"On the Mechanism of Stromboli." By Robert Mallet, M.A., F.R.S. Received May 17, 1874 *.

Stromboli and Masaya stand alone, so far as observation has yet gone, amongst the volcanic vents of our planet, in the remarkable characteristic of having a distinctly rhythmical intermittence and recurrence in their eruptive action. Masaya, though known for about 300 years, has been but little observed, so that some doubt may exist as to whether its action be truly intermittent and recurrent or not; and if we leave it aside for future observation, Stromboli stands unique amongst terrestrial volcanoes in the rhythmical character of its eruptions, more or less accurate observations as to which are upon record for above 2000 years. Every volcanic vent is indeed intermittent, and often recurrent, in its action, which has been properly denominated paroxysmal, but no law can be traced in the intervals of time elapsing between the paroxysms. A vent may suddenly open and a cone be thrown up, as in the case of Monte Nuovo, and after this burst volcanic effort may cease there, perhaps permanently; or, as in the case of Vesuvius, prior to A.D. 79, a period of repose may exist in a volcanic cone already formed, exceeding human local tradition, to be succeeded by paroxysmal efforts, varying enormously in intensity, and with intervals in time between successive eruptions varying from hours to centuries. In all these there is no rhythmical recurrence, or at least none that, upon the narrow scale open to our observation, can be viewed as such. In Stromboli, on the contrary, there is a distinctly rhythmical intermittence and recurrence, so regular in time, and preserving for centuries such a general uniformity in energy, and of such slight violence, as to point to some distinct train of mechanism as producing it—that mechanism, whatever be its nature, being comprehended within a moderate distance from the surface, and not referable to the more mighty and deep-seated forces which determine the uncertain and altogether unpredictable paroxysms of volcanoes generally. Not that the rhythmic intervals of Stromboli are precisely the same at all times, as has been erroneously stated by many travellers, nor the violence of its outbursts at all times alike; but both vary within narrow limits during the immense historic period that it has been observed. No satisfactory explanation has yet been given, so far as the author is aware, of the physical and mechanical condition constituting the mechanism upon which this extremely curious rhythmical action depends; and it is the object of this paper to point out what appears to be its real nature. It is the more worthy of attentive study, as Stromboli is in reality the link that connects two widely different phenomena—namely, the ordinary cone of eruption and the geyser. Stromboli is, in fact, a volcano and a geyser united and acting together in the same vent, the rhythmical action which characterizes the geyser

* Read June 18, 1874. See *antè*, p. 473.

being thus communicated, within certain limits, to the otherwise irregular and accidental activity of the volcano.

Passing ancient accounts, Stromboli has been visited in modern days, amongst men of science, by Spallanzani, Dollomieu, Hoffman, Scrope, Daubeny, and several others; but no very full or exact description of the crater and its adjuncts, much less any adequate explanation of the curious mechanism of its action, has been given by any of these writers.

Hoffman's account of the phenomena witnessed by him, though far from clear or satisfactory, is curious enough to deserve translation here:—"The volcano appeared to have changed into a hot mineral spring; then at irregular times we observed that the continually developing steam became stationary, and, with a jerking uncertain motion, rushed back into the mouth of the crater. At the same time we felt a terrifying trembling of the ground, accompanied by visible oscillations of the loose crater-sides. Then followed a hollow roar, and a volume of steam shot out of the crater, accompanied by a shrill crackling. Thousands of lava-fragments, which had been carried up with the steam, spread in the air like sheaves, and then fell back, either into the mouth or on the surrounding cinder and sand walls. We could distinctly see (particularly on this occasion) the boiling, seething lava dash against the sides of the shaft, separate into two streams, and then fall back; but the lava ejected in bubbles flew far through the air, twisting and tearing along, foaming drops, bright as cooled glass, clattering as they rolled down the declivity."

Mr. Scrope makes the following remarks in his 'Volcanos' (second edition, pp. 332–334):—

"The remarkable circumstance in this small but interesting volcano is that the column of lava within its chimney is shown, by the constant explosions that take place from its surface at intervals of from five to fifteen minutes, casting up fragments of scoriform lava, to remain permanently at the same height, level with the lip of the orifice at the bottom of the crater, and therefore some 2000 feet above the sea-level. It is evident from this that nearly a perfect equilibrium is preserved between the expansive force of the intumescent lava in and beneath the vent, and the repressive force, consisting in the weight of this lofty column of melted matter, together with that of the atmosphere above it; consequently a very small addition to or subtraction from the latter, such, for instance, as a change in the pressure of the atmosphere, must to *some* extent, however small, derange the equilibrium. It need not therefore surprise us that the inhabitants of the island, chiefly fishermen, who ply their perilous trade day and night, within sight of the volcano, declare that it serves them in lieu of a weather-glass, warning them by its increased activity of a lightening of the atmospheric pressure on the volcano—equivalent to a fall of the mercury—and by its sluggishness giving them assurance of the

reverse. It is the tension of heated steam or water disseminated through the lava in and beneath the vent which occasions its eruptive action, and the boiling-point of every drop or bubble must be sensibly affected by every barometric variation. . . . .

"In the foul weather of winter I was assured by the inhabitants that the eruptions are sometimes very violent, and that the whole flank of the mountain immediately below the crater is then occasionally rent by a fissure, which discharges lava into the sea, but must be very soon sealed up again, as the lava shortly afterwards finds its way once more to the summit, and boils up there as before. Captain Smyth found the sea in front of this talus unfathomable, which accounts for the remarkable fact that the constant eruptions of more than 2000 years have failed to fill up this deep-sea hollow."

Dr. Daubeny ('Volcanos,' second edition, p. 248) appears to have given but a cursory examination to the crater; and in his observations on its phenomena only repeats Spallanzani, Hoffman, and Mr. Scrope, as follows:—

"The unremittent character of the eruptions of Stromboli appears to arise, as Mr. Scrope has suggested, from the exact proportion maintained between the expansive and repressive force. The expansive arises from the generation of a certain amount of aqueous vapour and of elastic fluids; the repressive from the pressure of the atmosphere, and from the weight of the superincumbent volcanic products."

The mechanism, as imagined by Mr. Scrope, fails, in the author's opinion, to account either for the rhythmical character of the eruptions or for the alleged connexion between them and the state of the weather. No equilibrium between the "expansive" and the "repressive" forces can possibly exist at the moment of an outburst, the circumstances of which prove an excess of pressure of many atmospheres, which has been gradually increasing since the last outburst became quiescent.

To account for the actual facts, we must have such a train of natural mechanism as shall cause a gradual, though rapid, increase of steam-pressure within or beneath the vent or tube of the volcano, until the accumulated pressure suffices to overcome whatever obstacles it may encounter, solid or liquid, and by blowing these away release the pressure itself in a burst of steam, stones, dust, &c. The conditions producing this gradual increase of steam-pressure must be such as shall give rise to the rhythmical recurrence, at comparatively short intervals, of the phenomena. These conditions are certainly not to be found, either in the general nearness of balance of any expansive and repressive forces alone, or in any conceivable relation between these and variations of atmospheric pressure.

