M. le Professeur Renard
With the Author's kind regards

ON VOLCANOS.

[*Extracted from the* GEOLOGICAL MAGAZINE, January, 1875.]
Published by TRÜBNER & Co., 57 and 59, Ludgate Hill, London.

CONTRIBUTIONS TO THE STUDY OF VOLCANOS.

By J. W. Judd, F.G.S.

Introduction.

THE study of the nature and causes of the phenomena of volcanic activity, which for some time previously seemed to have almost fallen into abeyance, has during the last few years attracted the attention of many patient observers and earnest thinkers. In proof of this statement, we need only point to the valuable essays upon the subject which have recently been published by Dana, James Hall, Le Conte, Shaler, Hilgard, Sterry Hunt, and others in America, and to those by Mr. Mallet, Captain Hutton, the Rev. O. Fisher, and others in this country.

But while we cannot but regard with pleasure the revival of research in this important department of geological inquiry, it will be well not to overlook a source of danger in the direction which it seems to be almost exclusively taking.

The earliest speculations on the subject of Vulcanology belong to the domain of Cosmogony, rather than to that of Geology. With the smallest basis of knowledge of the actual phenomena of volcanic activity, theorists sought to build up "Systems of the Earth," in which recourse was freely had to igneous action to accomplish all such operations which were felt to be necessary for the removal of the difficulties of their hypotheses.

During the latter portion of the last century, however, the accurate study of the phenomena presented by active volcanos was commenced by Sir William Hamilton, Dolomieu, and Spallanzani, in that district of Europe where they are most admirably displayed, namely, Southern Italy. A little later Hutton, with his able coadjutors and exponents, Sir James Hall, Playfair, and Macculloch, sought to apply the phenomena of active volcanos to the explanation of the appearances presented by those ancient rocks, in which the signs of igenous action were clearly visible; and in no country could they have been more favourably situated for carrying on such researches than in Scotland.

In the two schools which we have thus noticed as taking their rise at no distant date from one another, in Italy and Scotland respectively, we have an indication of the two branches of inquiry into which the study of Vulcanology must necessarily tend to flow. A suggestive comparison may be draw between the investigation of volcanic action on the earth and that of vital action in the human body. In either case our opportunities for *direct experiment* are comparatively few; and in both, therefore, we are compelled to resort to indirect means in order to attain the desired results. To acquire an understanding of the nature and causes of vital action, one class of inquirers—the Physiologists—study the phenomena presented by the living body as it performs its various functions; while another class—the Anatomists—examine, in the dead subject, the machinery by which the various processes are carried on, and the structure which is built up by their operations. As in Biology, so in Geology, we have inquirers investigating, by the aid of mathematics, physics, and chemistry, the movements, products, and other attendant phenomena of volcanic activity—the Physiology of the Earth; while others devote themselves to researches connected with the position and relations of the masses which constitute it—the Earth's Anatomy; and these latter find in the ruins of extinct volcanos, and the intrusive masses connected with them, alike the mechanism and the products of igneous activity. There is, indeed, this difference between the study of the Anatomy of the *Microcosm* and that of the *Macrocosm*—that, while in the former we are able by dissection to examine the structure of its parts at our will, in the latter we can only attain our object by taking advantage of those revelations of its interior, effected by the conjoint action of subterranean movements and surface denudations.

It will not, perhaps, be doing violence to our comparison, if we venture to push it one step farther, and to remark that, as the progress of Biology has in recent years been very greatly furthered by the microscopic study of the minute tissues of which organized bodies are composed, so a new department of Geology has arisen—Micro-petrology, the homologue of Histology—which promises equally to advance our knowledge of the origin, nature, and succession of those series of changes which constitute the "life of the globe." The study of the internal structure of rocks by the aid of the microscope, the initiative to which was given in 1858 by Mr. Sorby's remarkable paper "On the Microscopical Structure of Crystals, indicating the Origin of Minerals and Rocks," has recently, in the hands of Zirkel, Forbes, Vogelsang, Rosenbusch, Allport, and a host of other enthusiastic observers, made most prodigious strides, and promises to afford the most valuable aid to geological research.

The first attempt at a general treatise on Vulcanology was that of Mr. Scrope in 1825. Unfortunately, while following out the two lines of inquiry which we have just indicated, and attaining many important results, the correctness and value of which have been established by subsequent investigations, the author permitted himself to be drawn aside from the true paths of geological inquiry into the speculations of Cosmogony. No one was more conscious of this blemish of his work than the author himself, as was shown by the subsequent publication of his well-known work, "The Geology and Extinct Volcanos of Central France," in which this error is most carefully avoided; and also in a second edition of his general treatise, in which the speculative portions are omitted. In the latter he has confined his researches within the true limits of geological inquiry, and the work remains the most complete and masterly treatise on the subject which has yet been produced.

In the "Principles of Geology" due weight has been assigned by Sir Charles Lyell to igneous action in producing the existing features of the globe. In order to illustrate the manner in which the phenomena presented by the rocks of the globe are capable of explanation by the operations now taking place on its surface, both the "physiological" and "anatomical" branches of the subject are treated with that force of argument, that justice of illustration, and that felicity of language, with which every geologist is familiar. Mr. Darwin's works on South America and the Volcanic Islands of the Atlantic may be regarded as additional and very valuable illustrations of the "Principles of Geology," the work which, as he has himself assured us, first led him into those lines of research in which he subsequently attained such preeminent success.

During the last fifty years innumerable very valuable contributions to both branches of the science of Vulcanology have been made. Geographers and travellers, physicists and chemists, mineralogists and petrologists, have accumulated the most valuable details, illustrating the nature and distribution, the characters and materials, the phenomena and products of active volcanos. Humboldt, von Buch, Hoffmann, Junghuhn, and others have occupied themselves with their general features; Gustave Rose, Abich, Scacchi, vom Rath, and Fuchs, with the rocks of which they are composed; and Daubeny, Deville, Fouqué, and Janssen, with the chemical operations taking place within them.

Equally valuable have been the labours of those physical geologists who have supplied us with detailed descriptions and accurate maps, illustrating the features presented by the older igneous rock-masses and their relations to the stratified deposits with which they are associated. Foremost in this category we must mention Charles Maclaren, who at so early a date described with admirable clearness the volcanic rocks in the neighbourhood of Edinburgh. The maps and memoirs of the Geological Survey, especially those relating to North Wales and Central Scotland, also afford very valuable illustrations of the older volcanic rocks.

In some of the latest researches on Vulcanology, to which I have referred at the commencement of this article, however, a tendency is shown towards abandoning these safer methods of inquiry, based on the doctrine of Uniformity, and reverting to the earlier methods—in effect, to the substitution of Cosmogony for Geology. In the ingenious theory elaborated by Mr. Mallet a still bolder course is adopted, and, almost entirely ignoring the results of geological inquiry, this author endeavours to build up on the foundation of the nebular hypothesis of Laplace, and by the aid of those laws of Physics which he regards as fully established, a system of "Vulcanicity." Had the Physical Sciences attained their final stage of development, Mr. Mallet might perhaps have been justified in taking such high ground as he does in dealing with one of the natural sciences; but when we find that not a few of the data and principles of calculation on which he relies are disputed by authorities of equal eminence with himself in their special departments, geologists may be forgiven for thinking that the tone assumed by him in dealing with this subject was scarcely warranted. Nor is their confidence in the value of his speculations increased, when they find him arriving by means of them at conclusions totally at variance with the clearest results of geological observation,—such, for example, as that ordinary explosive volcanic eruptions did not take place during the Palæozoic period!

We are far from denying the advantage of inquiries and speculations of this character. It cannot but be of interest to the student of Geology, and at the same time calculated to afford him suggestions in the carrying out of his investigations, to see how far the conclusions at which he has arrived by direct observation can be made to harmonize with the hypotheses based on the latest results of Physical Science. But, as these latter are continually undergoing modification and development from the progress of research, we must ever be on the guard against allowing such theories to have undue weight, or being supposed capable of replacing the methods of geological inquiry, at first so well developed by Hutton, and afterwards so clearly illustrated by the labours of Lyell, Scrope, and Darwin—methods based on the principle that the explanation of the phenomena of the past can only be obtained by a study of the operations which are still going on around us.

In giving a series of sketches of the structure and phenomena of some of the most interesting volcanic districts in Europe, we shall endeavour, as far as possible, to avoid all subjects of a purely speculative character, and it will be our chief aim to direct especial attention to those features which suggest analogies with the volcanic formations of former geological periods, and appear to be calculated to throw light on the nature and succession of those operations by which these latter have been originated. While dwelling, however, upon the more general features of geological structure and igneous action, in our descriptions of the several districts, we shall endeavour not to lose sight of any of those results of chemical, mineralogical, or microscopical research which appear to throw light upon the subjects of our studies. Our object, in short, will be to confine these studies within what we have indicated as being the most important and legitimate paths of geological inquiry,—namely, the investigation of the structures and operations of extinct and active volcanos, with a view to arriving at the laws which have governed the developments and manifestations of igneous forces, alike in past geological periods and during the existing epoch.

I.—The Lipari Islands.

There is certainly no district in Europe, and perhaps none in the whole world, which affords such beautiful illustrations of the phenomena of volcanic action, and at the same time offers such remarkable facilities for their investigation, as the little group of

Mediterranean islands lying between the Phlegræan Fields of Calabria and Sicily. Etna, it is true, presents us with the monuments of igneous forces acting upon a grander scale, and Vesuvius excites a livelier interest by its historical associations, its fossil cities, and its proximity to a splendid capital; but neither of these volcanos can vie with those of the Lipari Islands, either in the remarkably suggestive features of their structure, in the permanent and interesting characters of their operations, or in the variety and beauty of their products.

Nor have the advantages here presented to the geologist been neglected by the pioneers of our science. Sir William Hamilton, Dolomieu, Spallanzani, and Scrope have, by the study of their active and extinct vents, contributed much towards our knowledge of the *modus operandi* of volcanic forces; Hoffmann, Allan, and Abich have described the interesting rocks of which the Lipari Volcanos are composed; while the last-mentioned author, with Daubeny, Charles Ste.-Claire Deville, Fouqué, and Janssen, have investigated the nature and products of the chemical actions going on within them.

