at the rate of about 7 miles an hour in an opposite direction to that of the wind which blew at the surface. On several occasions ashes from one of the Icelandic volcanoes have fallen so thickly between the Orkney and Shetland Islands that vessels passing there have had the unwonted deposit shovelled off their decks in the morning. In the year 1783, during an eruption of Skaptar-Jökull, so vast an amount of fine dust was ejected that the atmosphere over Iceland continued loaded with it for months afterwards. It fell in such quantity over parts of Caithness—a distance of 600 miles—as to destroy the crops; that year is still spoken of by the inhabitants as the year of "the ashie." Traces of the same deposit were observed even as far as Holland. Hence it is evident that volcanic deposits may be formed in regions many hundreds of miles distant from any active volcano. A single thin layer of volcanic detritus in a group of sedimentary strata would thus not of itself prove the existence of contemporaneous volcanic action in its neighbourhood. It might be held to have been wind-borne from a volcano in a distant and separate region.

Lava-streams.—A microscopic examination of their intimate structure shows that lavas have been truly molten rocks. They usually consist fundamentally of a glass through which are diffused, in greater or less abundance, various microlites and crystals. Their degree of liquidity, at the time of emission, seems to depend on the extent to which the rock remains in the condition of glass, viscidity increasing with the development of the microlites and crystals out of the glassy menstruum in which, no doubt, originally their component molecules were diffused. The fluidity may also be governed in no small degree by the amount of vapour existing interstitially in the molten mass. Mr Scrope indeed contended that aqueous vapour was the main cause of the mobility of such crystalline lavas as those of Vesuvius. But even where the lava pours forth with a liquidity like that of melted iron, it speedily assumes a more viscid motion, as the process of devitrification advances and the rock is exposed to the chilling effects of radiation and of contact with air and soil. An interesting fact, admirably shown by the microscope, but often easily observable with the naked eye, is that in lava still liquid and mobile well-defined crystals make their appearance. These sometimes are broken during the continued movement of the surrounding mass, the separated fragments becoming involved in the general glassy base or portions of that base, are injected into the fractures of the crystals. Well-defined crystals of leucite may be seen in specimens of Vesuvian lava, which has been ladled out from a white-hot stream, impressed with a stamp, and thus suddenly congealed. On the other hand, the obsidians have solidified in the condition of complete glass, often without any trace of devitrification. The green pyroxenic lava of Hawaii exhibits so extreme a degree of fluidity that, during its ebullition in pools of the crater, jets not more than a quarter of an inch in diameter are tossed up, and, falling back on one another, make "a column of hardened tears of lava," while, in other places, the jets thrown up and blown aside by the wind give rise to long threads of glass which lie thickly together like mown grass, and are known by the natives under the name of Pele's Hair, after one of their divinities.[1]

It would be of the highest interest and importance to know accurately the temperature with which a lava stream issues. The difficulty of making any direct observation at the point of outflow has hitherto been insuperable. Measurements have been taken at various distances below the point where the moving lava could be safely approached; but these are not satisfactory, seeing that the outer crust of the lava cools rapidly, and gives no measure of the temperature even a short way underneath. Experiments made by Scacchi and Sainte-Claire Deville on the Vesuvian lava erupted in 1855, by thrusting thin wires of silver, iron, and copper into the lava, indicated a temperature of scarcely 700° C. Earlier observations of a similar kind, made in 1819, when a silver wire $\frac{1}{30}$th inch in diameter at once melted in the Vesuvian lava of that year, gave a greatly higher temperature. Evidence of the high temperature of lava has been adduced from the alteration it has effected upon refractory substances in its progress, as where, at Torre del Greco, it overflowed the houses, and was afterwards found to have fused the fine edges of flints, to have decomposed brass into its component metals, the copper actually crystallizing, and to have melted silver, and even sublimed it into small octohedral crystals. But such facts, though full of interest and importance, give us no clue to the absolute initial temperature of the lava, which must be greatly higher than that of the stream after several miles of descent on the mountain slopes, and after some hours or days of cooling.

In spite of this very high temperature, however, the lava issues abundantly charged with aqueous vapour, to the expansion of which, as we have seen, its ebullition and expulsion are mainly due. As this vapour at once begins to escape when the lava issues into the air, it shows itself by a dense white cloud hanging over the moving mass. The lava streams of Vesuvius sometimes appear with as large and dense a steam cloud at their lower ends as that which escapes at the same time from the main crater. Even after the molten mass has flowed several miles, steam continues to rise abundantly both from its end and from numerous points along its surface.