Mr. Scrope has, as the author believes, greatly overrated the altitude of the fundus of the crater in stating it at 2000 feet above the sea. But let us suppose the height of the column of liquid lava, between the level of the sea

and the fundus of the crater, to be one fourth of this, and the expansive and repressive agencies in the nicely balanced equilibrium assumed, what effect could any variation of barometric pressure, within the limits ever experienced on any part of our globe, produce in disturbing such equilibrium? A rise or fall of the barometer at the rate of a tenth of an inch per hour is known only to occur in connexion with the most violent hurricanes. A fall of half an inch in the mercury within three or four hours exceeds probably the utmost that occurs in connexion with the most violent Mediterranean storms. But let us suppose a fall of two inches in the barometer to take place instantaneously, how far would that affect the equilibrium supposed of such a column, however supported, and whether free from aëriform matter or containing vesicles thereof? Two inches of mercury are equivalent to about $\frac{1}{15}$ of the usual pressure of the atmosphere, or to less than one pound to the square inch at the sea-level. The liquid lava supposed to fill the column may be allowed to have a specific gravity of at least 2·000; a rise or fall, therefore, of a single foot in the top surface of this column would equilibrate this exaggerated amount and rapidity of barometric change. But the head of the column itself is described by Hoffman as continually in oscillation upwards and downwards through several feet. It is obvious, therefore, that changes of atmospheric pressure have nothing whatever to do with the mechanism producing the recurrent action of this volcano.

Whatever reality there may be in the notion, long handed down, of some connexion between the degree of activity of this volcano and changes of weather appears to be merely superficial, and the true interpretation will be referred to further on. In any case this notion of equilibrium within the chimney of this particular volcano, and its disturbance by changes of atmospheric pressure, would be equally applicable to every volcanic vent in the world, and fails to throw any light upon the special phenomena which characterize Stromboli, viz. the quasi regular recurrence of its bursts forth. The geysers of Iceland belch forth water and steam, and occasionally stones, and the order of recurrence is the same which characterizes those of Stromboli. The latter does not send forth water *en masse*, its ejecta being steam mixed with some gases, carrying up considerable masses of solidified lava, chiefly in angular blocks, mixed occasionally, but not always, with torn shreds and lumps of half-solidified lava, in a more or less plastic state, together with a preponderant volume of dusty pulverulent matter. It is highly probable that water, not in the state of steam, but in that of solid drops, is frequently blown from Stromboli, and such may be felt falling to leeward after some of the bursts forth, though not after all. It may be doubtful, however, whether or not these drops may arise from steam condensed in the air.

We thus have, to the same succession of phenomena as those of the geyser, superadded in Stromboli some of those of a volcanic vent, of feeble but long-continued activity.

The phenomena of geysers were for a long time supposed peculiar to Iceland; and although they are now known to exist elsewhere, their characteristics are nowhere better observable than in Iceland.

The recurrence of their outbursts, their duration and intervals, were very well described by Von Troil in his 'Letters on Iceland' in 1772, and have been further described by Sir George Mackenzie in 1810.

Henderson had ascertained that stones, or other obstacles, thrown into the geyser-tube influenced the interval between two outbursts generally by increasing it, and gave rise to augmented violence in the outburst when it came, the stones being projected back along with the water, and rising much higher than the latter, as might have been predicted from dynamic considerations. Sir John Herschel suggested an explanation of geyser-phenomena, based upon modifications of the mechanism long previously proposed to account for those of intermittent springs. His explanation, though tenable, certainly does not apply to all observed cases, and is scarcely likely to be the true one, because a much simpler mechanism has been since pointed out; and it may be taken as certain that, in explaining all natural phenomena, the simplest is the true one. This was discovered by Bunsen and Des Cloizeaux, who in 1846 examined the geysers of Iceland, and ascertained the fact that towards the bottom of the tube of the Great Geyser, at a depth of 78 feet from the lip of the basin, a thermometer immersed in the rising column of water rose to 266° Fahr., or to more than 50° above the boiling-point of water, under atmospheric pressure only; and these authors conclude that, as the flow of water which replenishes the tube after an outburst causes the aqueous column gradually to rise to the lip of the basin, the temperature of the water at the lowest part of the column continues to rise; and whether it receives its accession of heat from the sides of the tube or from jets of superheated steam issuing into it, no considerable volume of steam can be generated until the boiling-point has been reached at the bottom of the column, as due to its insistent pressure there, when a sudden and large outburst of steam takes place, and the whole column of water is belched forth from the tube, succeeded by the blowing-off of the pent-up steam which expelled it, and with steam evolved from the column of water as it rises, until that falls back to atmospheric pressure. The curious facts ascertained by Professor Donny, of Ghent, that water absolutely free from combined air may be heated to even 275° Fahr. before it boils, and then bursts into steam explosively, have been appealed to as auxiliary to the phenomena, but seem unnecessary, even were it certain that the water of geysers is absolutely air-free. Were it so, however, there can be little doubt that the rise in the boiling-point of such water, under atmospheric pressure, would also take place in the same water under a head of 78 feet, or equal to more than two atmospheres, and thus would still further augment the temperature at the bottom of the tube, and further increase the violence of the outburst.

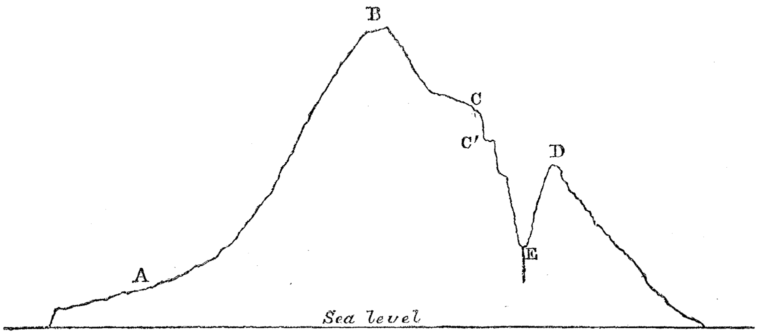
Bunsen is of opinion that the above is simply the mechanism of the Great Geyser; but that to account for some of the minor phenomena of the second, or Strokur Geyser, some additional mechanism, not widely differing from that suggested by Herschel, may be necessary. Some of the relations which subsist between geyser-phenomena, as thus explained, and those which he supposes to occur at various depths in the tubes of active volcanic vents, have been well discerned by Sir Charles Lyell, and are described in his 'Principles of Geology,' 10th edit. vol. ii. p. 220; but he has not applied them in explanation of the rhythmic recurrence of the outbursts of Stromboli. From Bunsen's explanation, as above sketched, it follows that the interval between two outbursts depends mainly on three conditions—the depth and capacity of the tube, the rate at which the water that fills it is supplied, and the rate at which heat, from whatever source, is transmitted to the water. Were these three all perfectly constant, the interval between two successive outbursts would be always the same, but it must vary, more or less, as any one of these three conditions may be altered. Again, the duration of the outburst, or time occupied in the expulsion of the column of water, and the height to which it is sent, as well as the volume of the jet, depend upon the capacity of the tube and the height to which the water rises within it before the blow-out commences, and must therefore vary in time with these conditions. The depth and capacity of the tube may vary secularly or be deranged suddenly; the temperature of the infiltrated water may vary, and therefore the time of its boiling under given conditions may alter with the season; and the temperature of the sides of the tube, and of the steam blown into it from fissures, must vary with the intensity of neighbouring volcanic action whence these are drawn.

