to allow him to assume that all the causes and modes of geological change have been definitively ascertained. On the earth itself there may remain for future discovery evidence of former operations by heat, magnetism, chemical change, or otherwise, which may explain many of the phenomena with which geology has to deal. Of the influences, so many and profound, which the sun exerts upon our planet, we can as yet only dimly perceive a little. Nor can we tell what other cosmical influences may have lent their aid in the evolution of geological changes.

In the present state of our knowledge, all the geological energy upon and within the earth must ultimately be traced back to our parent sun. There is, however, a certain propriety and convenience in distinguishing between that part of it which is due to the survival of some of the original energy of the planet, and that part which arises from the present supply of energy received day by day from the sun. In the former case we have to deal with the interior of the earth and its reaction upon the surface; in the latter we deal with the surface of the earth, and to some extent with its reaction on the interior. This distinction allows of a broad treatment of the subject under two divisions:—

I. *Hypogene or Plutonic Action*—the changes within the earth caused by original internal heat and by chemical action.

II. *Epigene or Surface Action*—the changes produced on the superficial parts of the earth, chiefly by the circulation of air and water set in motion by the sun's heat.

DIVISION I.—HYPOGENE ACTION.

An Inquiry into the Geological Changes in Progress beneath the Surface of the Earth.

In the discussion of this branch of the subject we must carry in our minds the conception of a globe still intensely hot in its interior, radiating heat into space, and consequently contracting in bulk. Portions of molten rocks from inside are from time to time poured out at the surface. Sudden shocks are generated by which destructive earthquakes are propagated to and along the surface. Wide geographical areas are pushed up or allowed to sink down. In the midst of these movements very remarkable changes are produced upon the rocks of the crust; they are shattered, fractured, squeezed, crumpled, rendered crystalline, and even fused.

Section I.—Volcanoes and Volcanic Action.

The term volcanic action (vulcanism or vulcanicity) embraces all the phenomena connected with the expulsion of heated materials from the interior of the earth to the surface. Among these phenomena there are some of an evanescent character, while others leave permanent proofs of their existence. It is naturally to the latter that the geologist gives the chief attention, for it is by their means that he can trace the former phases of volcanic activity in regions where, for many ages, there have been no volcanic eruptions. In the operations of existing volcanoes he can observe only the superficial manifestations of volcanic action. But, examining the rocks of the earth's crust, he discovers that in the lapse of ages, amid the many terrestrial revolutions which geology reveals, the very roots of former volcanoes have been laid bare, displaying subterranean phases of vulcanism which could not be studied in any modern volcano. Hence an acquaintance only with active volcanoes will not give us a complete knowledge of volcanic action. It must be supplemented and enlarged by an investigation of the traces of former volcanoes preserved in the crust of the earth.

The openings by which the heated materials from the interior reach the surface include volcanoes (with their accompanying orifices), hot-springs, and gas-springs. A volcano may be defined as a conical eminence, composed wholly or mainly of materials which have been ejected from below, and which have accumulated at the surface round the vent of eruption. As a rule it presents at its summit a cup-shaped cavity termed the crater, at the bottom of which is the top of the main funnel or pipe whereby the communication is maintained with the heated interior. A volcano, when of small size, may consist merely of one diminutive cone; when of the largest dimensions, it forms a huge mountain, with many subsidiary cones and many lateral fissures or pipes, from which the heated volcanic products are given out.

Volcanoes may break through any kind of geological formation. In Auvergne, in the Miocene period, they burst through the granitic and gneissose plateau of central France. In Lower Old Red Sandstone times they pierced contorted Silurian rocks in central Scotland. In late Tertiary and post-Tertiary ages they found their way through soft marine strata, and formed the huge piles of Etna, Somma, and Vesuvius. On the banks of the Rhine, at Bonn and elsewhere they have penetrated some of the older alluvia of that river. In many instances, also, newer volcanoes have appeared on the sites of older ones. In Scotland the Carboniferous volcanoes have risen on the sites of those of the Old Red Sandstone, those of the Permian period have broken out among the earlier Carboniferous eruptions, while the Miocene lavas have been injected into all these older volcanic masses. Again, the newer *puys* of Auvergne were sometimes erupted through much older and already greatly denuded basalt-streams. Somma and Vesuvius have arisen out of the great Neapolitan plain of marine tuff. In central Italy, also, newer cones have been thrown up upon the great Roman plain of more ancient volcanic debris.

