become gradually enlarged into ravines and valleys. As a rule, each rent is only a few yards long. Sometimes it may extend for half a mile or even more. In the earthquake which shook the South Island of New Zealand in 1848, a fissure was formed averaging 18 inches in width and traceable for a distance of 60 miles parallel to the adjacent axis of the mountain-chain. The subsequent earthquake of 1855, in the same region, gave rise to a fracture which could be traced along the base of a line of cliff for a distance of about 90 miles.

Remarkable circular cavities are sometimes formed in the ground during the passage of the earth-wave. In many cases these holes serve as funnels of escape for an abundant discharge of water, so that when the disturbance ceases they appear as pools. They are believed to be caused by the sudden collapse of subterranean water-channels and the consequent forcible ejection of the water to the surface.

2. *Effects upon Terrestrial Waters.*—Springs are temporarily affected by earthquake movements, becoming greater or smaller in volume, sometimes muddy or discoloured, and sometimes increasing in temperature. Brooks and rivers have been observed to flow with an interrupted course, increasing or diminishing in size, stopping in their flow so as to leave their channels dry, and rolling forward with increased rapidity. Lakes are still more sensitive to the tremors of the ground beneath. Their waters occasionally rise and fall for several hours, even at a distance of many hundred miles from the centre of disturbance. Thus, on the day of the great Lisbon earthquake, many of the lakes of central and north-western Europe were so affected as to maintain a succession of waves rising to a height of 2 or 3 feet above their usual level. Cases, however, have been observed where, owing to excessive subterranean movement, lakes have been emptied of their contents and their beds left permanently dry. On the other hand, areas of dry ground have been depressed, and have become the sites of new lakes.

Some of the most important changes in the fresh water of a region, however, are produced by the fall of masses of rock and earth. Landslips, by damming up a stream, may so arrest its water as to form a lake. The barrier, if of sufficient strength, may be permanent, and the lake will then remain. Owing, however, to the usually loose, incoherent character of its materials, the dam thrown across the pathway of a stream runs a great risk of being undermined by the percolating water. When this is the case, a sudden giving way of the barrier will allow the confined water to rush with great violence down the valley, and produce perhaps tenfold more havoc there than may have been caused by the original earthquake. When the landslip is of sufficient dimensions to divert the stream from its previous course, the new channel thus taken may become permanent, and a valley may be cut out or widened.

3. *Effects upon the Sea.*—The great sea-wave propagated outward from the centre of a sub-oceanic earthquake, and reaching the land after the earth-wave has arrived there, gives rise to much destruction along the maritime parts of the disturbed region. As it approaches the shore, the littoral waters retreat seawards, sucked up, as it were, by the advancing wall of water, which, reaching a height of sometimes 60 feet, rushes over the bare beach and sweeps inland, carrying with it everything which it can dislodge and bear away. Loose blocks of rock are thus lifted to a considerable distance from their former position, and left at a higher level. Deposits of sand, gravel, and other superficial

accumulations are torn up and swept away, while the surface of the country, as far as the limit reached by the wave, is strewn with debris. If the district has been already shattered by the passage of the earth-wave, the advent of the great sea-wave augments and completes the devastation.

4. *Permanent Changes of Level.*—It has been observed, after the passage of an earthquake, that the level of the disturbed country has been changed. Thus after the terrible earthquake of 19th November 1822 the coast of Chili for a long distance was found to have risen from 3 to 4 feet, so that along the shore the littoral shells were exposed adhering still to the rocks amid multitudes of dead fish. The same coast-line has since been further upraised by subsequent earthquake shocks. On the other hand, many instances have been observed where the effect of the earthquake has been to depress permanently the disturbed ground. For example, by the Bengal earthquake of 1762 an area of 60 square miles on the coast, near Chittagong, suddenly went down beneath the sea, leaving only the top of the higher eminences above water. The succession of earthquakes which in the years 1811 and 1812 devastated the basin of the Mississippi gave rise to widespread depressions of the ground, over some of which the river spread so as to form new lakes, with the tops of the trees still standing above the surface of the water.