From the wide extent of basalt dykes, such as those of Britain, some of which rise to the surface at a distance of 200 miles and upwards from the main volcanic regions of their time, it is evident that the molten lava may sometimes occupy a far greater superficial area underneath than the mere circumference of the actual pipe or of the volcanic cone. We must conceive of a vast reservoir of melted rock impregnated with superheated steam, and impelled upwards by the elastic force of the vapour. The lava may be regarded rather as the sign than as the cause of volcanic action. It is the pressure of the imprisoned vapour, and its struggles to get free, which produce the subterranean earthquakes, the explosions, and the outpouring of lava. As soon as the vapour finds relief, the terrestrial commotion calms down again, and the quiescence continues until another accumulation of vapour demands a repetition of the same phenomena.

It is evident that the vapour may succeed in effecting its escape without driving molten rock up to the surface. There may be tremendous explosions without an actual outcome of lava. But, in most cases, so intimately are vapours and lava commingled in the subterranean reservoirs that they rise together, and the explosions of the one lead to the outflow of the other. The first point at which the lava makes its appearance at the surface will largely depend upon the structure of the ground. Two causes have been assigned in a foregoing section (p. 244) for the fissuring of a volcanic cone. As the molten mass rises within the chimney of the volcano, continued explosions of vapour take place from its upper surface, the violence of which may be inferred from the vast clouds of steam, of ashes, and of stones which are hurled to so great a height into the air. These explosions must at the same time powerfully affect the sides of the funnel, exposed as these are to the enormous pressure exerted by the imprisoned vapour. We cannot therefore be surprised that, when a volcano experiences shocks of such intensity as to be felt over a radius 100

[1] Dana, *Geol. U.S. Explor. Exped.*, p. 179.

miles or more, its sides should at last give way, and large divergent fissures should be opened down its cone. Again, the hydrostatic pressure of the column of lava must have a potent influence. At a depth of 1000 feet below the top of the column the pressure exerted on each square foot of the surrounding walls must amount to more than 80 tons. We may well believe that such a force, acting upon the walls of a funnel already shattered by a succession of terrific explosions, will be apt to prove too great for their resistance. When this happens, the lava pours forth from the outside of the cone. So fissured is the cone sometimes that the lava issues freely from many points. A volcano so affected has been graphically described as "sweating fire." More usually the lava issues only from one or two points. Should these lie well down on the cone, far below the summit of the lava-column, the lava, on its first escape, driven by hydrostatic pressure, will sometimes spout up high into the air—a fountain of molten rock. This was observed in 1794 on Vesuvius, and in 1832 on Etna. In the eruption of 1852 at Mauna Loa, an unbroken fountain of lava, from 200 to 700 feet in height and 1000 feet broad, burst out at the base of the cone. Similar "geysers" of molten rock have subsequently been noticed in the same region. Thus, in March and April 1868, four fiery fountains, throwing the lava to heights varying from 500 to 1000 feet, continued to play for several weeks.

In a lofty volcano, therefore, the chances are always rather against the lava rising to the lip of the crater and flowing out there. It does so now and then; but more frequently it escapes from some fissure or orifice in a weak part of the cone. In minor volcanoes, on the other hand, where the explosions are less violent, and where the thickness of the cone in proportion to the diameter of the funnel is often greater, the lava very commonly rises in the crater. Should the crater walls be too weak to resist the pressure of the molten mass, they will give way, and the lava will rush out from the breach. This is seen to have happened in several of the puys of Auvergne, so well figured and described by Mr Scrope. But if the crater be massive enough to withstand the pressure, the lava, if still impelled upward by the struggling vapour, will at last flow out from the lowest part of the rim.

It was at one time supposed that lava beds could not consolidate on such steep slopes as those of most volcanoes, and that their present inclined position was to be attributed to a central upheaval of each mountain. This idea formed the subject of the famous theory of elevation-craters (*Erhebungskratere*) of L. von Buch, E. de Beaumont, and other geologists. It was a matter of prime importance in the interpretation of volcanic action to have this question settled. To Constant Prevost belongs the merit of having completely exposed the fallacy of this theory. He pointed out that there was no more reason why lavas should not consolidate on steep slopes than that tears or drops of wax should not do so. Mr Poulett Scrope also showed conclusively that the steep slope of the lava-beds of a volcanic cone was original. Sir Charles Lyell and Mr Hartung subsequently obtained abundant additional evidence from the Canary Islands, Etna, and other volcanic districts, to disprove the elevation theory. Geologists are now agreed that thick sheets of lava, with all their characteristic features, can consolidate on slopes of even 35° and 40°. The lava in the Hawaii Islands has cooled rapidly on slopes of 25°, that from Vesuvius, in 1855, is here and there as steep as 30°. On the east side of Etna, a cascade of lava, which poured, in 1689, into the vast hollow of the Cava Grande, has an inclination varying from 18° to 48°, with an average thickness of 16 feet. On Mauna Loa some lava-flows are said to have congealed on slopes of 49°, 60°, and even 80°, though in these cases it could only be a layer of rock stiffening and adhering to the surface of the steep slope. Even when it consolidates on a steep slope, a stream of lava forms a sheet with parallel, upper, and under surfaces, a general uniformity of thickness, and often greater evenness of surface than where the angle of descent is low.