It is usual to class volcanoes as *active*, *dormant*, and *extinct*. This arrangement, however, often presents considerable difficulty in its application. An active volcano cannot of course be mistaken, for even when not in actual eruption it shows, by its abundant evolution of steam and hot vapours, that it might break out into activity at any moment. But it is in many cases impossible to decide whether a volcano should be called extinct or only dormant. The volcanoes of Silurian age in Wales, of Carboniferous age in Ireland, of Permian age in the Hartz, of Miocene age in the Hebrides, are certainly all extinct. But the Miocene volcanoes of Iceland are still represented there by Skaptar Jökull, Hecla, and their neighbours. Somma, in the first century of the Christian era, would have been naturally regarded as an extinct volcano. Its fires had never been known to have been kindled within human tradition; its vast crater was a wilderness of wild vines and brushwood, haunted, no doubt, by wolf and wild-boar. Yet in a few days, in the autumn of the year 79 the half of the crater walls was blown out by a terrific series of explosions, the present Vesuvius was then formed within the limits of the earlier crater, and since that time volcanic action has been intermittently exhibited up to the present day. Some of the intervals of quietude, however, have been so considerable that the mountain might then again have been claimed as an extinct volcano. Thus, in the 131 years between 1500 and 1631, so completely had eruptions ceased that the crater had once more become choked with copsewood. A few pools and springs of very salt and hot water remained as memorials of the former condition of the mountain. But this period of quiescence closed with the eruption of 1631, —the most powerful of all the known explosions of Vesuvius, except the great one of 79.

In the island of Ischia, Mont Epomeo was last in eruption in the year 1302, its previous outburst having taken place,

it is believed, about 17 centuries before that date. From the craters of the Eifel, Auvergne, the Vivarais, and central Italy, though many of them look as if they had only recently been formed, no eruption has been known to come during the times of human history or tradition. From these examples it is clear that no real distinction can be drawn between dormant and extinct volcanoes. Also, from the fact above mentioned, that volcanoes have often appeared on areas occupied by those of previous geological periods, it is equally evident that volcanic action is apt to show itself again and again even at vast intervals within the same regions and over the same sites.

§ 1. *Volcanic Products.*

The materials erupted from volcanic vents may be classed as (1) gases and vapours, (2) lavas, (3) fragmentary substances. A brief summary under each of these heads may be given here; the mode and order of appearance of the several products will be stated in § 2.

1. *Gases and Vapours.*—These play an important part in volcanic activity; they show themselves in the earliest stages of a volcano's history, and continue to appear for centuries after all the other evidences of subterranean action have ceased to be manifested. By much the most abundant of them all is *steam*. It has been estimated to form $\frac{999}{1000}$ths of the whole cloud which hangs over an active volcano. In great eruptions it rises in prodigious quantities, and is rapidly condensed into a heavy rainfall. M. Fouqué calculated that during 100 days Etna had ejected vapour enough to form, if condensed, 2,100,000 cubic metres of water. But even from volcanoes which, like the Solfatara near Naples, have been dormant for many centuries it sometimes still rises without intermission and in considerable volume. Jets of vapour rush out from clefts in the sides and bottom of a crater with a noise like that made by the steam blown off by a locomotive. The number of these funnels is often so large, and the amount of vapour so abundant, that only now and then, when the wind blows the dense cloud aside, can a momentary glimpse be had of a part of the bottom of the crater; while at the same time the rush and roar of the escaping steam remind one of the din of some vast factory. Aqueous vapour rises likewise from rents on the outside of the volcanic cone. It issues so copiously from the molten lava which pours down the slopes of the cone that the stream of rock is almost concealed from view by the cloud; and it continues to escape from fissures of the lava, far below the point from which the molten matter proceeded, for a long time after the rock has solidified and come to rest. So saturated, as it were, are many crystalline lavas with the vapour of water that Mr Scrope even suggested that they derive their mobility from this cause.

Probably in no case is the steam mere pure vapour of water. It is associated with other vapours and gases disengaged from the potent chemical laboratory underneath. Of these probably the most abundant is *sulphuretted-hydrogen*, readily traceable by its characteristic odour. Its liability to decomposition leads to the deposition of a yellow crust of sulphur about the orifices from which it rises; perhaps, also, in great part to the alteration of this gas must we attribute the *sulphuric acid* so frequently observed at volcanic vents. Another gas especially abundant at Vesuvius, but not detected in all volcanoes, is *hydrochloric acid*, which comes away with the steam, and gives it its pungent suffocating fumes. *Carbonic acid* appears in most volcanoes, partly as one of their usual products, but chiefly given off during the feebler conditions of activity and in the last stages of vulcanism. After an eruption of Vesuvius this gas has sometimes been discharged so copiously that hundreds of hares, pheasants, and partridges have been suffocated by it. In the ancient volcanic regions of the Eifel and Auvergne, it still rises in prodigious quantities. Bischof estimates that the quantity of carbonic acid evolved in the Brohl Thal amounts to five millions of cubic feet, or 300 tons of gas in one day. *Nitrogen*, derived doubtless from the decomposition of atmospheric air dissolved in the water which penetrates into the volcanic foci, has been frequently detected among the gaseous emanations.