Before proceeding to connect the circumstances presented by Stromboli with the above facts in relation to geysers, it will be necessary to adduce some facts in relation to the former, derived from personal observation.

In the latter part of the year 1864 I examined the whole of the Lipari Islands, with the exception of Felicudi and Alicuda, which the lateness of the season rendered impossible. Starting from Cape Mellazo (Sicily) in a "well-found" speronala, with a crew of eight men, which I retained throughout the voyage amongst the group of islands, I had the pleasure and advantage of being accompanied for some days, and as far as Lipari Island, Panaria, and Stromboli, by my friend Colonel H. Yule, B.E., well known for his embassy to Siam, and recently for his noble edition of Marco Polo's travels, and by various other works. Our landing at Stromboli was difficult, from the high surf running in; and after our arrival the weather became so much more tempestuous as to detain us there some time. We enjoyed the hospitality of Padre Capellano Giusseppe Ranza, whose house is situated not far from the central parts of the island, and whence a steep but not difficult walk leads up to the

crater and to the highest point of the island. The statements which have been made as to the relative heights of different points of this island appear to be only derived from guess, and are greatly in error, as I am enabled to show, although I am not in a position to give heights which are rigidly correct, my hypsometric measurements having been made by means of a single aneroid.

Diagram No. 1.



The *pergola* of Padre Ranza's house (marked A, Diagram No. 1) was found to be 211 feet above the sea at St. Vincenzo, and the highest point of the island (marked B) is 2843 feet thus measured. Captain Smyth, however, gives the height as only 2576 feet: this was probably taken by him by the usual nautical methods of triangulation, and if so, may not be more exact than my own rough barometric measurement. The height of the ridge overhanging the crater, marked C, was in like manner found to be 1200 feet. We were enabled to clamber down from this over crags of lava, whose irregular terraces and ledges were capped, more or less deeply, with black volcanic sand, containing immense quantities of crystals of augite, down to a point overhanging the landward wall of the crater, and at no great distance from its verge, from whence we witnessed the phenomena of eruption. This point, marked C′, I found to be 904 feet above the level of the sea. From this point the great, irregular, and somewhat oval funnel-shaped crater was before us; and looking seaward the highly irregular walls bounding its edges sloped towards the sea, and were united transversely by the sharp irregular edge or summit of the mass of broken and in great part wholly discontinuous and angular ejected fragments, which form a slope down to the sea, between the opposite sides or jaws of the cove or reentrant angle in the coast-line called the Schiarrazza. From the point where we stood this edge (D on Diagram) was estimated by the eye and clinometer at about 300 feet below us; and the narrower width of the crater thus seen across at its brim I estimated at from 300 to 400 feet. The form of the crater as described by Smyth ('Sicily and its Islands,' p. 255) in 1824 was stated to be circular, and

its diameter about 510 feet. This statement can only be received as approximate, as at that date the brim of the crater cannot have been extremely different from what it was in 1864; and the bounding walls, which are of material the greater part of which is as ancient as is the island itself, can scarcely admit of its ever having been circular, or much different from the irregular gulf it presented when I saw it. From our position of observation, every thing around us was of the sable colouring of black lava and volcanic sand. We could not see with any distinctness the fundus or bottom of the crater, a cloud of vapour issuing from its bottom, and in places from its sides, nearly filling the cavity, and obscuring the bottom even between the outbursts. This vapour smelled strongly of hydrosulphuric-acid gas. At all the lower part, as well as I could discern, the steep and solid walls of the crater merged into a very steep funnel-shaped talus of loose materials, at the centre and bottom of which was the aperture of the tube or "chimney" of the volcano. This has been described by Hoffman as entering the funnel by three apertures. Judging from the form of the column of steam, dust, stones, &c., as seen at the first moment of ejection, the aperture appeared to me to be a single one, irregular in form, and with its longest dimension in the direction of the greatest width of the crater itself. Looking down from our position over the foreshortened slope of black débris which plunged into the sea 900 feet below us, the two jaws of the Schiarrazza are seen to be composed of huge broken-off beds of lava, which dip to seaward at various depths below the surface; these, partly by superficial decomposition, partly by being covered with serpulæ and corallines, are of a nearly white colour; and as we stood with the sun at our backs, the sea above these beds, at either side of the Schiarrazza, on which the sun was shining, presented the most glorious tints, varying with the depth of the water from golden-yellow to the purest emerald-green, while between these, and looking right down over the black slope of débris, the deeper sea was of an intense indigo, passing off into blackness. Nothing in the way of natural colouring and wild outline combined could exceed the weird horror and intense beauty of contrast when a burst from the volcano sent forth in the midst its volumes of white steam and dust, which, seen by the reflected light of the sunbeams shining through it, appeared of every tint of ruddy brown or blood-red. From what precedes, and by reference to Diagram No. 1, it will be seen that the bottom of the crater-funnel cannot be more than 300, or at most 400 feet above the level of the sea where the tube or tubes enter it, and that the statement made by Mr. Scrope ('Volcanos,' p. 332, 2nd edition), viz. "the lip of the orifice at the bottom of the crater is some 2000 feet above the level of the sea," is largely in excess of the truth. Were that a fact, the brim of the crater, which is 300 to 400 feet above the bottom, would be situated within a height of about 175 feet according to Smyth's measurement, or within about 300 to 400 feet according to my measurement of the highest point of the