At its first appearance, where it issues from the mountain, the lava glows with a white heat, and flows with a motion which has been compared to that of honey or of melted iron. It soon becomes red, and, like a coal fallen from a hot fireplace, rapidly grows dull as it moves along, until it assumes a black, cindery aspect. At the same time the surface congeals, and soon becomes solid enough to support a heavy block of stone. Its aspect depends, not merely on the composition and fluidity of the lava, but on the point of egress, whether from the crater or from a fissure, on the form of the ground, the angle of slope, and the rapidity of flow. Lavas which have been kept in ebullition within the central chimney are apt to acquire a rough cellular texture. The surface of the moving stream breaks up into rough brown or black cinder-like slags, and irregular rugged cakes, which, with the onward motion, grind and grate against each other with a harsh metallic sound, sometimes rising into rugged mounds or getting seamed with rents and gashes, at the bottom of which the red-hot glowing lava may be seen. When lava escapes from a lateral fissure it may have no scoriæ, but its surface will present froth-like, curving lines, as in the scum of a slowly flowing river, or will be arranged in curious ropy folds, as the layers have successively flowed over each other and congealed. These and many other fantastic coiled shapes were exhibited by the lava which flowed from the side of Vesuvius in 1858. A large area which has been flooded with lava is perhaps the most hideous and appalling scene of desolation anywhere to be found on the surface of the globe.

A lava stream at its point of escape from the side of a volcanic cone occupies a comparatively narrow breadth; but it usually spreads out as it descends, and moves more slowly. The sides of the moving mass look like huge embankments, or like some of the long mounds of "clinkers" one sees in a great manufacturing district. The advancing end of the mass is often much steeper, creeping onward like a great wall or rampart, down the face of which the rough blocks of hardened lava are ever rattling.

The rate of movement is regulated by the fluidity of the lava, by its volume, and by the form and inclination of the ground. Hence, as a rule, a lava-stream moves faster at first than afterwards, because it has not had time to stiffen, and its slope of descent is considerably steeper than further down the mountain. One of the most fluid and swiftly flowing lava-streams ever observed on Vesuvius was that erupted on 12th August 1805. It is said to have rushed down a space of 3 Italian ($3\frac{2}{3}$ English) miles in the first four minutes, but to have widened out and moved more slowly as it descended, yet finally to have reached Torre del Greco in three hours. A lava erupted by Mauna Loa in 1852 went as fast as an ordinary stage-coach, or 15 miles in two hours. Long after a current has been deeply crusted over with slags and rough slabs of lava it continues to creep slowly forward for weeks or even months.

It happens sometimes that, as the lava moves along, the pressure of the still molten mass inside bursts through the outer hardened and deeply seamed crust, and rushes out with, at first, a motion much more rapid than that of the main stream; but such an offshoot rapidly congeals and comes to rest, though sometimes not before doing much damage to vineyards, gardens, houses, or other property in its course. Any sudden change in the form or slope of the ground, too, will affect the flow of the lava. Thus, should the stream reach the edge of a steep defile or cliff, it will pour over it in a cataract of glowing molten rock, with clouds of steam, showers of fragments, and a noise utterly indescribable. Or if, on the other hand, the current should encounter a ridge or hill across its path, it will accumulate in front of it until it either finds egress round the side or actually overrides and entombs the obstacle. The hardened crust or shell within which the still fluid lava moves serves to keep the mass from spreading. We often find, however, that the lava has subsided here and there inside its crust, and has left curious cavernous spaces and tunnels. Into these, when the whole is cold, we may creep, and may find them sometimes festooned and hung with stalactites of lava.

As a rule a lava-stream shows three component layers. At its bottom lies a rough, slaggy mass, produced by the rapid cooling of the lava, and the breaking up and continued onward motion of the scoriform layer. The central and main portion of the stream consists of solid lava, often, however, with a more or less carious and vesicular texture. The upper part, as we have seen, is a mass of rough broken-up slags, scoriæ, or clinkers. The proportions borne by these respective layers to each other vary continually. Some of the more fluid ropy lavas of Vesuvius have an inconstant and thin slaggy crust; others may be said to consist of little else than scoriæ from top to bottom. These divergences in texture seem to depend largely upon the amount of interstitial steam imprisoned within the lava, and the conditions under which it can effect its escape. Throughout the whole mass, but more especially along its upper surface, the steam under its diminished pressure expands, and pushing the molten rock aside, segregates into small bubbles or irregular cavities. Hence, when the lava solidifies, these steam-holes are seen to be sometimes so abundant that a detached portion of the rock containing them will float in water. They are often elongated in the direction of the motion of the lava-stream.