With these gases and vapours are associated many substances which, sublimed by the volcanic heat, appear as deposits along crevices and surfaces wherein they reach the air and are cooled. Besides sulphur, which has been already mentioned, there are several chlorides (particularly that of sodium, and less abundantly those of iron, copper, and lead), sal-ammoniac, specular iron, oxide of copper (tenorite), boracic acid, and other substances. Sodium chloride sometimes appears so abundantly that wide spaces of a volcanic cone, as well as of the newly erupted lava, are crusted with salt, which can even be profitably removed by the inhabitants of the district. Considerable quantities of these chlorides may thus be buried between successive sheets of lava; and in long subsequent times may give rise to mineral springs, as has been suggested with reference to the saline waters which issue from volcanic rocks of Old Red Sandstone and Carboniferous age in Scotland. The iron-chloride forms a bright yellow and reddish crust on the crater walls, as well as on loose stones on the slopes of the cone. Specular iron forms abundantly as thin lamellæ in the fissures of Vesuvian lavas. Tenorite may be seen at the edge of the crater of Vesuvius, condensing into fine filaments which are blown away by the wind. An order of succession has been observed to take place in the appearance of the different volcanic gaseous discharges.

In connexion with the aqueous vapour of volcanoes, reference may be made here to the abundant discharges of water which accompany volcanic explosions. Three sources of this water may be assigned:—(1) from the melting of snow by a rapid accession of temperature previous to or during an eruption,—this takes place from time to time on Etna, and still more markedly in Iceland and among the snowy ranges of the Andes; (2) from the condensation of the vast clouds of steam which are discharged during an eruption,—this undoubtedly is the chief source of the destructive torrents so frequently observed to form part of the phenomena of a great volcanic explosion; and (3) from the disruption of reservoirs of water filling subterranean cavities, or of lakes occupying crater-basins,—this has several times been observed among the South American volcanoes, where immense quantities of dead fish, which inhabited the water, have been swept down with the escaping torrents. The volcano of Agua, in Guatemala, has never been known to discharge anything but water. In the large crater of Idjèn, one of the volcanoes of Java, lay a hot steaming lake of acid water. In the beginning of the year 1817 an eruption took place, by which the water was discharged with frightful destruction down the slopes of the mountain. After the explosion the basin filled again with water, but its temperature was no longer high.

In many cases the water rapidly collects volcanic dust as it rushes down, and soon becomes a pasty mud, or it issues at first in this condition from the volcanic reservoirs, from which, after violent detonations, it is discharged. Hence arise what are termed mud-lavas or aqueous lavas, which in many respects behave like true igneous lavas. This mud eventually consolidates into one of the numerous forms of tuff,—a rock which, as has been already stated (p. 239), varies greatly in the amount of its coherence, in its composition, and in its internal arrangement. Obviously, unless where subsequently altered, it can possess none of the crystalline structure of true lavas. As a rule it betrays its aqueous origin by more or less distinct evidence of stratification, by the multifarious pebbles, stones, blocks of rock, tree-trunks, branches, shells, bones, skeletons, which it has swept along in its course and preserved within its mass. Sections of this compacted tuff may be seen at Herculaneum. The *trass* of the Brohl Thal and other valleys in the Eifel district, referred to on p. 239, is another example of an ancient volcanic mud.

2. *Lavas.*—The term lava is applied generally to all the molten rocks which flow out from volcanoes.[1] The behaviour of the lava as it issues and flows down the volcanic cones will be described in the next sub-section. It will be sufficient to refer here to some of the leading peculiarities of the lavas viewed as volcanic products. (1.) Their specific gravity ranges between 2·37 and 3·22. (2.) The heavier varieties contain much magnetic or titaniferous iron, with augite and olivine, their composition being basic, and their proportion of silica averaging about 45 or 50 per cent. In this group come the basalts, dolerites, nepheline-lavas, and leucite-lavas. The lighter varieties contain commonly a minor proportion of metallic bases, but are rich in silica, their percentage of that acid ranging between 60 and 80. They are thus not basic but acid rocks. Among their more important species, trachyte, rhyolite, obsidian, pitchstone, and pumice may be enumerated. (3.) They differ much in texture. (*a*) Some are entirely crystalline, consisting of nothing but an interlaced mass of crystals and crystalline particles, as in some dolerites. (*b*) Some show more or less of a half-glassy or stony matrix, in which the constituent crystals are imbedded; this is the most common arrangement. (*c*) Others are entirely vitreous, such crystals or crystalline particles as occur in them being quite subordinate, and, so to speak, accidental enclosures in the main glassy mass. Obsidian or volcanic glass is the type of this group. (*d*) They further differ in the extent to which their mass has been affected by the interstitial steam at the time of their eruption. Some show no outward signs of any influence from that cause; in others, however, the expansion of the imprisoned steam has been such as to expand the still molten stone into an open cellular texture, somewhat like that of open ill-baked bread. Such a vesicular arrangement very commonly appears on the upper surface of a lava current. (4.) They vary greatly in colour and general external aspect. The heavy basic lavas are usually dark-grey, or almost black, though, on exposure to the weather, they usually acquire a brown tint from the oxidation and hydration of their iron. Their surface is commonly rough and rugged, until it has been sufficiently decomposed by the atmosphere to crumble into excellent soil which, under favourable circumstances, supports a luxuriant vegetation. The less dense lavas, such as phonolites and trachytes, are frequently paler in colour, sometimes pale yellow or buff, and decompose into light soils; but the obsidians present rugged black sheets of rock roughened with ridges and heaps of froth-like pumice.