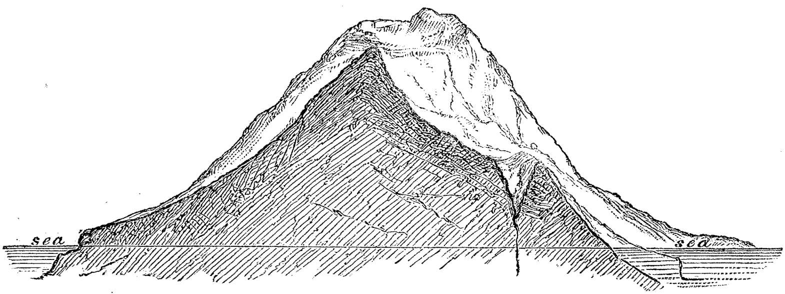
island, either of which is physically impossible. While we remained observing, the outbursts from the bottom of the crater were found to be very irregular as to time, varying, as timed by the watch, from a minimum of two minutes interval to a maximum of thirty minutes, and in one case, after we had commenced our descent, to forty minutes. I could not trace a very distinct correspondence between the largeness of this interval and the violence and volume of the outbursts following it, although the tendency seemed to be to such a correspondence; and the duration of the outburst was certainly greater as the interval between two was so. At each outburst a huge volume of dust and small material, and with more or less of large fragments of solidified lava, all angular or subangular, and with a few fragments and shreds of different sizes of lava still hot enough to be slightly plastic while falling, were ejected; none of the fragments were of any great size, none appearing to exceed in weight about 500 or 600 pounds, and none of the pieces of plastic lava reaching half this weight. The light wind blew from us towards the sea, out over which a portion of the finer dust was wafted after each outburst; but the great mass of the dust and fragments, whether small or large, fell back into the crater upon its bottom and steeply sloping funnel, a few only, and generally of the largest fragments, being thrown out over the crest of the crater at its sea side, and landing amidst the débris of the slope, down which they clattered. It was obvious that the orifice of the tube at the bottom of the crater was greatly obstructed by the loose material forming the funnel above it, which seemed after each outburst to be continually slipping, more or less *en masse*, and so blocking up the tube, along with the mass of ejected material which dropped back upon the orifice; for it was easily remarked that successive outbursts apparently took place from different points, distant occasionally some yards from each other, in the bottom of the crater—the main axis of the column, or its greatest thickness, varying thus in position, and also more or less diverging slightly from the vertical, sometimes one way and sometimes another, as though the ajutage of discharge was through loose material of partly large and entangled blocks, mixed with finer material, the positions of which were more or less altered after each discharge. None of the large fragments which we saw thrown out rose higher than the position at which we stood, and few even so high—that is, they did not rise more than 400 to 500 feet above the orifice at the bottom of the crater; but occasionally the height of projection must a good deal exceed this, as I found many angular fragments and large shreds of lava, which had fallen in a leathery or plastic state, to the landward and eastward sides of the brim of the crater, 150 feet or more above the level of our point of observation. The black sand and dust and crystals of augite are found in large masses still higher and further from the crater on the land side; but much of the latter are blown inland by the strong winds from the northward that prevail in winter. The solid mural precipices which form

the walls of the crater above the funnel of loose material consist of beds of solid lavas and agglomerated fragments, and appear to dip more or less towards the sea, or away from the centre of the island, and were no doubt formed by one of its great early and more central craters at a period excessively remote. *Suffioni* of steam issue in some spots from between these beds, and the percolation of water was seen in places not far below the brim of the crater. There is a perennial spring of percolated water much higher up upon the island, and under the steeps that mark the position of an ancient crater, so that it is highly probable that rain-water, in greater or less quantity, finds its way into the funnel, and even the tube, of the volcano, although the percolation of sea-water is no doubt the chief source of the supply, which is blown out as steam, and perhaps in part as pulverized water. Each outburst, while we continued to observe them, was preceded by several distinct low detonations, with intervals between each of from 4 or 5 seconds to as much as 80 seconds: these, though of a far deeper tone, greatly resembled the cracking noises that are heard when steam is blown into the water of a locomotive tender for the purpose of heating it. These detonations sensibly shook the rock beneath our feet.

The outburst, when it comes, does not rush forth quite instantaneously or like that of exploded gunpowder. It begins with a hollow growl and clattering sound of breaking or knocking together of fragments of hard material, which very rapidly increases to a roar at its maximum, continues at about the same tension for a period varying from a few seconds to a minute or two, and then rapidly declines, but less rapidly than the augmentation took place. At the first instant of the outburst, the rock on which we stood was very sensibly shaken, the vibrations being both vertical and more or less horizontal; at the end, and after the fragments have ceased to fall and the dust has cleared away, all tension of vapour in the tube seems for the moment at an end, and the funnel is seen filled merely with rolling clouds of vapour. The noise produced by the outburst is not very loud, and more resembles that of the rush of a heavy railway-train over an iron-girder bridge, when heard at some distance off, than any other sound to which I can compare it, but more fluffy and flat. On examining the existing surface of the island, it is easily discerned, by an eye educated to the observation of extinct volcanic regions, that successive craters have been formed, shifting their positions posterior to the production of that great and nearly central one from which the main mass of the island was thrown up. The existence of three such craters may be traced; and the existing little crater is situated at the landward or south-eastern side of a vastly larger crater, all the north-western or sea side of which has been destroyed and buried in deep water, and of which the heavy beds of lava seen under water at both sides of the Schiarrazza are the only remains to seawards of the existing slope of débris. This is represented by the Diagram No. 2, copied from my note-book, in which

the diagonally shaded portion represents an ideal section of the island as it now stands, taken through its highest point and the existing crater of Stromboli, while the lines beyond indicate the probable outlines of the island when the great crater was active, of which the Stromboli of to-day may be viewed as little more than a fumarole.

Diagram No. 2.



I may add here, in reference to the Lipari group generally, that all the islands present more or less distinctly these characteristics of craters whose axes have shifted and formed new ones at immensely ancient epochs, and with vast intervals of time intervening.

The entire group presents, though in various degrees in the different islands, the general character of great decadence of a once far more powerful volcanic activity; and, in every case, as the cone, or rather mound, of each island increased in mass and height, the original vent thus increasingly obstructed tended to move off and open new and easier vents in directions approaching the coast-lines, just as in the case of very old and massive volcanoes on land, such as Etna, migrations have occurred of their most ancient great craters, and, in more recent times, new ones have opened low down upon their flanks, such as Monte Rosso &c. The epoch of primordial activity was far from contemporaneous in all the islands; and we find in them now the most varied stages of volcanic decadence. In the island of Vulcano, we have an empty crater of enormous capacities and depth (1100 to 1200 feet), the bottom of which reaches to within a few feet of the sea-level, and is only separated from the shore-line at the north-east of the island by an extremely steep bank of compact tufa. The oldest craters having been situated much more centrally and far to the south-west, while the little crater of Vulcanello was thrown up to seaward of the ancient coast-line and between it and the deep crater just spoken of, boiling springs and boiling streams of superheated vapours issue below the sea-water, and a thermometer sunk amongst the pebbles of the beach in many spots rises to above 300° Fahr. In the bottom of the deep crater the principal " bocca," which is several feet in diameter, and though only blowing out superheated steam and gases with a mea-

sured sort of rise and fall in its snorting, is red-hot to the lips, which are of hard lava; and the temperature at the mouth I found, in 1864, was sufficient to melt brass wire, but not sufficient to fuse a similar wire of bronze (*i. e.* copper with about 5 per cent. of tin).