But, besides producing a general vesicular texture in the upper parts of the lava-stream, the aqueous vapour gives rise to much more striking features on the surface of the lava. If the outburst takes place from an orifice or fissure on the exterior of the volcanic cone, so vast an amount of steam will rush out there, with such boiling and explosion of the lava, that a cone of bombs, and slags, and irregular lumps of lava, will probably form round the spot—in fact a miniature or parasitic volcano, which will remain as a marked cone on its parent mountain long after the eruption which gave it birth has ceased. Moreover, even after such abundant discharge of steam, the lava-stream continues to exhale it, as it were, from every pore. Here and there on the surface of the moving mass a fissure opens, and a column of roaring hissing vapours rushes out from it, accompanied as before by an abundant discharge of lava-fragments, or even by the rise and outflow of the lava from beneath. Some lava-streams are thus dotted over with small cones a few feet or yards in height. Besides the steam which, in condensing, makes its presence so conspicuous, many other vapours entangled in the pores of the lava escape from its fissures. The points at which vapours are copiously disengaged are termed *fumarole*. Among the exhalations, chlorides may be mentioned as particularly prominent; chloride of sodium frequently shows itself, not only in fissures, but even over the cooled crust of the lava, in small crystals, in tufts, or as a granular and even glassy incrustation. Chloride of iron is deposited as a yellow coating at the *fumarole*, where also bright emerald green films and scales of chloride of copper may be more rarely observed. Many chemical changes take place in the escape of the vapours through the lava. Thus specular-iron, probably the result of the mutual decomposition of steam and iron chloride, forms abundant scales, plates, and small crystals in the *fumarole* and vesicles of the lava. Sal-ammoniac also appears in large quantity on many lavas, not merely in the fissures, but also on the upper surface of the current. This salt is not directly a volcanic product, but results from some decomposition, probably from that of the aqueous vapour, whereby a combination is formed with atmospheric nitrogen.

The hardened crust of a lava-stream is a bad conductor of heat. Consequently, when the surface of the mass has become cool enough to be walked upon, the red hot mass may be observed through the rents to lie only a few inches below. Many years therefore may elapse before the temperature of the whole mass has fallen to that of the surrounding soil. Eleven months after an eruption of Etna, Spallanzani could see that the lava was still red hot at the bottom of the fissures, and a stick thrust into one of them instantly took fire. The Vesuvian lava of 1785 was found by Breislak seven years afterwards to be still hot and steaming internally, though lichens had already taken root on its surface. The ropy lava erupted by Vesuvius in 1858 was observed in 1870 to be still so hot, even near its termination, that steam issued abundantly from its rents, many of which were too hot to allow the hand to be held in them. Hoffmann records that the lava which flowed from Etna in 1787 was still steaming in 1830. But still more remarkable is the case of Jorullo, in Mexico, which sent out lava in 1759. Twenty-one years later a cigar could still be lighted at its fissures; after 44 years it was still visibly steaming; and even in 1846, that is, after 87 years of cooling, two vapour columns were still rising from it.[1]

This extremely slow rate of cooling has justly been regarded as a point of high geological significance in regard to the secular cooling and probable internal temperature of our globe. Some geologists have argued indeed that, if so comparatively small a portion of molten matter as a lava stream can maintain a high temperature under a thin, cold crust for so many years, we may, from analogy, feel little hesitation in believing that the enormously vaster mass of the globe may, beneath its relatively thin crust, still continue in a molten condition within. More legitimate deductions, however, might be drawn, if we knew more accurately and precisely in each case the rate of loss of heat, and how it varies in different lava-streams. Sir William Thomson, for instance, has suggested that, by measuring the temperature of intrusive masses of igneous rock in coal-workings and elsewhere, and comparing it with that of other non-volcanic rocks in the same regions, we might obtain data for calculating the time which has elapsed since these igneous sheets were erupted.

In its descent a stream of lava may reach a water-course, and, by throwing itself as a great embankment across the stream, may pond back the water and form a lake. Such is the origin of the picturesque Lake Aidat in Auvergne. Or the molten current may usurp the channel of the stream, and completely bury the whole valley, as has happened again and again among the vast lava-fields of Iceland. No change in physiography is so rapid and so permanent as this. The channel which has required, doubtless, many thousands of years for the water laboriously to excavate, is sealed up in a few hours under 100 feet or more of stone, and a still longer interval may elapse before this newer pile is similarly eroded.