The geological interest attaching to the volcanos of the Lipari Islands has induced the French Academy to send out, on several different occasions, commissions charged with their investigation. Many undertakings, which in other countries require an appeal to the resources of the Government, are in our own safely left to individual enterprise; and Mr. Scrope, who more than fifty years ago experienced and called attention to the advantages which the Lipari Islands offer as objects of study, has furnished several students of volcanic geology, myself among the number, with the opportunity of carrying on researches in them.

As no general sketch of the geology of the Lipari Islands has been published since the admirable, but now somewhat obsolete, work of Friedrich Hoffmann, which made its appearance in 1834, it has been suggested to me that an account of some of the results of my own studies there in the spring of 1874 would be of interest to the readers of this Journal. The sketch which we are here able to give must, of course, be mainly descriptive, and it will be impossible, within its limits, to enter into detailed discussions of those numerous problems of volcanic geology, towards the solution of which this interesting group of islands affords such valuable materials.

The name by which this group of islands (a Sketch-map of which is given on page 7) is generally known is derived from its central, largest, and most populous member. An earlier designation, and one which is still often applied to them, is that of "the Eolian Isles," and there is a curious interest attaching to its derivation. The original Eolus appears to have been a prince or chief of the Greek colony which inhabited these islands, and, being probably a man of superior intelligence and shrewdness, he seems to have acquired some fame by employing the two active volcanos of his dominions as natural "weather-glasses." Stromboli is still believed by the Liparotes to respond, like a barometer, to changes of atmospheric pressure; and the characters of the vapour-clouds which rise both from it and from Vulcano are, unquestionably, indicative of hygrometric variations. The power of forecasting events is, by the vulgar mind, often confounded with that of bringing them to pass; and the hero or prophet of one generation becomes the demigod of the next, and the deity of succeeding ones. Hence it is not surprising to find Eolus invested, in later mythologies, with the dignity of "God of the Winds." Such is the account of the origin of the name as given by some eminent Italian scholars; but those who have experienced the fierce and sudden storm of the seas surrounding the Eolian Isles may perhaps be disposed to adopt a simpler explanation of the identification of these islands with the blusterous deity.

The group of the Liparis consists of seven inhabited islands and a great number of small islets and rocks. The whole of these are entirely composed of volcanic materials, and two of the islands, Vulcano and Stromboli, contain still active vents; in the others, craters and lava-streams, in various stages of freshness or ruin, testify to the former scale of igneous operations within them; while active fumaroles and hot springs indicate forces not yet wholly subdued.

In describing the geological structure of the Lipari Islands, it may be well to notice the several rock-masses in what appears to be their chronological order of formation. As in the case of the classical district of the Auvergne, this order of succession in the volcanic outbursts is sufficiently indicated by the varying extent to which the different formations have suffered from denuding forces, and the relations which they everywhere maintain towards one another.

A careful study of the district seems to prove that at one time there existed a great central volcanic mountain, now, like the volcano of Santorin in the Ægean sea, in great part submerged, and reduced to a few islands representing the crater ring. Radiating from this great central volcano, three fissures appear to have been originated, and at various points along these fissures volcanic cones were thrown up, and numerous eruptions took place. Finally, the apparently dying energies centred in this volcanic district have become localized at two almost extreme points, giving rise to volcanos so opposite in their mode of action and in the characters of their products, as to suggest questions of the highest interest to the geological inquirer. It must of course be borne in mind that these three periods of volcanic outbursts, though sufficiently well characterized for the purposes of geological classification, are merely different phases in the display of the same igneous activity; and that, as they do not appear to have been separated by periods of quiescence, they are by no means sharply and clearly divided from one another.

While Stromboli stands unrivalled as an example of a volcano in the phase of permanent moderate activity, offering facilities for quiet study, (of which the distracting sensations of overwhelming grandeur and personal danger can scarcely fail to deprive the observer, in the cases of volcanos in more violent stages of eruption), Vulcano furnishes us with a most admirable and easily accessible

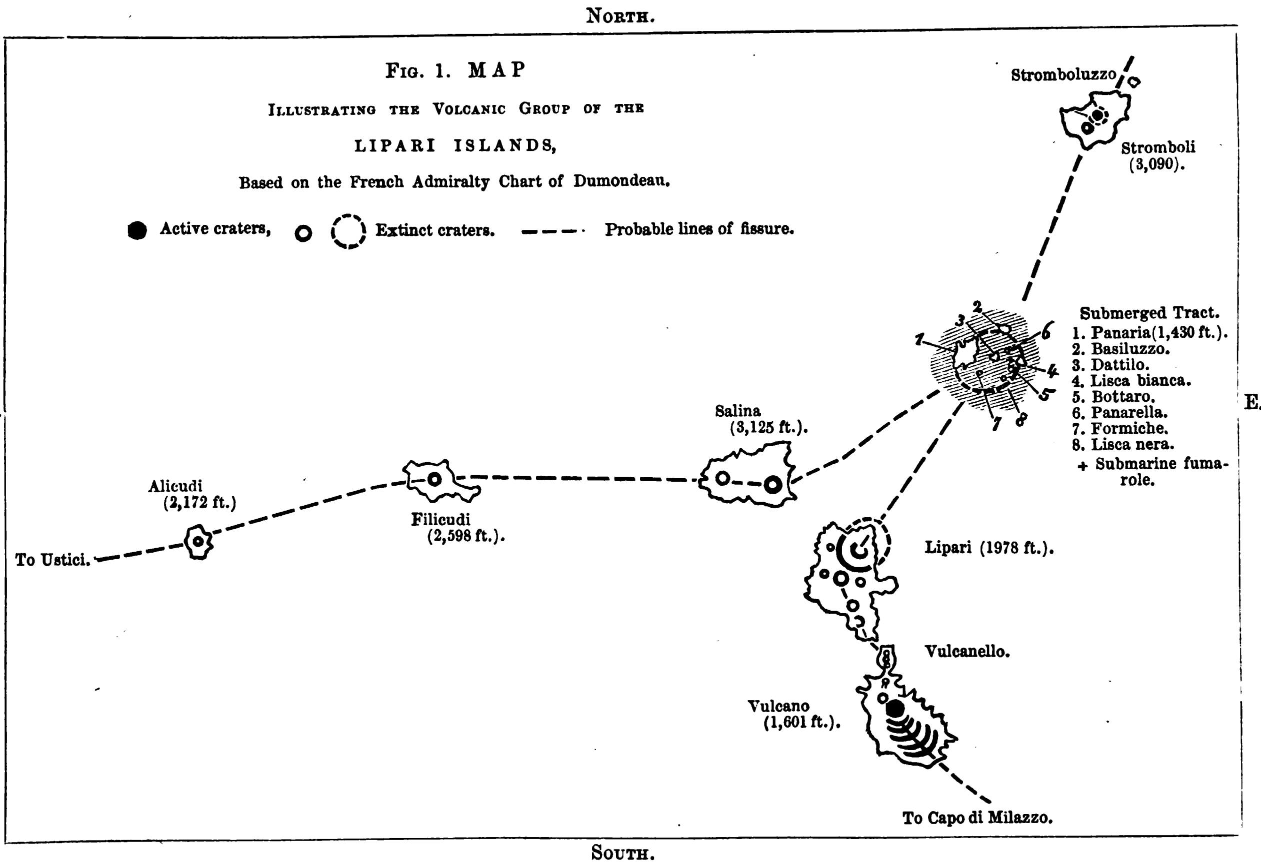


FIG. 1. MAP

ILLUSTRATING THE VOLCANIC GROUP OF THE

LIPARI ISLANDS,

Based on the French Admiralty Chart of Dumondeau.

crater, in the Solfatara condition, remarkable alike for the abundance and variety of its gaseous emanations, and for the beauty of the minerals which result from them, but at the same time subject to paroxysmic outbursts on the grandest scale. In all the islands we find the most beautiful illustrations of the constant shifting of centres of volcanic action along lines of subterranean fissure, and the most instructive examples of the wide diversities in the characters of lavas, from those of the most highly silicic or acid composition to those of the most ferruginous and basic, and from the highly crystalline varieties on the one hand, to perfect glasses on the other.

The analogy between the relations and order of formation of the great central volcano and the surrounding lines of volcanic vents in the Lipari Islands on the one hand, and the ruined volcanos of Central France, namely, the Mont Dore, the Cantal, and the Mezen, and the long chains of "Puys" surrounding them, on the other, must strike every student of volcanic geology, and is a sufficient justification for our adopting the following order in our descriptions of the Lipari volcanic formations :—

I. The great central volcano now almost entirely submerged, and of which we have only a few highly ruinous relics in Panaria and the surrounding islets.

II. The chains of extinct and more or less degraded cones which constitute the larger part of the other islands.

III. The very remarkable features and the interesting products of the still active or but recently extinct vents in Stromboli, Lipari, Vulcano and Vulcanello.

IV. Our sketch of the district will appropriately conclude with descriptions of the remarkable phenomena exhibited by Vulcano and Stromboli respectively, and a history of the changes which have taken place within them during the periods concerning which we have authentic records.

1.—*First Period of Volcanic Activity in the Lipari Islands.*

The submerged tract (see Map, p. 7) which marks the probable site of a great central volcano in the Lipari Islands is composed—judging from the nature of the islands and rocks which still rise above the sea-level—of various materials of the trachytic class. These occur in the form of tuffs and agglomerates, of lava streams, and of solid masses of enormous dimensions, which appear to have been extruded in a viscid or pasty condition in the manner so common with rocks of their class.

In the disposition of the materials in this central group of islets the student of volcanic geology at once recognizes those forms so characteristic of partially submerged and greatly denuded crater rings, which are so well exemplified in the ruined volcanos of Santorin in the Ægean Sea, and of Ventotiene, one of the Ponza Islands (*vide* Scrope's 'Volcanos,' 2nd ed. p. 209). As shown in the sketch (Fig. 2), the inclined streams of lava, with their alternating beds of tuff, which doubtless once constituted the sides of a great cone, gradually built up by their successive emission, now exist only as

FIG. 2.—Panaria and the surrounding Islands, as seen from Monte della Guardia in Lipari.