5. *Distribution and Geological Relations of Earthquakes.*—While no large space of the earth's surface seems to be free from at least some degree of earthquake-movement, there are regions more especially liable to the visitation. As a rule, earthquakes are most frequent in volcanic districts, the explosions of a volcano being very generally preceded or accompanied by tremors of greater or less intensity. In the Old World the great belt of earthquake disturbance stretches in an east and west direction, along that tract of remarkable depressions and elevations lying between the Alps and the mountains of northern Africa, and spreading eastward so as to enclose the basins of the Mediterranean, Black Sea, Caspian, and Sea of Aral, and to rise into the great mountain-ridges of Central Asia. In this zone lie numerous volcanic vents, both active and extinct or dormant, from the Azores on the west to the basaltic plateaus of India on the east. The Pacific Ocean is surrounded with a vast ring of volcanic vents, and its borders are likewise subject to frequent earthquake shocks. Some of the most terrible earthquakes within human experience have been those which have affected the western seaboard of South America.

6. *Causes of Earthquakes.*—An earthquake shock has been defined by Mr Mallett as the transit of a wave of elastic compression through the crust and surface of the earth, generated by some sudden impulse within the crust. The passage of such a wave has been imitated experimentally, and some of its characteristic features have been illustrated by accidental explosions at powder-works. But though the phenomena point to some sudden and violent blow inflicted upon the solid crust, it is impossible to do more than speculate on the probable nature of this blow. In some cases it may arise from the sudden flashing into steam of water in the spheroidal state, from the sudden condensation of steam, from the explosions of a volcanic orifice, from the falling in of the roof of a subterranean cavity, or from the sudden snap of subterranean rocks subjected to prolonged and intense strain. But we are still in ignorance as to the actual immediate cause of any earthquake in regions remote from active volcanoes. So much, at least, is certain, that the shock must arise from some sudden and violent impulse, whereby a wave or undulation is propagated in all directions through the solid substance of the crust.

Section III.—Secular Upheaval and Depression.

Besides the sudden movements due to earthquake-shocks, the crust of the earth undergoes in many places oscillations of an extremely quiet and uniform character, sometimes of an elevatory, sometimes of a subsiding nature. So tranquil are these changes that they produce from day to day no appreciable alteration in the aspect of the ground affected. Only after the lapse of several generations, and by means of careful measurements, can they really be proved. Indeed, in the interior of a country nothing but a series of accurate levellings from some unchanged datum-line might detect the change of level, unless the effects of this terrestrial movement showed themselves in altering the drainage. It is only along the sea-coast that a ready measure is afforded of any such movement. In popular language it is usual to speak of the sea as rising or sinking relatively to the land. But so long as the volume of the ocean remains the same, the general sea-level can neither rise nor fall, unless by some movement of the solid globe underneath it. And, as we cannot conceive of any possible augmentation of the oceanic waters, nor of any diminution save what may be due to the extremely slow process of abstraction by the hydration of minerals, or absorption into the earth's interior, we are compelled to regard the sea-level as practically a constant datum-line, any deviation from which, in the apparent heights of sea and land, must be due to movement of the land and not of the sea.

There are indeed certain cosmical causes which may affect the relative levels of sea and land. Thus the accumulation of large masses of snow and ice as an ice-cap at one of the poles would, as has been above pointed out (*ante*, p. 217), tend to displace the earth's centre of gravity, and as a consequence to raise the level of the ocean in the hemisphere so affected, and to diminish it in a corresponding measure elsewhere. The return of the ice into the state of water would produce an opposite effect. Dr Croll has also drawn attention to the fact that, as a consequence of the diminution of centrifugal force owing to the retardation of the earth's rotation caused by the tidal wave, the sea-level must have a tendency to subside at the equator and rise at the poles. A larger amount of land need not ultimately be laid bare at the equator, for the change of level resulting from this cause would be so slow that the general degradation of the surface of the land might keep pace with it, and diminish the terrestrial area as much as the retreat of the ocean tended to increase it. Dr Croll has further pointed out that the waste of the equatorial land, and the deposition of the detritus in higher latitudes, must still further counteract the effects of retardation and the consequent change of ocean-level.[1]

Such widespread general causes of change must produce equally far-reaching effects. But in examining the changes of level between land and sea, we find them to be eminently local and variable in character, pointing to some local and unequally acting cause,—so that, while admitting these cosmical and widespread influences to be part of the general system of geological change, we must yet hold the sea-level, for all practical purposes, to be invariable, any apparent oscillations of that level upon the land being due to terrestrial movements.