3. *Fragmentary Materials.*—Under this title we include all the substances which, driven up into the air by volcanic explosions, fall in solid form to the ground—the dust, ashes, sand, cinders, and blocks of every kind which are projected from a volcanic orifice. These materials must obviously differ greatly in composition, texture, and appearance, even during a single eruption, and still more in successive explosions of the same volcano. For the sake of convenience separate names are applied to some of the more distinct varieties. Of these the more important are the following. (1.) *Ashes and Sand.*—In many eruptions vast quantities of an exceedingly fine light grey powder are ejected. As this substance greatly resembles what is left after a piece of wood or coal is burnt in an open fire, it has been popularly termed *ash*, and this name has been adopted by geologists. If, however, by the word ash the result of combustion is implied, its employment to denote any product of volcanic action must be regretted as apt to convey a wrong impression. The fine ashlike dust ejected by a volcano is merely lava in an extremely fine state of comminution. So minute are the particles that they find their way readily through the finest chinks of a closed room, and settle down upon floor and furniture as ordinary dust does when a house is shut up for a short time. From this finest form of material gradations may be traced through what is termed volcanic sand into the coarse varieties of ejected matter. In composition the ash and sand vary necessarily with the nature of the lava from which they are derived. (2.) When the fragments range from the size of a pea to that of a walnut they are called *lapilli*. These are pieces of lava, round, subangular, or angular in shape, and having the same indefinite range of composition as the finer dust. As a rule, the coarse fragments fall nearest the focus of eruption. Sometimes they are solid fragments of lava, but more usually they have a cellular texture, while sometimes they are so light and porous as to float readily on water, and, when ejected near the sea, to cover its surface over a large area. (3.) *Volcanic Blocks* are large pieces of stone, often angular in shape. In some cases they appear to be fragments loosened from already solidified rocks in the chimney of the volcano. Hence we find among them pieces of older tuffs, and of lavas recognizably belonging to early eruptions. But in other and numerous instances they are not volcanic rocks at all, but belong to earlier formations through which the volcanic chimney has been drilled. Blocks of a coarsely crystalline granitoid lava have been particularly observed both on Etna and Vesuvius. In the year 1870 a mass of that kind weighing several tons was to be seen lying at the foot of Vesuvius, within the entrance to the Atrio del Cavallo. Similar blocks occur among the Carboniferous volcanic pipes of central Scotland. In the older tuffs of Somma, blocks of altered limestone form the chief repositories of the Vesuvian minerals. (4.) *Volcanic Bombs and Slags.*—These have originally formed portions of the column of lava ascending the pipe of the volcano, and have been detached and hurled into the air by the successive explosions of steam. In the case of a bomb, we have a round, elliptical, or pear-shaped and often discoidal mass of lava, from a few inches to several feet in diameter. Sometimes it is tolerably solid throughout, more usually vesicular. Not unfrequently it consists of a hollow interior, with a shell which is vesicular towards the centre and becomes more close-grained towards the outside. There can be no doubt that, when torn by eructations of steam from the surface of the boiling lava, the material of these bombs was in as thoroughly molten a condition as the rest of the mass. From the rotatory motion imparted by its ejection, it took a circular form, and in proportion to its rapidity of rotation and fluidity would be the amount of its "flattening at the poles." The centrifugal force within would allow the expansion of the interstitial vapour, while the outer surface would rapidly cool and solidify; hence the solid crust, and the porous or even cavernous interior. Such bombs, varying from the size of an apple to that of a man's body, were found by Mr Darwin abundantly strewed over the ground in the island of Ascension.[2] They have been found likewise in the tuff of

[1] "Alles ist lava was im Vulkane fliesst und durch seine Flüssigkeit neue Lagerstätter einnimmt" is Leopold Von Buch's comprehensive definition.