1. Panaria. 2. Spinazzola. 3. Basiluzzo. 4. Dattilo. 5. Bottaro. 6. Lisca bianca. 7. Stromboli, seen in the distance from the South.

isolated fragments, such as Basiluzzo, Dattilo, Bottaro, Lisca nera, and Lisca bianca, each of which presents the peculiar wedge-like forms so characteristic of the denuded segments of old crater rings. Some of the lava masses in this tract, especially those of Basiluzzo and Dattilo, exhibit a rudely columnar structure. Panaria was supposed by Dolomieu to afford traces of an old crater in its central valley, but this point seems to me, at best, very doubtful. The great mass of highly crystalline rocks of which this island is composed is probably, like the central trachytic bosses of Astroni and Rocca Monfina, to which it presents striking resemblances in chemical and petrological characters, the product of an outburst of highly viscid materials which have accumulated immediately around the volcanic vent, instead of flowing as lava streams; this result being due, as in the analogous examples of the domitic puys of Auvergne, to the imperfect liquidity of the rock at the time of its emission.

The lavas of the central volcano of the Lipari Islands have long been celebrated for their remarkable petrological characters. Composed of one or more species of felspar, with hornblende or mica, and some free quartz, their highly crystalline character led some of the early observers to class them as granites. On the other hand, that they were erupted near the surface, and in many cases under no very great pressure, is shown by the glassy and pumiceous characters which portions of their mass assume. Hence they have been described as exhibiting all the transitions from granite to pumice.

In their chemical characters these peculiar rocks offer points of as great interest as in their petrological structure. From true or ordinary ("quartzfrei") trachytes, with a specific gravity of 2·6, and an average per-centage of silica of about 62, they graduate in one direction up to the rocks designated by Abich as trachy-dolerites, with a specific gravity of 2·75, and a silica per-centage of 57; while in the other, by exhibiting a smaller specific gravity with a higher per-centage of silica and some free quartz, they approach the quartz-trachytes. These extremes of composition are exhibited in the rocks of Lisca nera, Lisca bianca, and Dattilo, on the one hand, and in those of Basiluzzo on the other. They are illustrated by the following analyses made by Abich:—

	Lava of Lisca nera, etc.	Lava of Basiluzzo, etc.
Specific gravity	2·7752	2·4008
Silica	57·67	67·09
Alumina	11·94	17·36
Oxides of Iron and Manganese ...	6·71	0·81
Lime	7·72	1·23
Magnesia...	7·02	1·20
Soda	not determined.	4·10
Potash		8·27

Two specimens of trachyte taken from Panaria were determined by the same geologist to have specific gravities of 2·6754 and 2·7225, and per-centages of silica of 64·37 and 61·39 respectively. A third variety from the same island was found to closely approximate to the rock of Basiluzzo in composition.

From these analyses it appears that the central volcano of the Liparis, so far as its rocks are open to our observation, consists of various trachytic materials approximating to, but never reaching, the basalts on the one hand, and the quartz-trachytes on the other.

The only signs of volcanic activity still exhibited by this vast central volcano, the antiquity of which is sufficiently indicated by its greatly denuded and altogether ruinous condition, consists in an insignificant sub-aerial *stufe*, in the island of Panaria, and a submarine *fumarole*, situated in the channel between Lisca nera and Lisca bianca. The occurrence of this still active vent of volcanic energy in the midst of the submerged and altogether ruined crater of the Liparis may be paralleled with that which exists in the midst of the similar crater of Santorin, which is, however, in a far more violent stage of action, and has given rise to eruptions that have attracted so much attention during the last few years. The submarine fumarole of the Liparis, which is opened in the white pumiceous rocks of the sea-bottom at a depth of 25 feet from the surface, pours forth considerable quantities of carbonic acid and sulphuretted hydrogen gases, the bubbles of which produce a beautiful effect in rising through the clear blue Mediterranean waters and cause the sea to appear in a state of ebullition. As an amusing instance of the power of imagination, we may mention that in a recently published and popular book of travels, the authoress describes in very graphic language the sensations of scalding which she experienced on thrusting her hand into this "boiling water"!

2.—*Second Period of Volcanic Activity in the Lipari Islands.*

Turning our attention to the second period of igneous activity, which has been characterized in the Lipari Islands, we find that we shall have to refer to it by far the larger portion of the rocks of the group. Constituting the entire masses of the islands of Salina, Filicudi, and Alicudi, they form also the basis of those of Lipari, Vulcano, and Stromboli, in which, however, they are to some extent buried and concealed under the products of the third and latest period of eruption.

The materials ejected during the second period consist of lavas and the agglomerates, tuffs, and ashes derived from them—the accumulations of fragmentary matters generally greatly preponderating in quantity over the solid rocks; which latter, nevertheless, in consequence of their greater power of resisting denuding forces, often constitute all the most prominent and conspicuous parts of the islands.

Nearly the whole of the lavas of the second period belong to the trachytic class, but there appears to be a constant tendency in the later formed of them to approximate towards the rocks of the basaltic type. This gradual change in the character of the lavas is well exemplified in the series of successive cones and craters so well displayed in the southern part of the island of Vulcano. As an example of the composition of the lavas of this period, we may instance the rock constituting the central mass, and forming by far the larger part of Stromboli, which Abich found to possess a specific gravity of 2·7307, and a per-centage of silica of 61·78.

The lavas of the second period may be divided into three classes, examples of all of which may be found in each of the islands in which the products of this period are developed.

A.—The most abundant of these varieties are the ordinary trachytes, usually rendered of a highly porphyritic character, by the dissemination through their mass of scattered crystals of sanidine, but occasionally compact and granular in texture, and sometimes exhibiting banded and ribboned structures. These old trachytes are often found assuming red and purplish tints on weathering, and then exactly resemble in appearance, as they also do in chemical constitution, many of the "porphyrites" of ancient geological periods.

B.—A somewhat less common but very beautiful form assumed by these trachytes is that of a dark grey or almost black granular base, through which crystals of sanidine are diffused; by the passage of the granular or stony base into a more or less perfect vitreous condition, the rock assumes the well-known characters of a "pitchstone-porphyry." This rock—of which beautiful examples are found in the lava-streams issuing from the old ruined crater of Monte Sant' Angelo, constituting the highest point of Lipari, above Tivoli in the same island, and also near La Malfi in Salina—forcibly recalls to the mind the precisely similar varieties of rocks, so abundant at Beinn Shiant and the Scùr of Eigg in the Western Highlands of Scotland.

C.—The third variety of the Lipari trachytes finds its exact analogue in the celebrated Arso lava of Ischia, which has been so admirably described by Fuchs. Its base is similar to that of ordinary trachytes; but scattered through its mass in greater or less abundance occur crystals of augite, mica, and magnetite, with grains of olivine, which impart to the rock a more basic composition, and cause it to approximate towards the trachy-dolerites of Abich. Trachytes of this third class are found in Monte Rosa in Lipari, near Rinella in Salina, and in great abundance and variety in the southern part of Vulcano.

One of the most interesting features of the Lipari Islands is the series of wonderful changes which their rocks have undergone, in consequence of the passage through them, subsequently to their eruption, of acid gases and vapours. By this means the hard and crystalline trachytic lavas of Lipari have, over very large areas, been reduced to a soft, white, earthy material, to the eye exactly resembling chalk; in other cases they have assumed the carious and open crystalline texture of the "alaunstein" of German petrologists; while in others again they are found less altered, and presenting the most beautiful variegated tints. Similar changes may be seen taking place in the lava of Olibano, where it issues from the crater of the Solfatara of Naples, but in Lipari they are far more complete in character, and on a much grander scale.

The accumulations of fragmentary materials which constitute the larger portions of the mass of the Lipari Islands exhibit also many varieties of character. It is interesting to notice that, while we have no proof from included shells or other marine remains of any part of these tuffs having been accumulated under the sea, but, on the contrary, find the clearest evidence, in the leaves and stems of terrestrial plants which they so abundantly yield, that a part at least of them were accumulated under sub-aerial conditions, yet they almost always exhibit some signs of stratification, and not unfrequently, indeed, are very finely laminated. In explanation of this circumstance, however, it is only necessary to point to the materials, certainly of sub-aerial origin, which cover Pompeii, and to the ashes ejected from Vesuvius in 1872 and still enveloping its cone, both of which exhibit an unmistakably stratified or laminated character. The remembrance of these facts may serve to prevent us from too hastily inferring the sub-aqueous origin of volcanic tuffs occurring among ancient geological deposits, from their stratified appearance. Of beautiful examples of false-bedding, unconformable stratification, and similar appearances due to the action of local causes, innumerable interesting examples might be adduced from among the deposits of fragmentary volcanic materials in the Liparis.

In respect to their structure, these accumulations sometimes present the character of agglomerates made up of angular blocks, including some of vast dimensions, of all the varieties of lava before mentioned, mingled with volcanic bombs, scoriæ, lapilli, and ashes. At other times they are composed of materials of more uniform character and constitute tuffs; while not rarely they are made up of fine volcanic sand or dust and form beds of ash. These latter are usually of a chocolate brown colour, and often contain white specks, which are probably decomposed fragments of felspar crystals.

Near Bagno Secco, on the western side of the Island of Lipari, beds of rather fine-grained tuff or coarse ash are found, between the laminæ of which beautifully preserved leaves and stems of plants occur, in much the same manner as at Somma.

To the student of British geology the analogy presented by these modern leaf-bearing tuffs with those of Miocene age at Ballypalidy in Antrim, and at Ardtun in Mull, not only in the characters of their materials and in the state of preservation of the fossils, but in the particular groups of plants represented in them, such as planes, poplars, willows, flags, sedges, and horse-tails, is very striking. The best preserved examples of the beautiful fossil plants of Lipari were formerly obtained at an almost inaccessible point of the cliff near Passo della Scarpa; but the adventurous Liparote, who used to obtain them, having lost his life in one of his attempts to reach the spot, it is now rather difficult to obtain good specimens. Fragments of stems and leaves, however, abound at several points, and can be procured without difficulty by any moderately good climber.

The tuffs, etc., of the second period of volcanic activity in the Lipari Islands have suffered, equally with the lavas which accompany them, from being traversed by acid gases and vapours. The action of sulphurous acid on the lime of these volcanic rocks has given rise to the formation in them of beautiful veins of selenite, accompanied by Misy and other basic sulphates of iron, which are found intersecting them in all directions. As an illustration of one among the many difficulties, the like of which we may not unnaturally anticipate experiencing, when seeking to define the exact character of some volcanic products of former geological periods, I may mention that, in some cases the bands of finer-grained ash in Lipari are converted into an intensely hard rock of jaspery aspect, and with a conchoidal fracture, to which—but for its mode of occurrence, its gradation into the ordinary tuffs around, and the plant-remains which it not unfrequently contains—probably no geologist would dream of attributing its true mode of origin.