§ 1. *Movements of Upheaval.*

Various maritime tracts of the land have been ascertained to have undergone in recent times, or to be still undergoing, a gradual elevation above the sea. Thus, the coast of Siberia, for 600 miles to the east of the river Lena, the western tracts of South America, and the Scandinavian peninsula, with the exception of a small area at its southern

[1] Croll, *Phil. Mag.*, 1868, p. 382; Sir W. Thomson, *Trans. Geol. Soc. Glasgow*, iii. 223.

apex, have been proved to have been recently upheaved. The proofs of this change of level chiefly to be relied on are the following[1]:—

(1.) The position of rocks covered with barnacles or other littoral adherent animals, or pierced by lithodomous shells. A single stone with these creatures on its surface would not necessarily prove anything, for it might be cast up by a storm; but a line of large boulders, which had evidently not been moved since the cirripedes and molluscs lived upon them, and still more a solid cliff with these marks of littoral or sub-littoral life upon its base, now raised above high-water mark, would be sufficient to demonstrate a rise of land. The amount of the upheaval might be pretty accurately determined by measuring the vertical distance between the upper edge of the barnacle zone upon the upraised rock, and the limit of the same zone on the present shore.

(2.) A line of sea-caves, now standing at a distance above high water-mark beyond the reach of the sea, would afford evidence of recent uprise, since caves of this kind are only hollowed out by the waves between tide-marks.

(3.) One of the most striking proofs of upheaval is furnished by what are termed *raised beaches*. A beach is the space between tide-marks, where the sea is constantly busy producing sand and gravel, mingling with them the remains of shells and other organisms, sometimes piling the deposits up, sometimes sweeping them away out into opener water. The terrace or platform thus formed is a well-marked feature of coast-lines skirting tidal seas. When the land rises with sufficient rapidity to carry up the line of littoral deposits above the reach of the waves, the flat terrace thus elevated is known as a raised beach. The former high-water mark then lies inland, and while its sea-worn caves are in time hung with ferns and mosses, it furnishes itself an admirable platform, on which meadows, fields, and gardens, roads, houses, villages, and towns spring up, while a new beach is made below the margin of the uplifted one. Raised beaches abound round many parts of the coast-line of Britain. Some excellent examples occur in Cornwall and Devon. The coast-line on both sides of Scotland is fringed with raised beaches, sometimes four or five occurring above each other, at heights of 25, 40, 60, 75 and 100 feet above the present high-water mark. Each terrace marks a former lower level of the land with regard to the sea, and probably a lengthened stay of the land at that level, while the intervals between them represent the vertical amount of each successive uplift of the land, and show that the land in its upward movement did not remain long enough at intermediate points for the formation of terraces. A succession of raised beaches, rising above the present sea-level, may therefore be taken as pointing to a former prolonged upheaval of the country, interrupted by long pauses, during which the general level did not materially change.

(4.) Any stratum of rock containing marine organisms, which have manifestly lived and died where their remains now lie, must be held to prove upheaval of the land. In this way it can be shown that most of the solid land now visible to us has once been under the sea. Even high on the peaks of the cliffs and the flanks of the Himalaya mountains, undoubted marine shells occur in the solid rocks.

(5.) In countries which have been long settled by a human population, it is sometimes possible to prove, or at least to render probable, the fact of recent uprise of the land by reference to tradition, to local names, and to works of human construction. Piers and harbours, if now found to stand above the upper limit of high-water, furnish indeed indisputable evidence of a rise of land since their erection.

[1] "Earthquakes and Volcanoes," by A. Geikie, Chambers's *Miscellany of Tracts*.

§ 2. *Movements of Subsidence.*

It is more difficult to trace the downward movement of the land, for the evidence of each successive sea-margin is carried down and washed away or covered up. Nevertheless, the fact of subsidence can be satisfactorily established by the following kinds of proof[2]:—