By suddenly overflowing a brook or pool of water, molten lava sometimes has its outer crust shattered to fragments by a sharp explosion of the generated steam, while the fluid mass within rushes out on all sides. Numerous instances have occurred where the lavas of Etna and Vesuvius have protruded into the sea. Thus a current from the latter mountain entered the Mediterranean at Torre del Greco in 1794, and pushed its way for 360 feet outwards, with a breadth of

[1] E. Schleiden, quoted by Naumann, *Geol.*, i. p. 160.

1100 and a height of 15 feet. So quietly did it advance that Breislak could sail round it in a boat and observe its progress.

In passing from a fluid to a solid condition, and thus contracting, lava acquires different structures. Lines of divisional planes or joints traverse it, especially perpendicular to the upper and under surfaces of the sheet. These lines at various irregular distances cross each other so as to divide the rock into rude prisms. Occasionally another series of joints at a right angle to these traverses the mass parallel with its bounding surfaces, and thus the rock acquires a kind of fissile or bedded appearance. The most characteristic structure, however, among volcanic rocks is the prismatic, or, as it is incorrectly termed, "basaltic." Where this arrangement occurs, as it does so commonly in basalt, the mass is divided into tolerably regular pentagonal, hexagonal, or irregularly polygonal prisms or columns, set close together at a right angle to the main cooling surfaces. These prisms vary from 2 or 3 to 18 or more inches in diameter, and range up to 100 or even 150 feet in length.

Considerable discussion has arisen as to the mode in which this columnar structure has been produced. The experiments of Mr Gregory Watt were supposed to explain it by the production of a number of spherical concretions in the cooling mass, and the gradual pressure of those soft balls into hexagonal columns, as the mass contracted in cooling. He melted a mass of basalt, and on allowing it to cool observed that, when a small portion was quickly chilled, it took the form of a kind of slag-like glass, not differing much in appearance from obsidian; a larger mass, more slowly cooled, returned to a stony state. He remarked that during this process small globules make their appearance, which increase in size by the successive formation of external concentric coats, like those of an onion. And he supposed, as each spheroid must be touched by six others, the whole, if exposed to the same pressure acting in every direction, must be squeezed into a series of hexagons. To account, however, for a long column of basalt, we should have to imagine a pile of balls standing exactly centrically one upon the other, an arrangement which seems hardly possible. The prismatic structure is a species of jointing, due to the contraction of the rock as a whole, and not to the production of any internal peculiarities of texture. The concretionary structure associated with the columnar arises from a common tendency to weather out into nodular forms, and may be observed even where the rock is not columnar. Prismatic forms have been superinduced upon rocks by a high temperature and subsequent cooling, as where coal and sandstone have been invaded by basalt. They may likewise be observed to arise during the consolidation of a substance, as in the case of starch. In that substance the columnar structure is apt to radiate from certain centres, as may also be seen sometimes in basalt and other igneous rocks.

Mr Mallet has recently investigated this subject, and concludes that "all the salient phenomena of the prismatic and jointed structure of basalt can be accounted for upon the admitted laws of cooling, and contraction thereby, of melted rock possessing the known properties of basalt, the essential conditions being a very general homogeneity in the mass cooling, and that the cooling shall take place slowly, principally from one or more of its surfaces."[1]

In the more perfectly columnar basalts the columns are sometimes articulated, each prism being separable into vertebræ, with a cup and ball socket at each articulation. This peculiarity is traced by Mr Mallet to the contraction of each prism in its length and in its diameter, and to the consequent production of transverse joints, which, as the resultant of the two contracting strains, are oblique to the sides of the prism, but, as the obliquity lessens towards the centre, assume necessarily, when perfect, a cup-shape, the convex surface pointing in the same direction as that in which the prism has grown. This explanation, however, will hardly account for cases, which are not uncommon, where the convexity points the other way, or where it is sometimes in one direction, sometimes in the other.[2] The remarkable spheroids which appear in many weathered igneous rocks besides basalts may probably be due to some of the conditions under which the original contractions took place. They are quite untraceable on a fresh fracture of the rock. It is only after some exposure to the weather that they begin to appear, and then they gradually crumble away by the successive formation and disappearance of external weathered crusts or coats, which fall off into sand and clay. Almost all augitic or hornblendic rocks, even granite, exhibit the tendency to decompose into rounded spheroidal blocks.