Of the lavas and tuffs of the second period of volcanic action in the Lipari Islands, a number of volcanic cones are built up, the craters of which, though usually clearly traceable, are often in the last stage of ruin and decay. Of these cones and craters we may instance the islands of Alicudi and Filicudi, each of which is a volcanic mountain rising directly out of the sea to the heights of 2,172 and 2,598 feet respectively, with vestiges of craters at their summits; in Salina we have the two similarly ruined volcanos of Monte Porri (2,850 feet) and Monte Salvatori (3,125 feet), the highest summit in the Lipari Islands; in the island of Lipari the lavas and tuffs we are now describing compose the Monte Sant' Angelo, the culminating point of the island, with its great axial crater and several smaller lateral ones on its eastern and western flanks; in Vulcano the period is represented by the series of ruined craters, forming all the southern parts of the island, and culminating in Monte Sarraceno (1,601 feet): and, lastly, the central cone of Stromboli, having an elevation of 3,090 feet, with the doubtful crater at its apex, and the much clearer one on its southern flank, also belongs to the same period.

In examining these old and much denuded craters, of which that on Monte Sant' Angelo (represented in Fig. 3) affords an excellent

Fig. 3.—Ruined Crater of Monte Sant' Angelo in Lipari, as seen from the summit of the Monte della Guardia in the same island.

example, the stratified arrangement of the tuffs, with converging dips in their interior parts and diverging ones exteriorly, a feature so characteristic of the structure of all volcanic cones (see Scrope's 'Volcanos,' 2nd ed. p. 60), is often very admirably displayed. The lava-streams can often be traced to their points of issue from the craters, but are sometimes cut up by denudation into isolated masses, capping hills composed of tuffs, like the plateaux of Ischia and the Auvergne. The lavas everywhere exhibit the characteristic slaggy or scoriaceous upper and under surfaces, and are often seen to rest on beds which are burnt to a bright red colour. The masses composed of soft tuffs are often furrowed by deep ravines, which render some parts of the islands almost impassable, but which, when accessible, afford the most beautiful illustrations of the structure of the volcanos.

But it is in the sea-cliffs of some of the islands, and more especially in those of the southern and older part of Vulcano, that we find the most instructive examples of that interlacing of agglomerates, lava-streams and dykes, which constitutes the characteristic architecture of volcanos. Not even the cliffs of Somma or the precipices of the Val del Bove can compare, in this respect, with the faces presented to the sea on the eastern, southern, and western sides of Vulcano, where the mountain has been deeply eaten into by the encroaching waves (see Fig. 4). For anything approaching in beauty and completeness to the wonderful sections here exhibited, we must go to the ruined and dissected volcanos of the Hebrides.

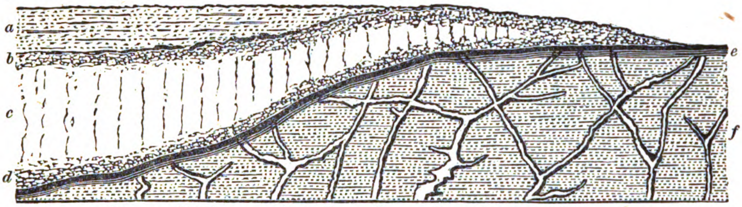


FIG. 4.—Section near Quaglia on the south-west coast of Vulcano.
a. Rudely stratified tuffs. *b*. Upper scoriaceous surface of lava stream. *c*. Compact central part of same. *d*. Scoriaceous under-surface of lava stream. *e*. Bed of burnt tuff of bright red colour. *f*. Tuffs traversed by many dykes.

That periods of great duration must have elapsed since the formation of the series of volcanic products which we have been describing, is indicated alike by the great amount of denudation which they have undergone and by the fact that they are covered by a younger series of deposits, some of which have themselves suffered not inconsiderably from the same cause. That, on the other hand, they are of no great antiquity, from a geological point of view, is shown by the fact that the vegetable remains imbedded in them all belong to well-known species of the Mediterranean area.

That movements of subsidence, similar in kind but less in degree than that which appears to have submerged the great central volcano of the group, must have taken place, in the case of the smaller and encircling cones, is shown by the relations which many of the lava-streams bear to them, as is particularly well seen in the coulées which form the peninsula of Monte Rosa, and which have evidently flowed from Monte Sant' Angelo. But that the movements which have taken place in them have not been uniformly those of depression, is also demonstrated by the existence around the shores of some of the islands of beautiful raised beaches, some of which are at least 100 feet above the sea-level. Of such raised beaches we have fine examples at the Rocca Piramida in Lipari and on the coast of Salina between La Malfa and La Capo (see Fig. 5).

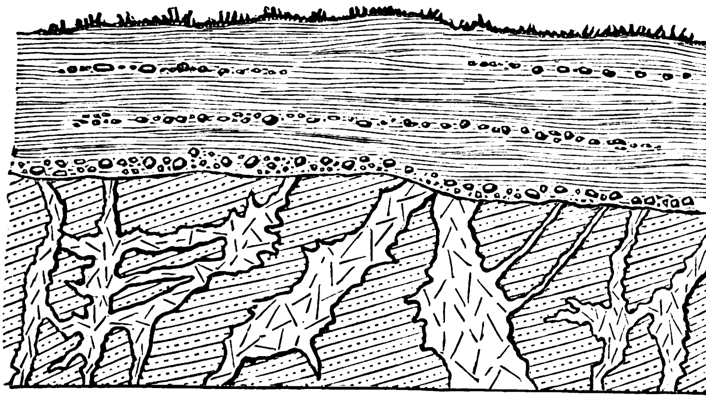


Fig. 5.—Interesting section at La Capo, the north-east point of Salino, exhibiting tuffs traversed by numerous dykes of lava and overlaid by stratified materials derived from them. (Raised-beach.)

We must postpone to a future communication the description of the remarkable linear arrangement of the volcanic vents of the Lipari Islands, when we hope also to give an account of some of the characteristics and products of the last series of igneous outbursts in the district.

3. *Third Period of Volcanic Activity in the Lipari Islands.*

Although, as we have already seen, the older volcanic formations of the Liparis present us with features of no little interest, yet it is on account of the cones and lava-streams, composed of rocks of singular beauty and almost unique character,—which are the product of the *latest* developments of igneous action in these islands, that the attention of geologists is most frequently directed to them.

Lofty cinder-cones, composed of snowy pumice, their vast craters breached by lava-streams of solid glass, seemingly fresh as when the fiery flood leaped from the volcano's throat, and poured with slow and tortuous current down its flanks; wide-spreading lava-fields, their horrid bristling surfaces coated by a reddish-brown crust, but exposing in grand cliff-sections the most marvellous combinations of variegated rocks;—these seen rising amidst the bright blue waters of the Mediterranean, and displayed in that clearness of outline and that vividness of colouring which only the brilliancy of an almost tropical sky can impart, constitute scenery of startling novelty and wondrous beauty—the impressions produced by which it is as hopeless to convey as it is impossible to forget. Nor is the geologist disappointed by a nearer approach to these remarkable scenes; every blow of his hammer revealing fresh examples of singular rock-structure, novel groupings of crystallized minerals, and lively illustrations of the multiform products which result from the action on rock-masses of the ever-varying combinations of many forces,—such as heat, chemical affinity, crystallization, pressure, tension, and the disengagement of imprisoned vapour and gas.

But before entering on a description of some of these remarkably interesting volcanic cones and lava-streams, composed of pumice and glass respectively, it will be well to pause in order to notice the very striking *linear arrangement* affected by the volcanic vents belonging to both the second and the third periods of igneous action in these islands. For nowhere, perhaps, is this constant feature of the development of volcanic forces—so unmistakably suggestive of the existence of subterranean fissures—more admirably and clearly illustrated than in the Lipari Islands.

Commencing with the southern part of the Island of Vulcano (see map, p. 7), the observer, standing on the summit of the Monte Saraceno, will have no difficulty in perceiving that there lie before him the remains of at least four different volcanic cones and craters, which have been successively formed through the continued shifting of the eruptive vent to more northerly positions. The great central cone of Vulcano, with its magnificent active crater, is evidently thrown up on a continuation of the same line. But an attentive study of this cone and crater-ring clearly indicates to the geologist that they are not the product of a stationary vent; on the contrary, we find clear evidence that the cone has been more than once partially destroyed by explosion and its crater re-formed. Indeed, portions of at least three successive crater-rings, which must have been clearly excentric with one another, can be easily traced. It is interesting to notice that the last eruption of this volcano (which, as will be described in a future chapter, took place only a year ago) threw up cinder-cones at the bottom of its great crater, not, however, at its centre, but at its extreme northern limit.

Again, we have proofs of the opening of a vent, still a little farther to the north, in the actual walls of the great cone, in the beautiful little crater called the Fossa Antico. The Faraglione, situated between Vulcano and Vulcanello, is a mass of volcanic agglomerates, in which mineral deposits of great beauty and value have been developed, in consequence of the permeation of the mass by acid gases and vapours; it is now burrowed over, like a rabbit warren, by the excavations which serve as houses for the workmen employed in the chemical works in the adjoining great crater; this mass of tuffs is clearly the greatly denuded and ruined vestige of a cinder-cone. Thus we find that in the island of Vulcano there exists evidence of the opening, along a single line, of at least *nine* different vents, which have given rise to eruptions differing very greatly in violence and duration.

On a continuation of the same line, we find in Vulcanello, now joined to Vulcano by a bank of cinders, three other well-marked craters. The features presented by Vulcanello are illustrated in the accompanying sketch (Fig. 6). Of these craters the newest is

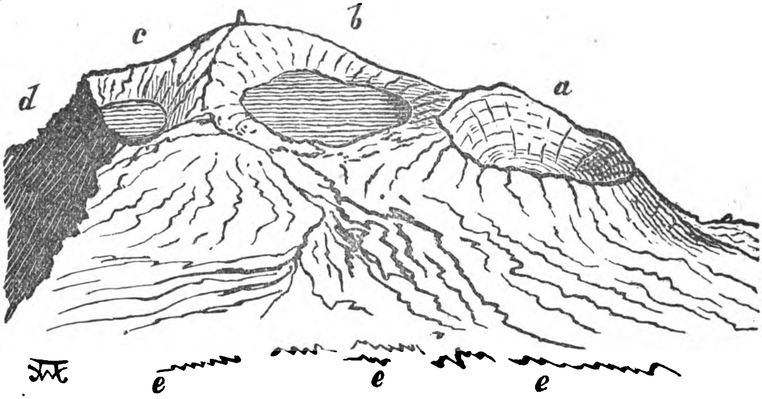


FIG. 6.—Vulcanello with its three craters as seen from the south end of the Island of Lipari. *a*. Most modern crater. *b*. Central, largest, and oldest crater. *c*. Portion of third crater. *d*. Section of cone in sea-cliff. *e*. Lava-stream.

clearly that which occupies the most southern position, and which was in all probability due to an eruption during the historical period. The most northern of the three craters of Vulcanello has had one-half of its periphery removed by the encroachments of the sea, and here we actually find a clear section of one of these small volcanic cones, as represented in Fig. 7. The central crater of Vulcanello is the largest, most ruined, and probably the oldest of the three.