(1.) The results of mere erosion by the sea and those of actual depression of the level of the land cannot always be distinguished without some care. The encroachment of the sea upon the land, involving, it may be, the disappearance of successive fields, roads, houses, villages, and even whole parishes, does not necessarily indicate a sinking of the land. Such destruction of the coast-line may, indeed, be in progress without any actual change of level. Should the sea, however, rise to the level of roads and buildings which it never used to touch, should former half-tide rocks cease to show even at low water, and should rocks, previously above the reach of the highest tide, be turned first into shore reefs, then into skerries and islets, we infer that the coast-line is sinking. Such kind of evidence is found in Scania, the most southerly part of Sweden. Streets, built of course above high-water mark, now lie below it, with older streets lying beneath them, so that the subsidence is of some antiquity. A stone, the position of which had been exactly determined by Linnæus in 1749, was found after 87 years to be 100 feet nearer the water's edge. The west coast of Greenland, for a space of more than 600 miles, is perceptibly sinking. It has there been noticed that over ancient buildings on low shores, as well as over entire islets, the sea has risen. The Moravian settlers have been more than once driven to shift their boat-poles inland, some of the old poles remaining visible under water.

(2.) As the land is brought down within reach of the waves, its characteristic surface-features are, of course, apt to be effaced, so that the submerged area which passes down beneath the sea may retain little or no evidence of its having been a land-surface. It will be covered, as a rule, with sea-worn sand or silt. Hence, no doubt, the reason why, among the marine strata which form so large a part of the stratified portion of the earth's crust, and where there are many proofs of depression, actual traces of land-surfaces are comparatively rare. It is only under very favourable circumstances, as, for instance, where the area is sheltered from prevalent winds and waves, and where, therefore, the surface of the land can sink tranquilly under the sea, that fragments of that surface may be completely preserved under overlying marine accumulations. It is in such places that "submerged forests" occur. These are stumps or roots of trees still in their positions of growth in their native soil. Beds of peat, full of tree-stumps, hazel-nuts, branches, leaves, and other indications of a terrestrial surface, are often found in similar situations. Sir Henry de la Beche has described, round the shores of Devon, Cornwall, and western Somerset, a vegetable accumulation, consisting of plants of the same species as those which now grow freely on the adjoining land, and occurring as a bed at the mouths of valleys, at the bottoms of sheltered bays, and in front of and under low tracts of land, the seaward side of which dips beneath the present level of the sea. Over this submerged land-surface sand and silt containing estuarine shells have generally been deposited, whence we may infer that in the submergence the valleys first became estuaries, and then sea-bays. If now, in the course of ages, a series of such submerged forests should be formed one over the other, and if, finally, they should, by upheaval of the sea-bottom, be once more laid dry, so as to be capable of examination by boring, well-sinking, or otherwise, they

[2] *Ibid.*

would prove a former long-continued depression, with intervals of rest. In such a case, the intervals of pause would be marked by the buried forests, and the progress of the depression by the strata of sand and mud lying between them. In short, the evidence would be strictly on a parallel with that furnished by a succession of raised beaches as to a former protracted elevation with long pauses.

(3.) An interesting kind of proof of an extensive depression of the north-west of Europe is furnished by the deep fjords or sea-lochs by which that region is indented. A fjord is a long, narrow, and often singularly deep inlet of the sea, which terminates inland at the mouth of a glen or valley. The word is Norwegian, and in Norway fjords are characteristically developed. The English word "firth," however, is the same, and the western coasts of the British Isles furnish many excellent examples of fjords. In Scotland they are usually called lochs, as Loch Hourn, Loch Nevis, Loch Fyne, Gareloch; in Ireland they are sometimes known by the name of loughs, as Lough Foyle, but more commonly by that of bays, as Dingle Bay, Bantry Bay. There can be little doubt that, though now filled with salt water, fjords have been originally land valleys. The long inlet was first excavated as a land-valley or glen. This valley exactly corresponds in form and character with the hollow of the fjord, and must be regarded as merely its inland prolongation. That the glens have been excavated by subaerial agents is a conclusion borne out by a great weight of evidence. If, therefore, we admit the subaerial origin of the glen, we must also grant a similar origin to its seaward prolongation. Every fjord will thus mark the site of a submerged valley. This inference is confirmed by the fact that fjords do not, as a rule, occur singly. Like the glens on the land they lie in groups; so that when they are found intersecting a long line of coast like that of the west of Norway, or the west of Scotland, we conclude that the land has there sunk down so as to permit the sea to run far up and fill the submerged glens.