By the outpouring of lava two important kinds of geological change are produced. In the first place, the surface of a country is thereby materially changed. Stream-courses, lakes, ravines, valleys, in short all the minor features of a landscape, may be completely overwhelmed under a sheet of lava, 100 feet or more in thickness. The drainage of the district is thus effectually altered, and all the numerous changes which flow from the operations of running water over the land are arrested and made to begin again in new channels. In the second place, considerable alterations may likewise be caused by the effects of the heat and vapours of the lava upon the subjacent or contiguous ground. Instances have been observed in which the lava has actually melted down opposing rocks, or masses of slags, on its own surface. Interesting observations, already referred to, have been made at Torre del Greco under the lava stream which overflowed part of that town in 1794. It was found that the window-panes of the houses had been devitrified into a white, translucent, stony substance, that pieces of limestone had acquired an open, sandy, granular texture, without loss of carbonic acid, and that iron, brass, lead, copper, and silver objects had been greatly altered, some of the metals being actually sublimed. We can understand therefore that, retaining its heat for so long a time, a mass of lava may induce many crystalline structures, rearrangements, or decompositions in the rocks over which it comes to rest, and proceeds slowly to cool. This is a question of considerable importance in relation to the behaviour of ancient lavas which have been intruded among rocks beneath the surface, and have subsequently been exposed, as will be referred to in the sequel.

But, on the other hand, the exceedingly trifling change produced even by a massive sheet of lava has often been remarked with astonishment. On the flank of Vesuvius we may see vines and trees still flourishing on little islets of the older land-surface completely surrounded by a flood of lava. Professor Dana has given an instructive account of the descent of a lava-stream from Kilauea in June 1840. Islet-like spaces of forest were left in the midst of the lava, many of the trees being still alive. Where the lava flowed round the trees the stumps were usually consumed, and cylindrical holes or casts remained in the lava, either empty or filled with charcoal. In many cases the fallen crown of the tree lay near, and so little damaged that the epiphytic plants on it began to grow again. Yet so fluid was the

[1] See an abstract of his paper, *Proc. Roy. Soc.*, January 1875.

[2] Mr Scrope pointed this out (*Geol. Mag.*, September 1875), though Mr Mallet (*Ibid.*, November 1875) replied that in such cases the articulations must be formed just about the dividing surface between the part of the rock which cooled from above, and that which cooled from below.

lava that it hung in pendent stalactites from the branches, which nevertheless, though clasped round by the molten rock, had barely their bark scorched. Again, for nearly 100 years there has lain on the flank of Etna a large sheet of ice which, originally in the form of a thick mass of snow, was overflowed by the molten flood, and has thereby been protected from the evaporation and thaw which would certainly have dissipated it long ago, had it been exposed to the air. The heat of the lava has not sufficed to melt it. There seems reason to suspect, however, that in other cases snow and ice have been melted in large quantities by overflowing lava. The great floods of water which rushed down the flank of Etna, after an eruption of the mountain in the spring of 1755, have been thus explained.

One further aspect of a lava-stream may be noticed here—the effect of time upon its surface. While all kinds of lava must, in the end, crumble down under the influence of atmospheric waste and, where other conditions permit, become coated with soil and support some kind of vegetation, yet extraordinary differences may be observed in the facility with which different lava-streams yield to this change, even on the flank of the same mountain. Every one who ascends the slopes of Vesuvius remarks this fact. After a little practice it is not difficult there to trace the limits of certain lavas even from a distance, in some cases by their verdure, in others by their barrenness. Five hundred years have not sufficed to clothe with green the still naked surface of the Catanian lava of 1381; while some of the lavas of the present century have long given footing to bushes of furze. Some of the younger lavas of Auvergne, which certainly flowed in times anterior to those of history, are still singularly bare and rugged. Yet, on the whole, where lava is directly exposed to the atmosphere, without receiving protection from occasional showers of volcanic ash, or being liable to be washed bare by heavy torrents of rain, its surface decays in a few years sufficiently to afford soil for a few plants in the crevices. When these have taken root they help to increase the disintegration. At last, as a more or less continuous covering of vegetation spreads over the rock, the traces of its volcanic origin one by one fade away from its surface. Some of the Vesuvian lavas of the present century already support vineyards.

Torrents of Water and Mud.—We have seen that large quantities of water accompany many volcanic eruptions. In some cases, where ancient crater-lakes or internal reservoirs have been shaken by repeated detonations, and finally disrupted, the mud which has thus been produced issues at once from the mountain. Such "mud-lavas," on account of their liquidity and swiftness of motion, are more dreaded for their destructiveness than even the true melted lavas. On the other hand, rain or melted snow, rushing down the cone and taking up loose volcanic dust, is converted into a kind of mud that grows more and more pasty as it descends. The mere sudden rush of such large bodies of water down the steep declivity of a volcanic cone cannot fail to effect much geological change. Deep trenches are cut out of the loose volcanic slopes, and sometimes large areas of woodland are swept away, the debris being strewn over the plains below.