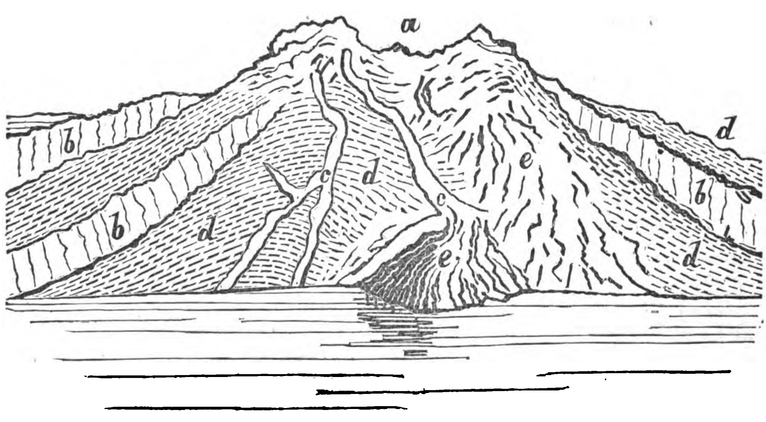


FIG. 7.—Section of cone of Vulcanello in sea-cliff (*d* in Fig. 6). *a*. Crater. *b*, *b*. Lava-streams. *c*. Dykes which have clearly formed the ducts through which lava has risen to the crater. *d*, *d*. Stratified volcanic tuffs and agglomerates, exhibiting the characteristic arrangement of the interior of volcanic cones. *e*. Portions of cliff concealed by taluses of fallen fragments

The island of Lipari must be looked upon as only accidentally separated from that of Vulcano and Vulcanello; the same line of volcanic cones and craters which we have described in the latter being clearly continued in the former. In the southern part of the island of Lipari we find at Punta Capparo, Formiche, Monte della Guardia, and Fossa del Monte, weathered and unmistakable craters and lava-streams, composed of materials of highly acid or siliceous character, namely, pumice and quartz-trachyte (Liparite), passing into obsidian, perlite, retinite, etc., and evidently belonging to the latest period of volcanic eruption. The central parts of the island of Lipari are entirely composed of the tuffs and lavas of the second period; these are, however, as we have already seen, much altered by the gaseous emanations, still represented by the hot mineral springs of San Calogero and the stufe of Bagno Secco, which must be assigned to the third period. The great central crater of Monte Sant' Angelo (see Fig. 3, page 14) is thrown up on the same great line of fissure which we have been tracing to the southwards; but on the west and east sides of it respectively we find the smaller lateral craters of Mazza Carusæ and Monte Perrara or Forgia Vecchia, the latter belonging to the latest period of eruption.

The northern part of the island of Lipari, like its southern extremity, exhibits a fine series of pumice cinder-cones and lava-streams of volcanic glass graduating into Liparite, evidently of recent origin, and forming a continuation of the same north and south line of vents. These we shall presently describe in greater detail.

Thus we have clear evidence that along a line, directed towards the earliest and great central volcano of the Lipari group, at least *twenty* distinct vents, giving rise to volcanic cones and craters of varying size, have been formed. It seems probable, as suggested by Hoffmann, that the volcanic products of Capo di Milazzo may be regarded as a continuation of the same line.

The twin volcanos of Salina (the Didyma of the ancients) with those of Filicudi and Alicudi are evidently situated on another line, which may perhaps be produced to Ustica. This line also radiates from the same central volcanic mountain.

Lastly, in Stromboli, with its linear arrangement of old and recent craters, and in Stromboluzzo, doubtless the last relic of another volcanic pile, we see evidence of a third string of volcanic vents, the direction of which points to the same great centre of igneous activity.

That the linear arrangement of volcanos, such as we have described as so well exemplified in the Lipari Islands, points clearly to the existence of great fissures in the earth's crust, along different parts of which eruptions have successively taken place, has been recognized by all geologists. Indeed, in the fissures produced at Etna during the recent eruption (1874), as described by Professor Silvestri, of Catania, in the earlier eruptions of the same mountain in 1669, 1811, and 1819, and in many analogous cases, we have had ocular demonstration that such is the case. Fresh proofs of the correctness of this conclusion are afforded by the great fissures filled with volcanic materials, with which all geologists are familiar, as traversing older rock-masses where exposed by denudation.

Nor must we forget that the volcanic band, which has been indicated as passing through the great central vent of the Liparis and Stromboli, would, if produced, strike the great earthquake-shaken tract of Calabria, and by a slight deflection pass through the volcanic districts of Southern and Central Italy; while the southern continuation of the same, passing through Lipari, Vulcanello, and Vulcano, points to Etna, the Val di Noto, and the volcanic islands lying south of Sicily. These facts are interesting, as indicating that Von Buch's classification of volcanos, according to their mode of arrangement, in linear systems and groups, cannot be sustained. All volcanic action appears to be developed along lines of fissure, though these may present very varied relations and connexions with one another, I shall take occasion, hereafter, to show that the principal of these combinations assumed by volcanic lines of fissure may be classified as radial and parallel series.

The fissures of the Lipari group afford an interesting example of the radial arrangement, with some illustration of the production of lateral or branching fractures on either side of the principal ones. The whole, however, being probably a subordinate part of a great band of subterranean volcanic action.

It is a most interesting circumstance, and one by no means devoid of suggestiveness to the geologist, that the two active volcanic vents of the Lipari Islands are situated at distant, almost indeed extreme, points of the group; and that while one of them, Stromboli, ejects materials of the most highly *basic* character—dolerite and basalt—the other produces rocks of extremely *acid* composition, quartz-trachyte (Liparite) and obsidian. The striking differences in the specific gravities of these two classes of rocks has been commented on by many geologists. As every great volcanic area may fairly be supposed to have beneath it a reservoir of materials in either an actually or potentially[1] liquefied state, we may, without adopting Durocher's notions of *universal* acid and basic magmas, suggest a possible explanation of the peculiarities of the existing volcanic phenomena of the Lipari Islands. If we imagine the area to be underlaid by a reservoir of liquefied materials which is of intermediate composition, this might have supplied the products of all the earlier eruptions of the district; and it is only necessary to suppose that, by the action of gravity, the materials (magmas) of different densities were in process of time separated from one another, while distinct fissures were opened connecting the upper and lower portions of the mass, respectively, with different parts of the surface,—to see that just such phenomena as now take place would be called into play.

[1] By a rock in a *potentially* liquefied state, I of course mean one which, either from its elevated temperature or its condition of internal tension from imprisoned volatile constituents, would assume a liquid form on being relieved from the pressure which maintains it in a solid state.

Reserving for a future occasion, when some other volcanic districts have been described, all general remarks upon the classification of the products of volcanic action, we may notice that the modern lavas of the *northern* fissure (Stromboli and Stromboluzzo) produce rocks of the most typical basic character, namely, basalts and dolerites. Abich's analyses of these lavas gave the following results—their specific gravity being between 2·86 and 2·96.

	Lava of Stromboli.	Lava of Stromboluzzo.
Silica	50·25	53·88
Alumina	13·09	12·04
Oxide of Iron	10·55	9·25
Oxide of Manganese...	0·38	—
Lime	11·16	7·96
Magnesia	9·43	8·83
Soda (with some Potash)...	4·92	4·76
Loss	—	2·78

The second of these rocks appears to have undergone a certain amount of alteration.

These doleritic lavas appear to consist mainly of an aggregation of nearly equal proportions of crystals of Labradorite felspar and augite, to which variable quantities of magnetite and olivine are added in different examples.

As is usually the case with igneous rocks of basic composition, the lavas of Stromboli only very rarely assume the vitreous condition. The scoriæ which are ejected from the active crater of Stromboli, at intervals of a few minutes only, sometimes fall so near to the observer that he can approach them while still in a soft and plastic condition, and thrust coins or other hard objects into them. These cinders are found on examination to be perfectly stony in character; but they are completely full of vesicles, formed by the escape of volatile materials from their midst, and they usually inclose nearly perfect and very beautifully formed crystals of augite—sometimes of considerable size. But besides the scoriæ, showers of volcanic sand also fall around the observer standing beside the crater of Stromboli. This volcanic sand proves on examination to be, like the similar materials ejected from Mount Klut in Java in 1864, and from the volcano of Georg in the Gulf of Santorin in 1866, both of which were submitted to microscopical examination by Vogelsang, an aggregate of more or less broken and rubbed crystals of augite, felspar, olivine, and magnetite, with comminuted fragments of scoriæ.

Around the sides of the crater of Stromboli crystals of augite can be collected in great abundance; they are usually macled, and sometimes form beautiful stellar groups and other interesting combinations. These are doubtless in part ejected directly from the crater, but in other cases result from the breaking up of the light cindery fragments in the midst of which they were inclosed at the time of their ejection. That these crystals were actually formed *within* the volcanic vent there is not the smallest room for doubt.

That Stromboli has in comparatively recent times given forth streams of basaltic lava of very considerable magnitude is clear to any geologist who studies the fresh and undecomposed fields of lava

(Sciaras) which surround the island. Sometimes this lava assumes the finely columnar structure so common in rocks of this class. Thus, a very fine series of columns is exhibited at Punta Labronzo, the northern point of Stromboli, and ruder ones at Punta del Uomo, on the south-east of the island. On the extremest verge of this latter lava-stream is situated one of those little shrines, which, in spite of the apparent inaccessibility of its position, has its burning lamp constantly replenished. The voyager in these seas is startled when, on reaching these spots, the wild cries and strange songs of the boatmen are suddenly hushed, all engaging for a few moments in silent devotion to the saint who is supposed to warn, by means of this primitive and not very efficient lighthouse, the mariner who approaches these inhospitable shores.