The falling-in of any considerable proportion of the walls of this grand crater, which, on the landward side, consist of nearly horizontal beds of volcanic rock and conglomerate, forming at that side a vast mural precipice, though almost wholly of compacted tufa for the remainder of its periphery, would easily give rise to a renewal of volcanic energy, such as nowhere exists now in the Lipari group.

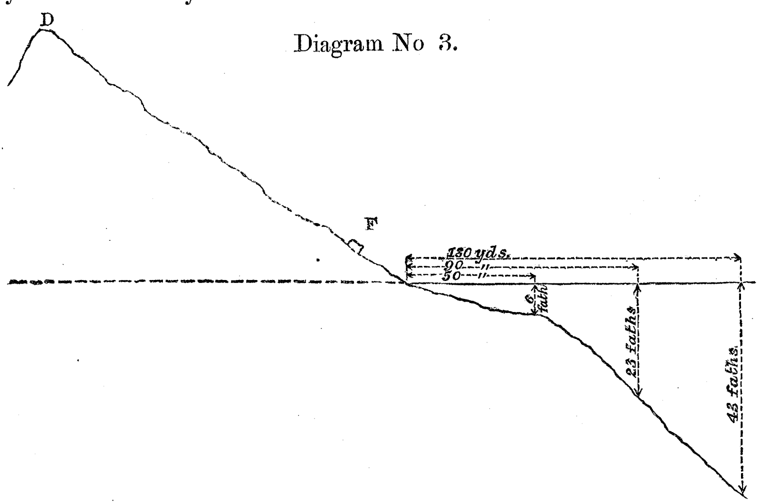
Stromboli is the next to this in existing energy; but though the persistence and character of its activity excite much more attention, the actual evolution of volcanic heat is greatly inferior to that constantly going on from the unobstructed "bocca" of Vulcano, which, if again obstructed, would produce very violent effects. In Lipari Island we have the traces of several great craters of extreme antiquity, the most recent being that which evolved the mountainous masses of pumice and the enormous stream of pumice and obsidian which falls into the sea at the north-east of the island; but the greatest sign of present activity is found on the shore at the opposite side of the island, at Il Stufi, where innumerable jets of hot water and superheated steam with sulphurous acid issue from the heavy beds of trachyte, which they rapidly decompose and convert into clays and hyalite.

In others of the islands, such as Panaria and Saline, no sign of activity remains, and the most practised eye with difficulty seeks to recover the positions or outlines of the very ancient craters. Lastly, in the small islands of Basiluzzo, in the low rocks of Liscanera and Liscabianca, and in the huge spire of Datola, formed of vertically parted and splintery trachyte of the most obdurate character, we have but the last shreds of one or more great volcanic islands which once occupied the shallow sea-spaces between all these islands, and probably connected them into a single vast cone. A hot spring still rises in water of 4 or 5 fathoms deep between Liscanera and Liscabianca, which possibly mark the site of one of the most recent of the craters at this spot, the islands which they formed, at a period too distant for imagination, having here almost disappeared under the eroding influence of the comparatively tranquil and tideless waters of the Mediterranean, aided perhaps by local subsidence, but of which there is little or no evidence. It will thus be seen that the change in position and decadence in energy ascribed to the existing crater of Stromboli, although for 2000 years its energy has seemed to be constant or not greatly diminished, are circumstances in complete accordance with the facts presented generally by the volcanic islands of the whole group. The existing tube of Stromboli, like that which leads to the "bocca" of Vulcano, has but a lateral and indirect and very much choked-up communication with those great central ducts which once gave vent to

the products of the great craters. Lava from these, generally imperfectly melted, but occasionally in a complete state of fusion, still finds its way from these into the upper parts of the existing tube of Stromboli, but in comparatively very small quantity.

On leaving St. Vincenzo we circumnavigated the island of Stromboli, and examined the slope of débris in Schiarrazza cove; the actual average angle of slope is much overrated by Mr. Scrope at 50° ('Volcanos,' page 32). By the clinometer it proved to be from 34° to 36° with the horizontal. The slope consists almost wholly of angular fragments, averaging but a few hundredweight each, and of shreds and tails of lava that have fallen in a semifused condition. Mixed with these, in a wholly irregular manner, are here and there sinuous and twisted flakes of lava. These have been often taken for dykes of lava forced out by hydrostatic pressure through the bank of débris, when the crater has been assumed brim-full of liquid lava; but I am not aware of any evidence whatever in support of the notion that this crater ever has been so filled. Its steep walls present no traces of the contact of liquid lava at any time since their formation; and it can scarcely be doubted that had the crater ever been filled with liquid lava to the brim, the loose and incoherent slope of débris would have been utterly unable to sustain the pressure, and must have been forced bodily into the sea, into which the mass of liquid lava must have followed it. The base of the slope appears to consist of solid and, no doubt, comparatively water-tight beds of lava, like those described, as seen from above, at both sides of the Schiarrazza; and but for these the existing crater could have never been formed, or its activity preserved, for it must have been drowned out by the inroad of the sea, as so many other and recent craters in the other islands prove to have been. The sinuous masses of lava seen at various parts of the slope of débris appeared to me no more than huge splashes of very liquid lava, which, in outbursts of greatly more than usual intensity (such as was one of those witnessed by Hoffman) and with a larger supply of lava than usual, were blown out over the crest of the slope and fell amongst the blocks of débris. Fresh deposits of débris obscure the features of most of these plashes; but I observed, in some cases, that the lava had distinctly moulded itself, like a mantle, to the sinuosities between and the forms of the blocks upon which it fell. Within a yard or two of the base, or water-line, of the slope were two blocks of lava of exceptional magnitude, the larger having a volume of 8 or 10 cubic yards. These blocks were confidently affirmed to us to have been projected during some violent burst forth and thrown clean over the crest of the slope, and to be in fact *blocs rejetés* thrown from the bottom of the crater; examination proved that they could be nothing of the sort. They were sharply angular, and all the surfaces had the crystalline texture of dark pyroxenic lava not very long fractured, except in some places, where distinct signs of weathering were evident in the larger block. Had they been *blocs rejetés*

they would have presented on all their surfaces and edges the more or less rounded outlines and extreme induration and closeness of grain due to long-continued torrifaction, which are the invariable characteristics of such blocks. The true history of these great blocks is, that they had been detached by the shakings of the outbursts from one of the steep cliffs of the ancient crater-walls which overhang the crests of the slope, and had thence rolled down to the position in which we found them at about F in Diagram No. 3, which is a section of the slope of débris and of the sea-bottom in line extending from its base. In this line we took a few soundings at distances from the water-line at the base of the slope, which we had to guess. These distances, as guessed by me, exceeded those guessed by Colonel Yule, though not very greatly; and I have preferred to adopt those derived from his military experience in guessing distances by the eye rather than my own.