During the great Vesuvian eruption of 1622 a torrent of this kind poured down upon the villages of Ottajano and Massa, overthrowing walls, filling up streets, and even burying houses with their inhabitants. It was by similar streams from the same volcano that some of the Roman cities on its flanks were overwhelmed in the first century. Many of the volcanoes of Central and South America discharge large quantities of mud directly from their craters. Thus in the year 1691 Imbaburu, one of the Andes of Quito, emitted floods of mud, so largely charged with dead fish that pestilential fevers arose from the subsequent effluvia. Seven years later (1698), during an explosion of another of the same range of lofty mountains, Carguairazo (14,706 feet), the summit of the cone is said to have fallen in, while torrents of mud, containing immense numbers of the fish *Pymelodus Cyclopum*, poured forth and covered the ground over a space of four square leagues. The carbonaceous mud (locally called *moya*) emitted by the Quito volcanoes sometimes escapes from lateral fissures, sometimes from the craters. Its organic contents, and notably its siluroid fish, which are the same as those found living in the streams above ground, prove that the water is derived from the surface, and accumulates in craters or underground cavities until discharged by volcanic action. Similar but even more stupendous and destructive outpourings have taken place from the volcanoes of Java, where wide tracts of luxuriant vegetation have at different times been buried under masses of dark grey mud, sometimes 100 feet thick, with a rough hillocky surface from which the top of a submerged palm-tree might have been seen protruding.

Between the destructive effects of mere water-torrents and that of these mud-floods there is, of course, the notable difference that, whereas in the former case a portion of the surface is swept away, in the latter, while sometimes considerable demolition of the surface takes place at first, the main result is the burying of the ground under a new tumultuous deposit by which the surface is greatly changed, not only as regards its temporary aspect, but in its more permanent features, such as the position and form of its water-courses.

Mud-volcanoes.—Though probably seldom if ever strictly volcanic in the proper sense of that term, certain remarkable orifices of eruption may be noticed here to which the names of mud-volcanoes, salses, air-volcanoes, and macalubas have been applied. These are conical hills formed by the accumulation of fine and usually saline mud, which, with various gases, is continuously or intermittently given out from the orifice or crater in the centre. They occur in groups, each hillock being sometimes less than a yard in height, but ranging up to elevations of 100 feet, or even sometimes, as in the plains of the lower Indus, to 400 feet. Like true volcanoes, they have their periods of repose, when either no discharge takes place at all, or mud oozes out tranquilly from the crater, and their epochs of activity, when large volumes of gas, and sometimes columns of flame, rush out with considerable violence and explosion, and throw up mud and stones to a height of several hundred feet.

The gases play much the same part therefore in these phenomena that steam does in those of true volcanoes. They consist of carbonic acid gas, carburetted hydrogen, sulphuretted hydrogen, and nitrogen. The mud is usually cold. In the water occur various saline ingredients, among which common salt generally appears. Naphtha is likewise frequently present. Large pieces of stone, differing from those in the neighbourhood, have been observed among the ejections, indicative doubtless of a somewhat deeper source than in ordinary cases. Heavy rains may wash down the minor mud cones and spread out the material over the ground, but gas-bubbles again appear through the sheet of mud, and by degrees a new series of mounds is once more thrown up.

There can be little doubt that these phenomena are to be traced to chemical changes in progress underneath. Dr Daubeny explained them in Sicily by the slow combustion of beds of sulphur. The frequent occurrence of naphtha and of inflammable gas points, in other cases, to the disengagement of hydrocarbons from subterranean strata.

Mud volcanoes occur in Iceland, in Sicily (Macaluba), in

many districts of northern Italy, at Tamar and Kertch, at Baku on the Caspian, over an area of about 1000 square miles near the mouth of the Indus, and in other parts of the globe.

Gaseous Discharges.—Some of these belong to true volcanic phenomena, others are closely associated with the mud-volcanoes. To the former class we may assign the copious emanations of carbonic acid which so frequently take place in districts where volcanic activity has been long dormant or extinct. The gas either comes out directly from fissures of the rock, or rises dissolved in the water of springs. The old volcanic districts of Europe furnish many examples. Thus on the shores of the Laacher See—an ancient crater lake of the Eifel—carbonic acid gas issues from numerous openings called *moffette*, round which dead insects, and occasionally mice and birds may be found. In the same region occur hundreds of springs more or less charged with the gas. The famous Valley of Death in Java contains one of the most remarkable gas-springs in the world. It is a deep, bosky hollow, from one small space on the bottom of which carbonic acid issues so copiously as to form the lower stratum of the atmosphere. Tigers, deer, and wild-boar, enticed by the shelter of the spot, descend and are speedily suffocated. Many of their skeletons, together with those of man himself, have been observed.

In the second class of gas-springs we may group the emanations of carburetted hydrogen, which, when they take fire, are known as Fire-wells. They occur in many of the districts where mud-volcanoes appear, as in northern Italy, on the Caspian, in Mesopotomia, in southern Kurdistan, and in many parts of the United States. It has been observed that they rise especially in regions where beds of rock-salt lie underneath, and as that rock has been ascertained often to contain compressed carburetted hydrogen, the solution of the rock by subterranean water, and the consequent liberation of the gas, has been offered as an explanation of these fire-wells.