The products of the modern eruptions along the *southern* line of fissure—that, namely, which extends beneath the islands of Lipari and Vulcano—offer, as we have already remarked, the most striking contrast to those of Stromboli. These lavas belong to that highly silicated class so well illustrated in the Ponza Islands, the Euganean Hills, and Hungary. The highly acid lavas, to which the name of quartz-trachyte is usually applied, but which by Roth were called "Liparite," and by Richtofen "Rhyolite," are in their ultimate composition almost identical with the granites; and when highly crystalline, are seen to be composed of precisely the same constituent minerals—namely, several species of felspar, orthoclase being always predominant, free quartz, and variable quantities of hornblende or mica. By the peculiar *arrangement* of their materials, however, the highly silicated lavas are well characterized; and in their internal structure they present features which almost always serve to distinguish them from the granites, with which they were by early geologists so frequently confounded.

In illustration of the ultimate composition of these highly acid lavas of Lipari, we give the following analyses of Abich, with which others by Berthier and Klaproth closely agree:

	Obsidian of Lipari.	Pumice of Lipari.
Silica	74·05	73·70
Alumina	12·97	12·27
Oxide of Iron	2·73	2·31
Lime...	0·12	0·65
Magnesia	0·28	0·29
Soda...	4·15	4·52
Potash	5·11	4·73
Water	0·22	1·22
Chlorine	0·31	0·31

The specific gravity of the obsidian is 2·3702, and of the pumice 2·3771. When in its most completely stony condition, the rock has a specific gravity of 2·53, and consists almost entirely of orthoclase felspar, quartz, and hornblende, in about the following proportions:

Felspar	77	per cent.
Quartz	18	„
Hornblende or Mica	5	„

In the less compact or stony and more cavernous varieties of

Liparite, the ordinary hornblende and mica crystals do not appear; but instead of them, we find in the mass grains of magnetite with groups of acicular, filiform, or capillary crystals, which we should at first sight refer to *Breislakite,* but which, considering their association, may probably be regarded as a variety of *hornblende*, bearing the same relation to the Amphibole series which Breislakite does to the Pyroxene series.

In striking contrast to the basic lavas of Stromboli, the highly acid lavas of the Lipari and Vulcano constantly tend to assume the vitreous condition; some of the lava-streams being, indeed, composed of solid volcanic glass. These glasses in turn frequently assume a more or less pumiceous structure, through the inflation of their materials with blisters and bubbles, as a consequence of the disengagement of those volatile constituents which the researches of many chemists show that obsidians so abundantly contain. The cones formed of the ejected fragments of these newer volcanos of Lipari and Vulcano consist of fragments of typical pumice. So excellent and abundant is the pumice of Campo Bianco in Lipari, that it is sent to all parts of the world; and its collection, preparation by drying, and exportation, constitute one of the most important sources of wealth to the islanders.

Mingled with the white pumice, which constitutes fragments of every conceivable size, there occur numerous volcanic bombs, in which every stage of the transition from obsidian to pumice can be admirably studied. The exterior surface of these bombs is covered with a crust of solid obsidian, which is usually cracked into a number of polygonal fragments; but, as we pass towards the centre of the bomb, blisters gradually increase in number, till the centre is found to be composed of a mass as light and porous as a sponge. Bombs of this character, sometimes many feet in diameter, and which have been usually broken by their fall, are found scattered around the active cone of Vulcano, and are in all probability the product of its last grand eruption in 1786.

The wonderful variety of the acid rocks of the Liparis arises from the fact that every possible gradation between the stony, vitreous, and pumiceous characters, may be observed in them. The liquefied material may, according to the conditions of its consolidation, assume one of three forms, Liparite, Obsidian, or Pumice, or it may form a material in which the diverse characters of these three products are united in the most singular and unexpected combinations.

Some of these remarkable and interesting varieties, which may be well studied at Rocche Rosse, Monte Perrara, Monte della Guardia, Fossa del Monte, Punta Capparo and many other points in Lipari, and in the great modern lava stream of Vulcano, it will be necessary briefly to notice.

First Series.—The most perfect glass is found passing by insensible gradations into rocks of less strikingly vitreous lustre—pitchstones or retinites—and thence through materials of pearly or porcellanous appearance into the most perfectly stony and crystalline, almost indeed granitic, masses. This series of changes is effected without the appearance in the mass of any definite arrangements of crystallites.[1]

Second Series.—Much more frequently, however, the passage from the vitreous to the stony series takes place by the appearance in the mass of scattered "sphærulites," composed of radiating crystals of felspar, entangling others of quartz, magnetite, and other minerals. Occasionally these sphærulites are found scattered in a promiscuous manner through the vitreous matrix; but, far oftener, they assume very striking and definite arrangements; these are clearly seen to be the result of the conditions of pressure, tension, and slow-dragging movements to which the slowly consolidating mass was subjected. Sometimes the alternate laminæ of vitreous or colloid and stony or crystallized materials have assumed a parallel arrangement, and the rock is almost as perfectly *cleaved* as a piece of slate; at others they assume all the beautiful wrinklings and corrugations so characteristic of metamorphic *foliated* schists. The light which these remarkable products throw upon the mode of formation of many of the older rocks will be illustrated on a future occasion.

Third Series.—At times the obsidian base of the rock is porphyritic, that is to say, it has crystals, often large and well formed, most commonly of brilliant sanidine, but not unfrequently of quartz, hornblende, or black-mica, floating through its mass. It then assumes the characters of an "obsidian-porphyry" (porphyritic obsidian). No one can study this rock, as exhibited in Lipari, without being convinced that the crystals which it contains were ejected, ready-formed, with the lava as it issued from the volcanic vent. Not only is there no trace of crystals in various stages of formation, as in the case of the sphærulites, etc., but sometimes pumiceous masses, evidently blown out of a volcanic vent, may be found entangling just such perfect crystals. We shall not at present enter on the discussion of those interesting problems which the phenomena of these perfect crystals of minerals of such different degrees of fusibility, floating in the same liquefied highly siliceous magma, must suggest to every geologist. We shall only notice, in this place, that the combinations of these ejected crystals with those gradually developed in the mass by the growth of crystallites, the whole modified by the peculiar mechanical conditions to which the masses have been subjected, result in the formation of rocks of wonderful diversity, exquisite beauty, and remarkable suggestiveness to the petrologist.

Fourth Series.—Fresh complexities of rock structure are originated and new varieties of lava produced, when, in either of the kinds already noticed, disengagement of volatile materials in the midst of the mass began to take place. The vesicular cavities thus originated were variously modified by the strains and movements to which the plastic mass was subjected. The most stony and highly crystalline, as well as the most vitreous varieties of these lavas, are thus affected

[1] The exceedingly beautiful and clear obsidian of Lipari, like that of Mexico, has been employed by the ancient inhabitants of the island for cutting instruments and weapons.

by the more or less complete disengagement of their volatile constituents; and while in the former, cavities originate which are occasionally lined with the most beautifully developed crystals of the component minerals of the rock,—in the latter, a laminated structure is produced, the planes of which sometimes coincide with, but not unfrequently cross, those produced by the devitrification of the mass under pressure.

But this attempt at a classification is far from exhausting the varieties of the beautiful quartz-trachytes of Lipari. New forms are originated through masses of obsidian being broken up and entangled in a stony matrix, or by glassy streams enveloping stony or perlite fragments, or, as is not unfrequently the case, by their catching up in their flow angular fragments of lavas of different composition, and belonging to earlier periods of eruption. Thus are originated the most singular brecciated structures, and rocks of very peculiar and, at first sight, puzzling character are produced.

When, however, these rocks are studied by the aid of the microscope, new features of interest continually make their appearance, only a very few of which it will be possible to notice in this place.

In the most clear and translucent volcanic glasses which have yet been examined, the beginnings of the process of *devitrification* can always be detected. Minute acicular crystals of felspar (Belonites) are seen, which, in a later stage of development, assume rectangular forms and ruin-like terminations, and thus gradually approximate to the ordinary characters of sanidine crystals. Other acicular or filiform crystals of hornblende (Trichites) appear and combine into radiating groups or tree-like masses of marvellous beauty. Where these crystals reach the surface of a cavity in the lava, free development of them often takes place, and we are enabled to study their nature and characters with the greatest facility.

Most frequently, however, the crystals unite in radiating masses, giving rise to those globular concretions known as *sphærulites*. In some cases the formation of these sphærulites has been determined by the liberation, in the midst of the vitreous mass, of an infinitesimal bubble of volatile matter. By the development of these crystalline globules with such exquisitely beautiful concentric and radiated internal structures, the peculiar forms and distinctive opalescent lustre of "perlite" is originated.

Nowhere, perhaps, can better materials be found for illustrating the development of these peculiarly interesting structures in vitreous rocks than in Lipari. Some of the pearlstones of this island, as, for instance, that of the lava-stream above Canneto, contain sphærulites of the size of peas. To attempt anything like an adequate account of the varieties assumed by the crystalline interiors and semi-vitreous envelopes of these, would require numerous figures and an amount of detailed description which would be out of place in these sketches.

It is in the northern part of Lipari that we find the best examples of the volcanic cones, craters, and lava-streams of the latest period of eruption in the Lipari Islands.

Supposing a furnace containing many millions of tons of liquefied glass were allowed to pour forth its contents in a stream extending to a length of some miles, and to a thickness of hundreds of feet, what would be the nature of the phenomena attending its outburst, and of the products which would result from its gradual solidification?

This is no idle problem; for the solution of it may be found by the geologist at Campo Bianco and Rocche Rosse.

Campo Bianco or Monte Pelato is a volcanic mountain (see Fig. 8), composed entirely of the whitest fragmentary pumice, the highest portion of the crater-ring of which rises to the height of more than 1500 feet above the sea-level. This is partially embraced (as is Vesuvius by Somma) by the relics of an older and far larger cone of the same materials, which culminates in Monte Chirien, having an elevation of nearly 2000 feet. The soft white pumice tuffs of the flanks of both these cones have suffered greatly from denuding forces, acting on their light and incoherent materials, and giving rise to those long furrows producing the "umbrella form" which is admirably exemplified in them. The crater of Campo Bianco presents at its bottom a flat plain, covered with comminuted pumice-tuffs, and now forming a most productive vineyard at a level of 892 feet above the sea; its walls rising almost vertically around it to heights of from 400 to 600 feet on the northern, western, and southern sides. On the north-eastern margin of this crater, however, a petrified cascade of vitreous lava rises 100 feet above the crater-floor, and, sweeping away all that side of crater-wall, has poured with a current, half a mile in breadth, down to the sea. This lava-stream, now covered with a reddish-brown coating from the oxidation of its iron, is the Rocche Rosse. Near the point where it issues from the crater, a deep "bocca" exists, once evidently the place of discharge of powerful steam-jets—now an awful pitfall, which the islanders avoid and speak of with terror. The surface of the lava presents a most striking example of those rugged cooled surfaces, like the *Cheires* of the Auvergne, and presents one of the wildest and most desolate scenes which it is possible to imagine. The traversing of it is in many places a very difficult task.