(4.) Evidence of widespread depression over the area of the Pacific Ocean is furnished by the numerous atolls or coral islands scattered throughout that vast expanse of water. Mr Darwin ascertained that the reef-building corals do not live at a greater depth than about 15 or 20 fathoms. Yet reefs and circular islets of coral rise with nearly perpendicular sides from a depth of 2000 feet and upwards, until they reach the surface of the sea. As the corals could not have begun to grow upward from such vast depths, Mr Darwin first suggested that the sites of these coral reefs had undergone a progressive subsidence, the rate of upward growth of the reefs keeping pace, on the whole, with the depression. A fringing reef would first be formed fronting the land within the limit of the 20 fathom line. Growing upward until it reached the surface of the water, it would be exposed to the dash of the waves, which would break off pieces of the coral and heap them upon the reef. In this way islets would be formed which, by successive accumulations of materials thrown up by the breakers or brought by winds, would remain permanently above water. On these islets palms and other plants, whose seeds might be drifted from the adjoining land, would take root and flourish. Inside the reef there would be a shallow channel of water, communicating, through gaps in the reef, with the main ocean outside. Fringing reefs of this character are of common occurrence at the present time. In the case of a continent they front its coast for a long distance, but they may entirely surround an island. If the site of a fringing reef undergoes depression at a rate sufficiently slow to allow the corals to keep pace with it, the reef will grow upward as the bottom sinks downward. The lagoon channel inside will become deeper and wider, while, at the same time, the depth of the water outside will increase. In this way a barrier reef will be formed. Continued slow depression must continually diminish the area of the land enclosed within one of these rings of coral-reef, while the reef itself retains much the same size and position. At last the final peak of the original island disappears under the lagoon, and an atoll or true coral island is formed. Should any more rapid or sudden downward movement take place, it might carry the atoll down beneath the surface, as seems to have happened at the Great Chagos bank in the Indian Ocean, which is a submerged atoll. It has recently been suggested that barrier reefs do not necessarily prove subsidence, seeing that they may grow outward from the land upon the top of a talus of their own debris broken down by the waves, and may thus appear to consist of solid coral which had grown upward from the bottom during depression, although only the upper layer, 20 fathoms or thereabouts in thickness, is composed of solid, unbroken, coral growth. The explanation may doubtless account for some barrier-reefs, and for the way in which the steep seaward face of all such reefs is formed and maintained. But it does not elucidate the existence of submerged atolls, the presence of gaps in atolls answering to gaps in the fringing reefs opposite to the mouths of rivers; and the difficulty of supposing that, in a coral archipelago, there should have been scores of submerged peaks so nearly of the same height as to rise within 20 fathoms of the surface, and yet so seldom actually to tower above it. According to the simple and luminous theory of Mr Darwin, every stage in the progress of the changes is open to observation, from the incipient fringing reef to the completed and submerged atoll. Every observed fact fits in harmoniously with the others, and we reach the impressive conclusion that a vast area of the Pacific Ocean, fully 6000 geographical miles from east to west, has undergone a recent subsidence, and may be slowly sinking still.

It by no means follows, however, as some writers have imagined, that the present Pacific Ocean occupies the site of a vast submerged continent. All the coral islands seem to have been built on volcanic peaks. Wherever any non-calcareous rock appears it is of volcanic origin. We must therefore conceive of these oceanic islands as detached volcanic eminences rising out of a wide area of subsidence, and doubtless as deriving their existence from the results of that subterranean movement.

§ 3. *Causes of Secular Upheaval and Depression.*

These movements, without question, we must again trace back to consequences of the original internal heat of the earth. There are various ways in which the heat may have acted. Thus a considerable accession of heat expands rocks, and, on the other hand, a loss of heat causes them to contract. We may suppose therefore that, during the subterranean changes, a great extent of the crust underneath a tract of land may have its temperature slowly raised. The effect of this increment would be to cause a slow uprise of the ground above. The gradual transference of the heat to another quarter might produce a steady subsidence. Such variations in subterranean temperature, however, could give rise at the most to but very insignificant elevations or depressions.

A far more important and generally effective cause is to be sought in the secular contraction of the globe. If our planet has been steadily losing heat by radiation into space, it must have progressively diminished in volume. The cooling implies contraction. According to Mr Mallet, the diameter of the earth is less by at least 189 miles since the time when the planet was a mass of liquid.[1] But the contraction has not manifested itself uniformly over the whole

[1] *Phil. Trans.*, 1873, p. 250.