Geysers.—In various regions where volcanic action still continues, or where it has long been dormant, there occur eruptive fountains of hot water and steam, to which the general name of geysers is given, from the well-known examples in Iceland, which were the first to be seen and described. Besides the Great and Little Geysers, the Strokkr, and other minor springs of hot water in Iceland, other, perhaps still more striking, examples have in recent years been brought to light in that tract of the western territories of the United States set aside as the "Yellowstone National Park," and good illustrations are also found in New Zealand. A geyser possesses a vertical pipe in the ground, terminating at the surface in a basin which is formed of siliceous sinter, and may rise some feet or yards above the general level. At more or less regular intervals rumblings and sharp detonations occur underneath, followed by an agitation of the water in the basin, and then by the violent expulsion of a column of water and steam to a considerable height in the air. The hot water contains silica in solution, which, on cooling and evaporating, is deposited at the surface; and thus the geyser builds up its basin, sometimes raising it into a long, solitary, finger-like pillar.

Bunsen and Descloiseaux spent some days experimenting at the Icelandic geysers, and ascertained that in the Great Geyser, while the surface temperature is about 212° Fahr, that of the lower portions of the tube is much higher—a thermometer giving as high a reading as 266° Fahr. The water there must consequently be 48° above the normal boiling-point, but is kept in the fluid state by the pressure of the overlying column. At the basin, however, the water cools quickly. After an explosion it accumulates there, and eventually begins to boil. The pressure on the column below being thus relieved, a portion of the superheated water flashes into steam, and as the change passes down the pipe, the whole column of water and steam rushes out with great violence. The water thereafter gradually collects again in the pipe, and after an interval of some hours the operation is renewed. The experiments made by Bunsen proved the cause of the eruption to lie in the high temperature of a portion of the pipe. He hung stones by strings to different depths in the funnel of the geyser, and found that only those in the higher part were cast out by the rush of water, sometimes to a height of 100 feet, while at the same time the water at the bottom was hardly disturbed at all.[1]

These observations give an additional interest and importance to the phenomena of geysers in relation to those of volcanic action. They show that the eruptive force is steam; that the water column, even at a comparatively small depth, has a temperature considerably above 212°; that this high temperature is local; and that the eruptions of steam and water take place periodically, and with such vigour as to eject large stones to a height of 100 feet.

§ 3. *Structure of Volcanoes.*

It is now admitted that a volcano is due to the accumulation of material round the vent of eruption, and not to any blister-like expansion of the ground. The structure of a volcanic cone necessarily depends in great measure upon the nature of the substances ejected. The following are the more important and interesting types of this kind of structure :—

(1.) *Cones of Non-volcanic Materials.*—These are due to the discharge of steam or other aeriform product through the solid crust without the emission of any true ashes or lava. The materials ejected from the cavity are wholly, or almost wholly, parts of the surrounding rocks through which the volcanic pipe has been drilled. Some of the cones surrounding the crater-lakes or *maare* of the Eifel consist chiefly of fragments of the underlying Devonian slates.

(2.) *Tuff-Cones, Cinder-Cones.*—Successive eruptions of fine dust and stones, often rendered pasty by getting mixed with the water so copiously condensed during an eruption, form a cone in which the materials are solidified by pressure into tuff. Sometimes the cones are made up only of loose cinders, like Monte Nuovo in the Bay of Baiæ. Cones consisting entirely of loose volcanic materials often arise on the flanks or round the roots of a great volcano, as happens to a small extent on Vesuvius, and on a larger scale upon Etna. They likewise occur by themselves apart from any lava-producing volcano, though usually they afford indications that columns of lava have risen in their funnels, and even now and then that this lava has reached the surface. Admirable examples are furnished by the cones of the Phlegræan fields near Naples. Ancient cones of a similar character occur among the Carboniferous rocks of Scotland. The materials of the cone are arranged in more or less regular beds which dip away from the funnel, their inclination corresponding with that of the cone. Inside the crater they slope steeply inward towards the crater-bottom.

(3.) *Mud-Cones* or *Salses* are formed by the accumulation and consolidation of mud round the vents of mud-volcanoes. They sometimes reach a height of 400 feet.

(4.) *Lava-Cones.*—These are comparatively rare, since, in most cases, the emission of lava is accompanied by the discharge of ashes. Owing to its liquidity, the lava flows off quickly, and the cones have very gentle slopes. The most remarkable examples are those in the Hawaii Islands described by Professor Dana. They attain a great height, but so small is their angle of inclination, that they may be described as only gently-sloping mounds, and their craters have been compared to vast open quarries on a hill or moor.

[1] Bunsen, *Ann. der Chemie und Pharmacie*, lxii. (1847), p. 1.