Other similar cones, craters, and lava-streams abound in Lipari. On the western side of Monte Chirien, at an elevation of more than 1700 feet, is a second crater, much ruined, that of the Piano dell' altra Pecora; and on the south side of Campo Bianco is another, that of Forgia Vecchia, or Monte Perrara, at an elevation of 968 feet, from which another stream of vitreous lava flows to the sea. At the head of this lava-stream no less than three mouths communicating with abysses of unknown depth, similar to that of the Rocche Rosse, are seen. They doubtless mark the sites of explosive discharges of steam. At Canneto is an older stream of perlite, which probably flowed before the present crater of Campo Bianco was formed.

The craters of the southern part of the island of Lipari give rise to lavas similar in composition to those of the north end of the island. In the former, however, the stony characters predominate

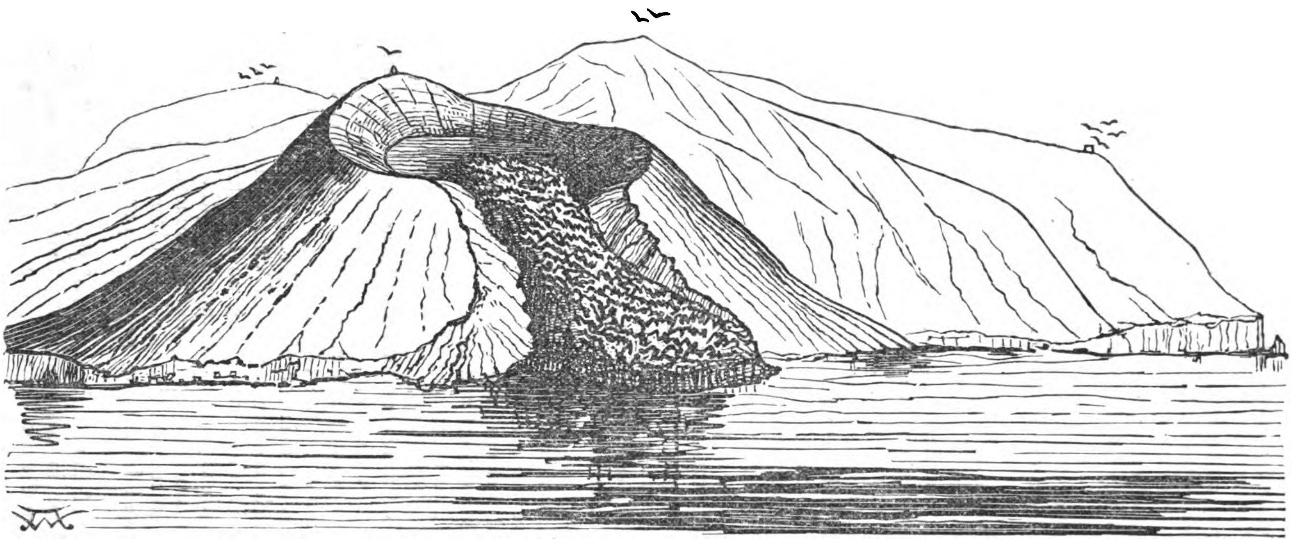


FIG. 8.—View of the breached crater of Campo Bianco, with the lava-stream of Rocche Rosse, seen from the sea.

Monte Pelato ; Monte Chirien ; Monte Sant 'Angelo ; Monte di Tre Pecore (in the distance).

over the glassy, while in the latter the reverse is the case. Old craters can be traced at Fossa del Monte, Monte della Guardia, and other points in the district.

Some of these lavas have undergone a certain amount of alteration from the passage through them of acid gases, as is shown by the following analysis by Abich of a Liparite from Monte della Guardia:

Silica	68·35
Alumina	13·92
Oxide of Iron	2·28
Lime	0·84
Magnesia	2·20
Potash	3·24
Soda	4·29
Volatile materials, principally Sulphur and Sulphuric Acid	4·64

While the action of the acid gases upon the *ordinary trachytes* of the second period of eruption in Lipari gives rise to the formation of selenite and basic sulphates of iron,—sulphate of alumina and free sulphur are the products of the same action on the later formed *quartz-trachytes.*

To those who regard the fluidity of lava as the result of simple fusion, nothing can be more startling than the behaviour of these obsidian currents of Lipari. While, as is well known, some of the highly crystalline lavas of Vesuvius have flowed with the most astonishing rapidity, these glassy masses have evidently possessed only the most imperfect fluidity. In proof of their viscosity I may point to the manner in which the modern obsidian stream of Vulcano is confined to the steep slope of the cone, at the bottom of which it has piled itself up in great hummocky masses, instead of spreading out in a fan-shaped manner, or continuing to flow in a stream over the smaller slopes. The same fact is more or less strikingly illustrated by all the glassy lava-streams. But even more decisive evidence of this slow movement of the obsidian lavas, and of the vast amount of tension and pressure to which their masses have been subjected, is afforded by their *internal structure.* Every conceivable condition of plication, crumpling and puckering, is illustrated by the sections afforded either in sea-cliffs or the ravines cut by mountain torrents in these obsidian lavas. The appearance presented at two different portions of the same lava-streams, as exposed in a steep escarpment at Porto delle Genti, south of the city of Lipari, are shown in Fig. 9: in A the mass has been bent into large but sharp folds; in B the folding has been accompanied by the most intense crumpling and puckering. As we shall show on a future occasion, these mechanical forces have combined with the forces producing devitrification to produce some most interesting phenomena in the minute internal structure of the rocks.

There can be little doubt that the last great effort of volcanic activity in the island of Lipari was that which produced the present crater of Campo Bianco, and the lava-stream of Rocche Rosse. In spite of traditions and obscure historical allusions, I find it difficult to believe, so much have the hard masses of lava suffered in places both from marine and subaerial denudation, that any record of this great eruption can have survived.

A. B.

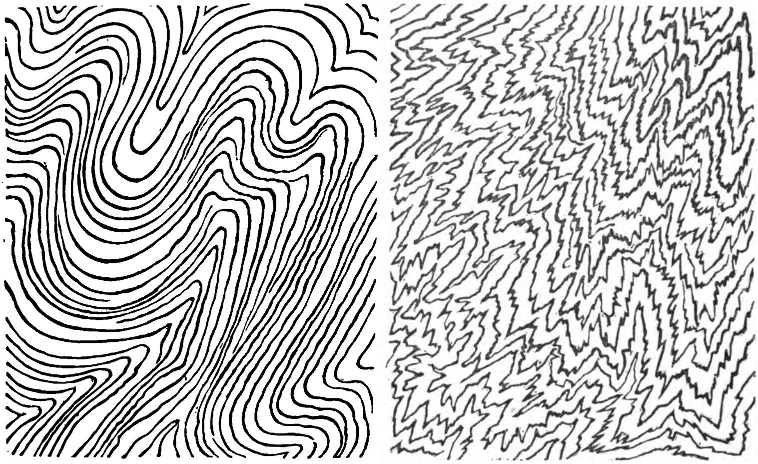


FIG. 9.—Sections of quartz-trachyte (Liparite) lava-streams at Porto delle Genti, illustrating the folding and crumpling of their interior portions, produced by the slow movement of the viscous mass. A. Exhibits a series of broad folds. B. A series of most complicated puckerings, exactly like that seen in many gneissose rocks.

To their permeation by gases and vapours, probably during the latest period of eruption, the altered trachytes and tuffs, with their veins of selenite and other minerals, are probably due. Only two vents, constituting the dying efforts of volcanic activity, once so powerful in this island, still remain, being situated on its western side; one of these is at Bagno, or la Fonte di San Calogero, and gives rise to a hot mineral spring; the other is at Bagno Secco, a little to the northward, and only dry stream, charged with hydrochloric and sulphurous acid gases, is evolved from it.

The hot spring of San Calogero has long been celebrated for its curative properties, having been mentioned by Diodorus Siculus; in 1870 a bath-house and hotel were erected here by the municipality of Lipari. In a medical tract by Dr. Guiseppe Eincotta, the use of these waters in various rheumatic and cutaneous affections is stated to be attended with the most beneficial results.

The water, which has a temperature of 198° F., that of the surrounding atmosphere being 77°, has been analyzed by Dr. Ferdinando Rodriguez, and also by Prof. Guiseppe Arrosto, of the University of Messina. It contains free carbonic acid and sulphuretted hydrogen, with the carbonates of lime and magnesia, and chlorides of calcium and sodium, and a little organic matter.

The following is the result of Prof. Arrosto's analysis:

Oxygen	0·0037
Nitrogen	0·0126
Carbonic Acid	0·2758
Sulphuric Acid	1·8842
Silicic Acid...	0·0082
Chlorine	3·8630
Lime	0·5286
Magnesia	0·3219
Potash...	0·1092
Soda	2·7629
Iron, Organic substances, and Alumina ...	traces.
Total solid and gaseous substances	9·7701
Water	990·2299
Total	1000·0000

The water deposits upon the walls and pipes of the bath-house a thick white incrustation.

Of the more active and very striking manifestations of volcanic activity at the present time in the Lipari Islands we shall treat in succeeding chapters, which we propose to devote to the description of the remarkable active volcanos of Vulcano and Stromboli.

During the earliest periods concerning which we have historical records in Southern Europe, Vesuvius was certainly inactive, its true character, indeed, long remaining wholly unsuspected; nor do the eruptions of Etna at this epoch appear to have been of such a character as to have powerfully arrested the attention and excited the imaginations of the oldest inhabitants of the district. Far otherwise was it, however, with the volcanos of the Lipari Islands; in these the manifestations of igneous activity had been so constant and striking, that priests, poets, and philosophers had successively associated the locality with their most marvellous stories.