It will be seen from these soundings that the statements made by the islanders, and wrongly attributed to Captain Smyth (see his 'Sicily' *in loco*), that the sea outside Schiarrazza cove is unfathomable, and hence swallows up the débris of more than 2000 years, is wholly erroneous. Indeed Smyth's soundings ('Sicily and its Islands'), as well as the Admiralty Chart, sufficiently indicate that for some miles in the offing here the Mediterranean does not exceed 100 fathoms in depth. The bottom along which I took these soundings consists of huge irregular and ovoidal masses, of 10 to 20 tons in weight, of volcanic rock, old and water-rounded. What, then, does become of the débris? Its quantity, in reality, is extremely small in a given time. A very large proportion of it consists of mere dust and glassy or angular lapillæ, and these, if blown seaward, fall at a considerable distance away, and are lost in the depths; those which fall nearer, including the fragments that form the average mass of

the slope, are slowly removed and carried out into deeper water by the under tow of the heavy seas in winter, and are lost in the chinks and crevices between the huge blocks at the bottom, which I found to be so deep and tortuous as often to render the extraction of the sounding-lead which had entered them difficult. The lava ejected by Stromboli, whether in the solidified or half-melted state, is extremely dark-coloured, almost black. It is highly pyroxenic and crystalline, and its fusibility is greatly increased by an intimate intermixture of dark obsidianic glass, of which particles as well as strings are met with everywhere. It is still leathery or plastic at a temperature considerably below a red heat, visible in daylight, and is probably in tolerably liquid fusion at a temperature not much exceeding 1200° Fahr. Its composition is by no means invariable, as may be seen on the slope of débris; and when the glassy material is very abundant, as from time to time seems to be the case, or from any of the causes which influence periodically the fluctuations of temperature more or less observable at all volcanic vents, this lava would become extremely liquid and be blown about by the outbursts in the way somewhat obscurely described by Hoffman, as well as urged in liquid flakes over the brim of the crater. The crystals of augite which are deposited in such abundance with the dust blown out may preexist in the lava, but appear to me, more probably, to be mainly formed by the disintegration of the hot lava by contact and churning up with water, under a considerable pressure and therefore high boiling-point, and perhaps by separation and recombination from solution of its constituents. The crystals, which are often an inch or more in length and frequently macled or cuneiform, have scarcely any lustre; and when the surfaces are closely examined with a lens, they are often seen to be minutely pitted with microscopic cavities. We now come to collect and correlate our facts and draw such conclusions as they warrant in explanation of the mechanism which produces the phenomena of Stromboli. The supply of water producing the immense volumes of steam constantly blown off at the rate, on the average, of three or four outbursts per hour may be derived in part from percolated fresh water; but this source alone, derived from the small gathering area of the island, would be wholly insufficient; and, were that the sole source, it would almost wholly fail towards the end of the dry season, so that a marked annual change in the volcanic phenomena must result, and could not fail to be observed. The supply of water, however, is manifestly regular, and very nearly constant at all times, and therefore is derived from the sea, and thus must enter the tube of the volcano below the sea-level—that is to say, more than 400 feet below the lip of the tube at the bottom of the crater-funnel. Whatever be the source of supply of the lava, therefore, it can never fill the tube as a solid column of melted matter reaching up to its lip; for in that case, whatever be the mechanism of the volcano at each outburst, the whole of this immense column of melted matter of more than 400 feet in height must be blown completely

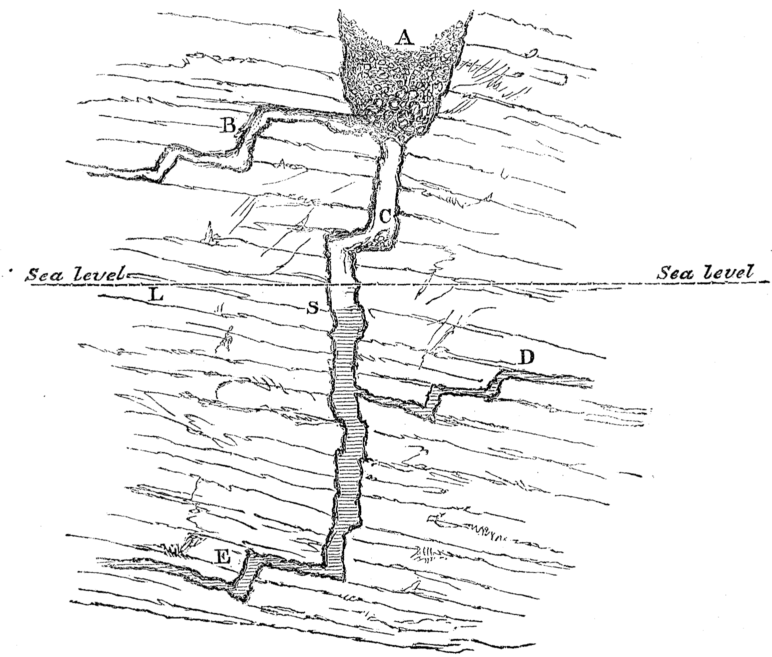
out of the tube, which actually is emptied, at the end of each outburst, of everything but gases and vapours, and these at a tension not greatly exceeding that of the atmosphere. We do not know the average section of the tube, and therefore cannot calculate the volume of lava that would be propelled thus out of the tube, if previously filled by each outburst; but it is manifestly so great that it would wholly change the character of the phenomena exhibited by the volcano, and must, during the last 2000 years, have produced a mass of ejected matter of enormous magnitude instead of the insignificant amount of mixed lava and débris which alone are to be seen.

Liquid or semiliquid lava does, however, continually make its way into the bottom of the crater-funnel and amongst the fragments collected there, which it more or less solders together, and along with which it is blown out at the outburst. Some may ooze into the tube lower down, and may more or less obstruct, but can never completely fill it. The walls of the tube, and those of all the fissures or cavities below the level at which the more or less fused lava reaches them, can scarcely have a lower temperature, and are most probably at a higher one than the lava itself. If the tube of the volcano were the main, or only, ajutage through which the liquid lava, as well as the steam to blow it out, were supplied—if, in fact, the tube were the main duct into the lowest depths of which both the liquid and vaporous matters entered—then, at irregular intervals, the tube, and even the crater, must become filled, and the whole phenomena of eruption would not differ in character from the highly irregular paroxysmal efforts of any common volcano of like energy. The tube, then, here plays a different part from what it usually does, and constitutes an additional element in its machinery, upon whose action in producing expulsion the rhythmical recurrence of the outburst depends.