[2] *Geological Observations on Volcanic Islands*, 2d edit., p. 42.

Lower Carboniferous date at Dunbar, in Scotland. When the ejected fragment of lava has a rough irregular form, and a porous structure like the clinker of an iron-furnace, it is known as a *slag*.

The fragmentary materials erupted by a volcano and deposited around it acquire by degrees more or less consolidation, partly from the mere pressure of the higher upon the lower strata, partly from the influence of infiltrating water. It has been already stated (part ii., p. 239) that different names are applied to the rocks thus formed. The coarse, tumultuous, unstratified accumulation of volcanic debris within a crater or funnel is called agglomerate. When the debris, though still coarse, is more rounded, and is arranged in a stratified form, it is a volcanic conglomerate. The finer-grained varieties, formed of dust and lapilli, are included in the general designation of tuffs. These are usually pale-yellowish, greyish, or brownish, sometimes black rocks, granular, porous, and often incoherent in texture. Organic remains sometimes occur in tuff. Where the volcanic debris has accumulated over the floor of a lake, or of the sea, the entombing and preserving of shells and other organic objects must continually take place. But even in the tuffs of a volcanic cone traces of animals and plants may be preserved. Professor Guiscardi of Naples has found about 100 species of marine shells of living species in the old tuffs of Vesuvius. Marine shells have been picked up within the crater of Monte Nuovo, and have been frequently observed in the old or marine tuff of that district. The showers of ash which fall on the outer slopes of a volcano, or the sheets of mud which sometimes are spread out there, cover over and often preserve the land-shells, insects, and vegetation living on the area at the time. The older tuffs of Vesuvius have yielded many remains of the shrubs and trees which at successive periods have clothed the flanks of the mountain.

§ 2. *Volcanic Action.*

We have now to consider the circumstances under which the various solid, liquid, and gaseous products of a volcano are emitted. Volcanic action may be either constant or periodic. Stromboli, in the Mediterranean, so far as we know, has been uninterruptedly emitting hot stones, steam, and lava, from the earliest period of history. Among the Moluccas the volcano Sioa, and in the Friendly Islands that of Tofua, have never ceased to be in eruption since their first discovery. The lofty cone of Sangay, among the Andes of Quito, is always giving off hot vapours; Cotopaxi, too, is ever constantly active. But, though examples of unceasing action may thus be cited from widely different quarters of the globe, they are nevertheless exceptional. The general rule is that a volcano breaks out from time to time with greater or less fury, and after longer or shorter intervals of quiescence.

To what particular cause or series of causes any special eruption may be due is a question to which at present no definite answer can be given. An attempt has been made to show that the explosions of a volcano are to some extent regulated by the conditions of atmospheric pressure over the area at the time. In the case of a volcanic funnel like Stromboli, where, as Mr Scrope pointed out, the expansive subterranean force within, and the repressive effect of atmospheric pressure without, just balance each other, any serious disturbance of that pressure might be expected to make itself evident by a change in the condition of the volcano. Accordingly, it has long been remarked by the fishermen of the Lipari Islands that in stormy weather there is at Stromboli a more copious discharge of steam and stones than in fine weather. They make use of the cone as a weather-glass, the increase of its activity indicating a falling, and the diminution a rising barometer. In like manner Etna, according to S. von Waltershausen, is most active in the winter months. When we remember the connexion now indubitably established between a more copious discharge of fire-damp in mines and a lowering of atmospheric pressure, we may be prepared to find a similar influence affecting the escape of vapours from the upper surface of the lava column of a volcano; for it must not be forgotten that it is not so much to the lava itself as to the expansive vapours accompanying it that the manifestations of volcanic activity are due. Among the Vesuvian eruptions since the middle of the 17th century, the number which took place in winter and spring was to that of those which broke out in summer and autumn as 7 to 4. But there may be other causes besides atmospheric pressure concerned in these differences; the preponderance of rain during the winter and spring may be one of these. At present we must wait for further data.

Kluge has sought to trace a connexion between the years of maximum and minimum sun-spots and those of greatest and feeblest volcanic activity, and has constructed lists to show that years which have been specially characterized by terrestrial eruptions have coincided with those marked by few sun-spots and diminished magnetic disturbance.[1] Such a connexion cannot be regarded as having yet been satisfactorily established. Again, the same author has called attention to the frequency and vigour of volcanic explosions about the middle of August, at or near the time of the yearly meteoric shower. But in this case, likewise, the cited examples can hardly yet be looked upon as more than coincidences.