We can now discern the very simple mechanism by which the actual phenomena are produced, a description of which will be rendered more intelligible by reference to the ideal Diagram No. 4, in which A is the lower part of the funnel of the crater, filled more or less with the fragmentary mass which has fallen back into it from the preceding outbursts. B is a lateral duct conveying more or less liquid lava into the bottom of the crater. C is the tube leading to the bottom of the funnel from a depth considerably below the sea-level, supposed to be, at the line L, at about 400 feet below the upper lip of the tube. D is a duct communicating with the sea, and enabling sea-water to find access to the interior of the tube, and to rise therein, if otherwise unimpeded, to the sea-level. E is either a lateral duct or a continuation of the tube itself, through which steam at a high temperature and tension enters the tube at some point much below the level of the sea. The lava- and steam-ducts, B and E, may be supposed to come from the ancient great volcanic channels still remaining under the more central parts of the island, and which supplied its great ancient craters. The duct D may consist of many

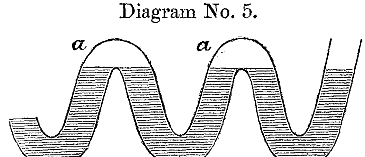
small fissures, permitting sea-water to percolate through the mass of consolidated and hardened volcanic rock, which, at this depth, constitutes the mass of the island, and in which all three classes of ducts or channels, B, D, and E, are formed, most probably between the partings of superimposed beds; or a single large duct may bring in the supply of seawater, and have such a form, however irregular, as to preclude the steam in the tube from blowing out into the sea, although having a tension many times greater than the direct statical head of the sea-water itself *.

Diagram No. 4.



All of the three ducts, B, C, and D, may be multiform, irregular, and varied to almost any extent, provided only that they retain their relative positions, and these only within certain large limits, as shown in the Diagram No. 4. Supposing an outburst finished, and its fragmentary matter partly returned to the bottom of the funnel of the crater at A, the required conditions of whose form are only such that the fallen-back

Diagram No. 5.



* The well-known phenomena of a tube repeatedly bent in a vertical plane filled with water, but containing air or vapour at the upper part of each of its bends, as at *a, a*, Diagram 5, described in almost all large treatises on hydraulics, may be referred to as sufficiently illustrating what has been above stated.

débris shall have some sort of landing-place and support for the larger portion of the mass, so as not all to drop into and permanently block the tube. The lava oozing from the duct, or ducts, B, escaping amongst these fragments, solders them more or less together; and in proportion as its rate of supply is greater or less, some of it may overflow and drop, in a more or less liquid state, into the tube C and into whatever water it may contain. The tube, however, is emptied at the outburst of nearly all that it contains, and the tension therein being that of the atmosphere, or little more, the sea-water again begins to fill it by the ducts D. This water is already probably considerably warmed in the ducts D; it receives accessions of warmth from the sides of the tube and from the continual blowing into it of superheated steam and vapours through the ducts E, whose temperature is probably not far different from that of the lava at B. The column of sea-water rises in the tube to a level, we will suppose S, by which time the boiling-point has been reached at the lowest point of the column, namely, that due to the statical head of water, and to all such obstructions above the lip of the tube as tend to hinder the escape and so increase the tension of the vapours and gases occupying the otherwise empty upper part of the tube. At such an instant, the whole column may be lifted through a few inches or feet vertically by the steam locally generated at the bottom of the tube; and as this incipient evolution of steam escapes upwards the whole column of liquid will be suddenly dropped back upon the bottom of the tube, to be again similarly lifted, and so on until every portion of the column of water has acquired the full boiling-point due to its depth, &c. This is the cause of the detonations heard before the outburst. As soon as this has been reached, the whole mass of water below S is driven violently upwards, and partly by its impulse, but mainly by actual steam-tension, drives before it the mass of obstructing matter filling the bottom of the funnel at A, and the whole is driven forth together in a mingled cloud of dust, stones, shreds of half-melted lava, steam, and pulverized water. When the tube is left empty, and after the fall back of the fragments, the whole apparatus is ready for a repetition of the process. It is obvious that the depth of the tube below the level of the sea, and the temperature of its sides and that of the steam entering at E, determine the force of the outburst, that the rate of supply of water and steam determine the intervals between the outbursts, and that the proportion between the volume of steam and that of pulverized water, at each outburst, depends upon the capacity (that is, the greater or less section) of the tube C. If that be narrow in proportion to its total depth, as is probably the fact, then very little water will be ejected in any state but that of steam. It is not necessary that the temperature of the column of water in any part of the tube C should ever reach the tension due to a temperature equal to that of the lava escaping from B; it only needs to be such as shall raise its own column to the lip of the tube and overcome the obstructions there encountered with a sufficient residual tension left to blow these a greater or less height

into the air. The augite crystals are probably formed within the tube, from small portions of lava dropping in a liquid state into the water it contains.

Reverting now to the remarks made at the beginning upon the relations traditionally said to exist between the phenomena of this volcano and the state of the weather. It is obvious that the notions of nicely balanced equilibrium in a tube always filled to the lip with liquid lava can no more account for any such relation with the weather than it can explain the rhythmical recurrence of the outbursts themselves; and if supposed relations with changes of weather, as alleged to be indicated by Stromboli, could be thus explained, every constantly active volcano in the world would be equally a "weather-glass." Kilauia, for example, must present upon an exaggerated scale all the weather-prognostics attributed to Stromboli. In examining the vague statements made upon this subject, we should bear in mind the extreme incapacity of ignorant peoples to observe phenomena with accuracy, their proneness to exaggeration, and the readiness with which they accept traditional statements, however improbable. The statements made to me by several of the more intelligent people of Stromboli as to the height to which stones were alleged to be thrown, viz. far above the highest point of the island, as to the filling of the crater brim-full with liquid lava (which, however, no one had actually himself seen), and the forcing through the slope of débris of vertical dykes thereof, as well as the projection of the huge blocks we saw at the bottom of the slope, and such like, should be borne in mind before we attempt to square theoretic views with statements of facts that probably have no real existence. The only intelligible statements that I could gather from the inhabitants of Stromboli as to relations between the weather and their volcano resolved themselves really into two propositions: first, that in fine weather the light reflected upwards from the crater was more brilliant, and apparent at a greater distance, than in windy or uncertain weather; secondly, that in cold and broken weather the light was diminished, and a heavy cloud of vapour hung more or less over the crater.

These are intelligible facts, and admit easily of being accounted for on well-known meteorological principles. A tendency, though not a marked one, to the production of sea- and land-breezes in the morning and evening is observable in these islands, the sun-heat during the day being often very great, as also the nocturnal radiation. These, taken in connexion with the prevailing direction of the wind at a given time, viz. whether it sweeps over the island and over the highest points from the southward and eastward, or blows against its steep north-western face and into the crater, will, by altering the state of the atmosphere above the latter, tend to produce changes both in the light and in the vapour-cloud of the volcano. But that there is any real connexion, in the way of direct cause and effect, between the energy or frequency of the outbursts and the state of the weather, or fluctuations of barometric pressure, or *vice versâ*, seems devoid of any foundation whatever.

Diagram No. 2.

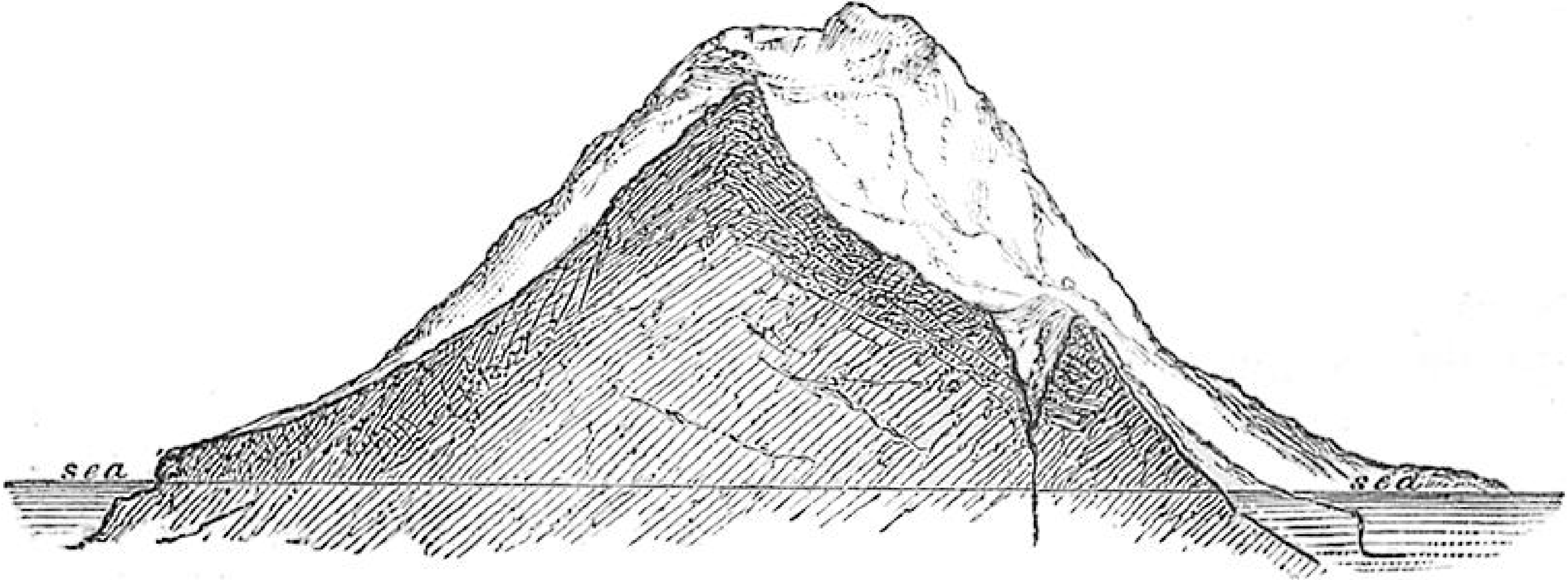


Diagram No. 4.

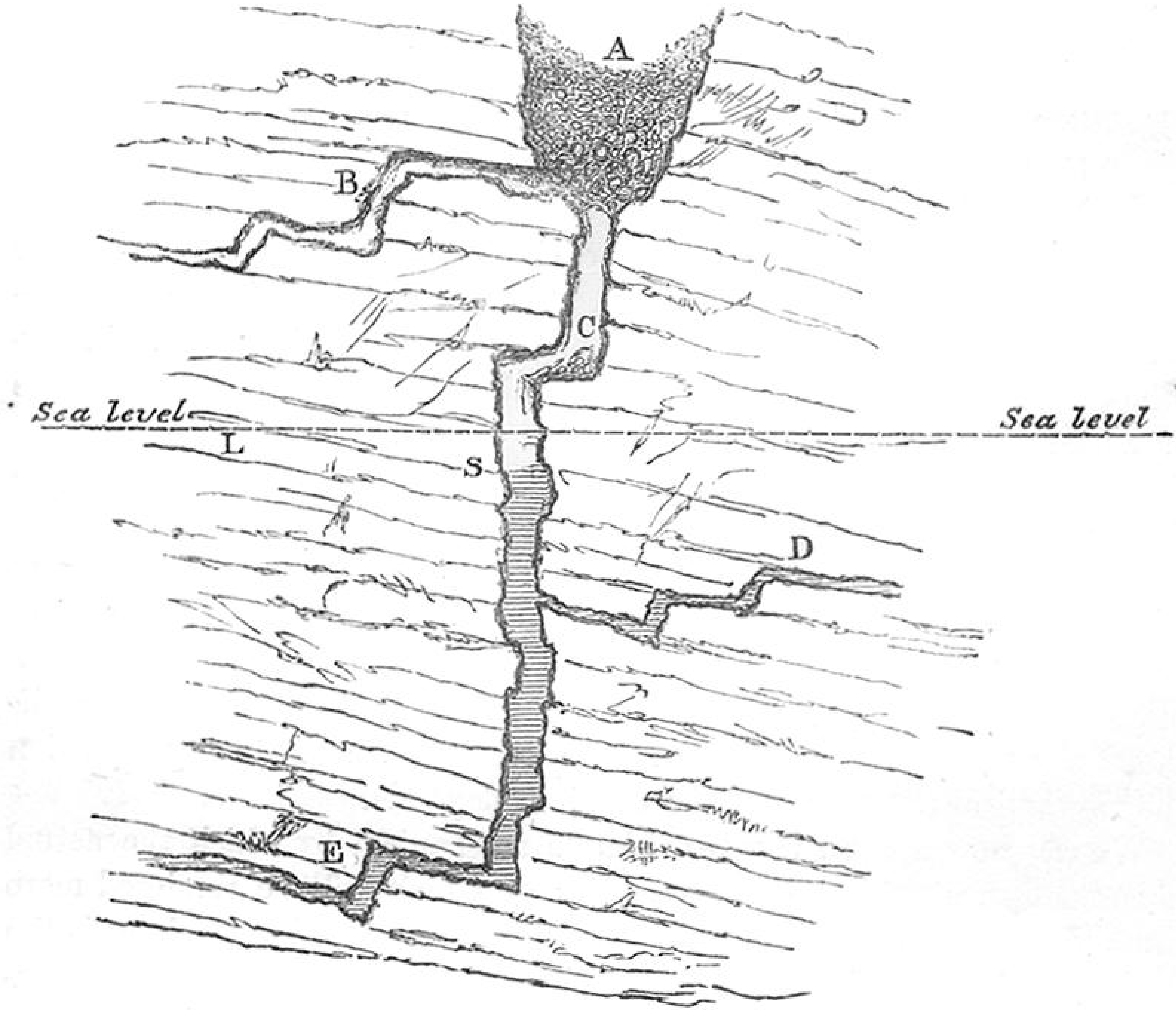


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Diagram No. 5.