The case of Kilauea, in Hawaii, seems to show a regular system of eruptive periods. Dana has pointed out that outbreaks of lava have taken place from that volcano at intervals of from eight to nine years, this being the time required to fill the crater up to the point of outbreak, or to a depth of 400 or 500 feet. But the great eruption of 1868 did not occur until after an interval of 18 years. The same author suggests that the missing eruption may have been submarine.

The approach of an eruption is not always indicated by any premonitory symptoms, for many tremendous explosions are recorded to have taken place in different parts of the world without any perceptible warning. Much in this respect would appear to depend upon the condition of liquidity of the lava, and the amount of resistance offered by it to the passage of the escaping vapours through its mass. In Hawaii, where the lavas are remarkably liquid, vast outpourings of lava have taken place quietly without earthquakes during the present century. But even there the great eruption of 1868 was accompanied by tremendous earthquakes.

The eruptions of Vesuvius are often preceded by a failure or diminution of the wells and springs in the district. But more frequent indications of an approaching outburst are conveyed by sympathetic movements of the ground beneath. Rumblings and groanings from a subterranean source are heard; slight tremors succeed, increasing in frequency and violence till they become distinct earthquake shocks. The vapours from the crater rise more abundantly into the air. All this time the lava column in the pipe or funnel of the volcano has been slowly ascending, forced upward and kept in perpetual agitation by the passage of the elastic vapours through its mass. If a long previous interval of quiescence has elapsed, there may be much solidified lava towards the top of the vent which will restrain the ascent of the still molten portion underneath. A vast pressure is thus exercised on the sides of the cone. Should these be too weak to resist, they will open in one or more rents, and the

[1] *Ueber Synchronismus und Antagonismus*, p. 72.

liquid lava will issue from the outer slope of the mountain; or the energies of the volcano will be directed towards clearing the obstruction in the chief throat, until, with tremendous explosions, and the rise of a vast cloud of dust and fragments, the bottom and sides of the crater are finally blown out, and the top of the cone disappears. The lava may now escape from the lowest part of the lip of the crater, while, at the same time, immense numbers of red-hot bombs, scoriæ, and stones are shot up into the air, most of them falling back into the crater, but many descending upon the outer slopes of the cone, and some even upon the country beyond the base of the mountain. The lava rushes down at first like one or more rivers of melted iron, but, as it cools, its rate of motion lessens. Clouds of steam rise from its surface, as well as from the central crater. Indeed, every successive paroxysmal convulsion of the mountain is marked, even at a distance, by the rise of huge ball-like wreaths or clouds of steam, mixed with dust and stones, forming a vast column which towers sometimes a couple of miles above the summit of the cone. By degrees these diminish in frequency and intensity. The lava ceases to flow, the showers of stones and dust dwindle down, and after a time, which may vary from hours to days or months, even in the *régime* of the same mountain, the volcano becomes once more tranquil.

Let us now consider some of the aspects of this action which have more particular geological interest from the permanent changes with which they are connected, or from the way in which they enable us to detect and realize conditions of volcanic energy in former periods.

Fissures.—During the convulsions which culminate in the formation of a volcano, as well as in the subsequent progress of the mountain so formed, the ground at and around the focus of action is liable to be rent open by fissures. These tend to diverge from the focus; but around the vent where the rocks have been most exposed to concussion the fissures sometimes intersect each other in all directions. In the great eruption of Etna, in the year 1669, a series of six parallel fissures opened on the side of the mountain. One of these, with a breadth of two yards, ran for a distance of 12 miles, in a somewhat winding course, to within a mile of the top of the cone. Similar fissures, but on a smaller scale, have often been observed on Vesuvius; and they are recorded from many other volcanoes.

Two obvious causes may be assigned for the production of fissures:—(1) the enormous expansive force of the imprisoned vapours acting upon the walls of the funnel and convulsing the cone by successive explosions; and (2) the hydrostatic pressure of the lava-column in the funnel, amounting to about 125 ℔ per square inch, or 8 tons on the square foot, for each 100 feet of depth. Both of these causes may act simultaneously.

Into the rents thus formed the molten lava naturally finds its way. It is indeed forced into them, and solidifies there like iron in a mould. The cliffs of many an old crater show how marvellously they have been injected by such *veins* or *dykes* of lava. Those of Somma, and the Val del Bue on Etna, have long been known. The dykes project now from the softer tuffs like great walls of masonry. Such wedges of solid rock driven into the cone must widen its dimensions, and at the same time from their length and ramifications must bind the substance of the cone together, and thus strengthen it against the effects of future convulsions. We can understand, therefore, how there should be for a time an alternation in the character of the eruptions of a volcano, depending in great measure upon the relation between the height of the cone on the one hand and the strength of its sides on the other. When the sides have been well braced together by interlacing dykes, and further thickened by the spread of volcanic materials all over their slopes, they may resist the effects of explosion and of the pressure of the ascending lava-column. In this case the volcano may find relief only from its summit, and if the lava flows forth it will do so from the top of the cone. As the cone increases in elevation, however, the pressure from within upon its sides augments. Eventually egress is once more established on the flanks by means of fissures, and a new series of lava-streams is poured out over the lower slopes.

Though lava very commonly issues from the lateral fissures on a volcanic cone, it may sometimes approach the surface without actually flowing out. The great fissure on Etna in 1669, for example, was visible even from a distance by the long line of vivid light which rose from the incandescent lava within. Again, it frequently happens that minor volcanic cones are thrown up on the line of a fissure. This may arise either from the congelation of the lava round the point of emission, or from the accumulation of ejected scoriæ round the fissure-vent. Of the former structure examples occur in Hawaii, where the lava is remarkably liquid, and rapidly hardens into tears or drops, like wax down the sides of a candle. Where in viscid lavas the steam tears off and throws up many scoriæ and bombs, a cone of such loose materials will naturally form round the orifice by which the lava escapes from the flank of the mountain.

Explosions.—Although volcanic materials may be erupted to a large extent without the appearance of visible fissures, they cannot in such cases reach the surface without some explosive action, and the consequent displacement and removal of previously existing rock. Vents are thus blown out of the solid crust, the volcanic energy being, as it were, concentrated on a given point, which we may suppose must usually be the weakest in the structure of that part of the crust. The operation has often been observed in volcanoes already formed, and has even been witnessed on ground previously unoccupied by a volcanic vent. The history of the cone of Vesuvius brings before us a long series of such explosions, beginning with that of 79—the greatest which has occurred within the times of human history—and coming down to the present day. Even now, in spite of all the lava and ashes poured out during the last eighteen centuries, it is easy to see how stupendous must have been that earliest explosion, by which the southern half of the ancient crater was blown out. At every successive important eruption, a similar but minor operation takes place within the present cone. The hardened cake of lava forming the floor is burst open, and with it there usually disappears much of the upper part of the cone, and sometimes, as in 1872, a large segment of the crater-wall. In the year 1538 a new volcano, Monte Nuovo, was formed in 24 hours on the margin of the Bay of Naples. A cavity was drilled by successive explosions, and such quantities of stones, scoriæ, and ashes were thrown out from it as to form a hill 440 English feet above the sea-level, and more than a mile and a half in circumference. Most of the fragments now to be seen on the slopes of the cone and inside its beautifully perfect crater are of various volcanic rocks, many of them being black scoriæ; but pieces of Roman pottery, together with fragments of the older underlying tuff, and some marine shells, have been obtained; and these doubtless formed part of the soil and subsoil dislocated and ejected during the explosions.

It is not necessary, and it does not always happen, that any actual solid or liquid volcanic rock is ejected even when explosions of considerable violence take place, whereby the rocks through which the funnel rises are much shattered. Thus among the cones of the extinct volcanic tract of the Eifel, some occur consisting entirely, or nearly so, of comminuted debris of the Devonian greywacke and slate which

form the prevailing rocks there, and through which the various volcanic vents have been opened. Evidently in these cases elastic vapours only forced their way to the surface; and we see what probably often takes place in the early stages of a volcano's history, though the fragments of the underlying disrupted rocks are in most instances buried and lost under the far more abundant subsequent volcanic materials. Sections of ancient volcanic necks or pipes sometimes afford an excellent opportunity of observing that these orifices were originally opened by the blowing out of the solid crust and not by the formation of fissures. Many examples occur in Scotland among volcanic rocks of Old Red Sandstone, Carboniferous, and Permian age. The orifices are there filled with fragmentary materials wherein portions of the surrounding and underlying rocks form a noticeable proportion.

Showers of Dust and Stones.—A communication having been opened, either by fissuring or explosion, between the heated interior and the surface, fragmentary materials seldom fail to be ejected from it. These may consist at first mainly of the rocks through which the orifice has been opened, as has just been explained. But if eruptive energy continues, they soon appear in larger quantities, and consist of thoroughly volcanic substances. In a great eruption vast numbers of red-hot stones are shot up into the air, and fall back partly into the crater and partly on the outer slopes of the cone. But instances are known where large stones, ejected obliquely, have described huge parabolic curves in the air, and fallen at a great distance. Stones 8 ℔ in weight occur among the ashes which buried Pompeii. The volcano of Antuco in Chili is said to send stones flying to a distance of 36 miles, and Cotopaxi is reported to have hurled a 200-ton block 9 miles.

But in many great eruptions, besides a constant shower of stones and scoriæ, a vast column of exceedingly fine dust rises out of the crater, sometimes to a height of more than a mile, and then spreads outwards like a sheet of cloud. So dense sometimes is this dust-cloud that the sun is obscured, and for days together the darkness of night reigns for miles around the volcano. In 1822 this was the case at Vesuvius, the ashes not only falling thickly on the villages round the base of the mountain, but travelling as far as Ascoli, which is 56 Italian miles distant from the volcano on one side, and as Casano, 105 miles on the other. But probably the most stupendous outpouring of volcanic ashes on record was that which took place, after a quiescence of 26 years, from the volcano Coseguina, in Nicaragua, during the early part of the year 1835. On that occasion utter darkness prevailed over a circle of 35 miles radius, the ashes falling so thickly that, even 8 leagues from the mountain, they covered the ground to a depth of about 10 feet. It was estimated that the rain of dust and sand fell over an area at least 270 geographical miles in diameter. Some of the finer materials, thrown so high as to come within the influence of an upper air-current, were borne away eastward, and fell four days afterwards at Kingston, in Jamaica—a distance of 700 miles.

An inquiry into the origin of these showers of fragmentary materials brings vividly before us some of the essential features of volcanic action. We find that bombs, slags, and lapilli may be thrown up in comparatively tranquil states of a volcano, but that the showers of fine dust are discharged with violence, and only appear when the volcano becomes more energetic. Thus, at the constantly, but quietly, active volcano of Stromboli, the column of lava in the pipe may be watched slowly rising and falling with a slow rhythmical movement. At every rise the surface of the lava swells up into blisters several feet in diameter, which by and by burst with a sharp explosion that makes the walls of the crater vibrate. A cloud of steam rushes out, carrying with it hundreds of fragments of the glowing lava, sometimes to a height of 1200 feet. It is by the ascent of steam through its mass that a column of lava is kept boiling at the bottom of a crater, and by the explosion of successive larger bubbles of steam that the various bombs, slags, and fragments of lava are torn off and tossed into the air. It has often been noticed at Vesuvius that, after each great concussion, a huge ball-like cloud of steam rushes up from the crater. Doubtless it is the sudden escape of that steam which causes the explosion. The violence of the explosion will depend greatly upon the viscidity of the lava, and the consequent resistance offered to the upward passage of the steam. Explosions and accompanying scoriæ are abundant at Vesuvius, where the lavas are comparatively viscid; they are almost unknown at Kilauea, where the lava is remarkably liquid.

The steam, collecting into larger or smaller vesicles, works its way upward through the substance of the molten lava. As the elasticity of this compressed vapour overcomes the pressure of the overlying lava, it escapes at the surface, and there the lava is thus kept in ebullition. But this comparatively quiet operation, which may be watched within the craters of many active volcanoes, does not produce clouds of fine dust. The friction of the millions of stones ascending and descending through the air in the dark column above the crater, though it must doubtless cause much dust and sand, can give rise to but an insignificant proportion of what is actually reduced to the condition of extreme subdivision necessary to produce widespread darkness and a thick far-reaching deposit of ashes. The explanation now accepted calls in the explosive action of steam as the immediate cause of the trituration. A sudden and powerful explosion of steam, it is maintained, will blow the top of the lava column into dust, like water shot out of a gun. We must remember that the aqueous vapour by which many lavas are so largely impregnated must exist interstitially far down in the lava-column, under an enormous pressure, and at a white heat. The sudden ascent of lava so constituted will relieve the pressure rapidly without sensibly affecting the temperature of the mass. Consequently the white-hot steam will at length explode, and reduce the molten mass containing it to the finest powder.

Evidently no part of the operations of a volcano has greater geological significance than the ejection of such enormous quantities of fragmentary matter. In the first place, the fall of these loose materials round the orifice of discharge is one main cause of the growth of the volcanic cone. The heavier fragments gather around the vent, and there too the thickest accumulation of finer dust takes place. Hence, though successive explosions may blow out the upper part of the crater-walls, and prevent the mountain from growing so rapidly in height, every eruption must add to the diameter of the cone. In the second place, as every shower of dust and sand adds to the height of the ground on which it falls, thick volcanic accumulations may be formed far beyond the base of the mountain. In these are entombed trees and other kinds of vegetation, together with the bodies of many animals, as well as the works of man. Hence new geological formations arise which, in their component materials, not only bear witness to the volcanic eruptions which produced them, but preserve a record of the land-surfaces over which they spread. In the third place, besides the distance to which the fragments may be hurled by volcanic explosions, or to which they may be diffused by the ordinary aerial movements, we have to take into account the vast spaces across which the finer dust is sometimes borne by upper currents in the atmosphere. An instance has already been cited where ashes from Coseguina fell 700 miles away, having been carried all that long distance by a high counter-current of air, moving apparently