Identified in the older mythologies with the forge of Vulcan and the workshop of the Cyclops, it is not surprising to find the superstitious mariners applying to the southern and more violently active of the Lipari volcanos the name of Hiera—or the Sacred Isle. And its vast crater, presenting by day bellowing fumaroles, and by night glowing fires, is not inappropriately selected by Virgil as the scene of the forging of the armour of Æneas.

In later times, when fear and fancy had begun to give place to curiosity, the historians, geographers, and philosophers of Rome gave more sober and accurate accounts of the phenomena of this island; and its later name of "Vulcano" or "Volcano" has gradually come to be applied to all mountains where igneous forces are similarly displayed. Nor, as we shall attempt to show in this chapter, is this volcano unworthy of the distinction which it thus accidentally acquired—that of serving as the prototype of all the members of its class. Observations, carried on during longer periods, and over far larger portions of the earth's surface, have made us acquainted with many grander volcanic piles and with more striking manifestations of igneous action; yet it may, perhaps, be doubted whether in any of these the nature, products, and causes of the phenomena displayed can be so advantageously studied as in Vulcano.

In seeking to sketch the early history of this volcano it would be a hopeless task to attempt the separation of truth from its embellishments in the legendary stories of the oldest classical writers; yet we may at least accept the traditions associated with Vulcano as proving that, during the earliest periods of the occupation of the district, its outbursts had been both frequent in their occurrence and striking in their characters. As we come to later times, however, more trustworthy statements concerning its general condition and its paroxysmal displays of violence are found, in the writings both of geographers and historians.

Thucydides, in the fifth century before Christ, speaks of Vulcano as throwing out a considerable smoke by day and flame by night. The appearance of flames was doubtless due, as in all volcanic eruptions, to the reflexion of glowing surfaces of lava in the crater from the clouds of ejected matter rising above it, or to fragments of incandescent solid or liquid matter mingled with the latter.

In the next century, Aristotle records a grand eruption of Vulcano, during which a new hill was formed; the quantity of ashes thrown out being so great as to entirely cover the city of Lipari (six miles distant from the volcano), and to extend to several of the towns of Italy. This eruption had not entirely ceased at the time when Aristotle wrote.

Callias, writing in the third century before Christ, describes Vulcano as possessing two craters; one of which was nearly 2000 feet in circumference, and threw out burning stones of prodigious size, with a noise that could be heard at a distance of more than fifty miles.

In the next century a very remarkable and important eruption took place, during which a new island gradually rose above the sea-level, great numbers of fish being killed. This account is usually interpreted as applying to the formation of Vulcanello. Posidonius, Pliny, and other writers who record this interesting event, are not, however, agreed as to the exact year in which it took place. From an account of Vulcano, written in this same century by Polybius, and preserved by Strabo, the mountain appears to have had three craters, two tolerably well preserved, and one in part fallen in. The larger crater was round, and about 1000 yards in circuit; its interior was funnel-shaped, the bottom of it being only about 50 feet in diameter, and 600 feet above the sea-level. It is clear that these observations must have been made during a period of inactivity in the volcano.

Diodorus, who was a native of Sicily, speaks of Vulcano in his time, namely the century before the Christian era, as throwing out burning stones, like Stromboli and Etna. Strabo, who wrote just before the time of Christ, tells us that the three openings or craters of Vulcano ejected ignited matters, that filled up a part of the sea to a considerable extent. We may also infer from the account of Strabo that Vulcano ejected lava in his time.

Lucilius Junior, Pliny, and Mela Pomponius, all of them writing in the first century of the Christian era, speak of Vulcano as being in a state of activity.

As soon, however, as we lose the guidance of the classical authors, the history of Vulcano becomes involved in the greatest obscurity. The inhabitants of the Lipari Islands suffered greatly from the invasions of pirates and slave-hunters, a circumstance of which the name of "Monte della Guardia," applied to the highest summits in almost all of the islands, furnishes a melancholy testimony. It is not therefore surprising to find that the Liparotes gradually acquired a ferocity of disposition, which caused their inhospitable shores to be shunned by mariners during the lawless mediæval times. So late, indeed, as the last century, the evil reputation of the islanders was such as to prevent travellers from venturing among them; and it was not until the Mediterranean was cleared of the Barbary pirates, at the commencement of the present century, that these islands could be visited with perfect safety.

The long period of obscurity, to which we have alluded, is only broken by a brief reference of Eusebius, and another by Orosius, in the fifth century; and by the following, perhaps legendary, account:

In a biography of St. Willebald, who is said to have lived between the years 701 and 786, there occurs the following passage:—"From Reggio St. Willebald sailed to see Vulcano, one of the Lipari Islands, then in a state of eruption. The saint wished to obtain a view of the boiling crater, called the '*infernum of Theodoric*,' but they could not climb the mountain from the depth of the ashes and scoriæ. So they contented themselves with a view of the flames, as they rose with a roaring like thunder, and the vast column of smoke ascending from the pit."

It would seem from this passage that, if Vulcano had lost the reputation of being the forge of Vulcan, its state of activity and the terrors which it inspired during the Dark Ages were such as to cause it to be identified with a still more dreadful place. Brydone, visiting Etna in 1770, found the Sicilian peasants holding the belief that its crater was the place of confinement for poor Anne Boleyn, who had exercised so unfortunate an influence on the "Defender of the Faith." Vulcano appears, in still earlier times, to have been fixed upon as the place of torture for an Arian emperor.

The modern history of Vulcano commences with the accounts given by Fazello, who was a native of Sicily, and lived between the years 1490 and 1570. He states that on the 5th of February, 1444, a great eruption occurred, which shook all Sicily, and alarmed the coast of Italy as far as Naples; the sea is declared to have boiled all around the island, and rocks of vast size to have been discharged from the crater. A number of submarine eruptions are said to have taken place all round the island, fire and smoke rising above the waves; and as the result of these the navigation around the island was totally changed, rocks appearing where there was before deep water, and many of the straits and shallows being completely filled up. At a later period, Fazello appears to have himself visited the island, and relates that the mountain was in a state of continual conflagration. He states that from its gulf (crater), which lay in the middle of the island, a cloud of thick smoke continually issued, while through the fissures of the stones and narrow apertures a pale flame arose in the midst of a dark cloud. It would thus appear that, after the grand outburst in the fifteenth century, the volcano relapsed into a condition similar to that which it now presents. Another interesting fact recorded by Fazello is, that in his time Vulcanello was still a distinct island, separated from Vulcano by a narrow channel, in which ships could lie in safety; but that this channel was subsequently filled up by new eruptions.

Fresh outbursts of Vulcano appear to have occurred early in the seventeenth century, for Cluverius states that, standing on the opposite shores of Sicily, he could perceive fire and dark smoke arising from the mountain.

Father Bartoli, who visited the island in 1646, relates that "it contained a deep gulf, entirely in a state of conflagration within, and, in a small degree, to be compared to Etna; and from its mouth a copious smoke continually exhaled." This appears to have been a time of comparative rest in the volcano.

In 1727, however, when M. d'Orville visited the island, the volcano was certainly in a much more active state. It had then wo distinct craters, each of which was situated at the summit of an eminence. From the most southern of these, which was about a mile and a half in circuit, there was ejected, besides "flame" and smoke, ignited stones; and its roaring was not less than the loudest thunder. From the bottom of the gulf rose a small hill about 200 feet lower than the top of the crater, and from this hill, which was entirely covered with "sulphur" and dirty corroded stones, fiery vapours exhaled in every part. M. d'Orville had, however, scarcely reached the edge of this "burning furnace," when he was obliged to retire precipitately.

The second crater lay towards the northward of the other. Its "conflagrations" were more frequent and ardent; and its ejections of stones, mixed with ashes and an extremely black smoke, almost continual. M. d'Orville further relates that the noise of this volcanic island was heard for many miles; and was so loud at Lipari (six miles away) that he could not sleep the whole night that he remained there.

This very clear and explicit account of the state of Vulcano is of great interest to us, exhibiting as it does a distinct image of the two cones and craters upon the great line of subterranean fissure and the rise of an internal cone from the bottom of one of them. More than sixty years after, Spallanzani found that some of the oldest of the inhabitants of Lipari still retained an imperfect recollection of the existence of the two craters.

At what period these were obliterated and the single cone formed, we have not the means of exactly determining. It is clear that between the years 1730 and 1740 the volcano was in a state of almost continual eruption; the Abbe Don Ignazio Rossi, a native of the island of Lipari, kept a diary of observations made during these years, which was published in 1761 by Signor Don Salvadore Papacuri of Messina. Rossi speaks of an almost continual discharge of ashes and smoke taking place, sometimes rising in clouds of great density, and at other times accompanied by explosions of great violence, earthquake shocks and loud roarings. He believed from his observations that the changes in the condition of the volcano were related, in some way or other, to the variations in the state of the atmosphere and the directions from which the wind blew. This question we shall have occasion to refer to more particularly hereafter. Deville speaks of violent eruptions having taken place in 1731 and 1739.

That a series of almost continual ejections during more than ten years should have greatly affected the form of the cone and crater of Vulcano is no more than might have been expected. Fortunately, we have in the "Travels" of M. W. de Luc an account of the state of the volcano in 1757. He appears to have been the first writer on the island who ventured to enter the crater. On the 30th of March, in the year mentioned, he managed to reach the bottom of the crater by a narrow passage (probably a great fissure rent in the side of the cone, like that produced in Vesuvius in 1872), which afforded him admission to the interior, but at great risk of being suffocated by the dense sulphurous fumes that enveloped him. His guide, a native of Lipari, refused to accompany him. He describes the bottom as being very rugged and uneven, with a number of apertures, from some of which issued a "strong wind," and from others sulphurous vapours, while an abyss, 60 paces in circuit, near one of the sides, gave off a column of smoke 15 or 18 feet in diameter, with a roaring sound "like that of the vapour of boiling water, when it escapes from a vessel not closely covered." The floor of the crater is described as oval in form, with a longer diameter of 800 to 900 paces, and a shorter of 500 to 600; but the sides of the crater, which are spoken of as perpendicular, are estimated to have been only from 150 to 200 feet high. We may probably infer, therefore, that the crater had become, in 1757, almost filled up by the fragmentary ejections of the long period of constant activity.

M. de Luc also informs us that the sea around the island had a yellow colour in places, and in others emitted fumes, the heat at the latter places being intolerable, and the fish of the sea killed. A little above the sea-level he found springs of warm water issuing from the beach and flowing into the sea; and around these spots the surface of the latter was covered with dead fish. It seems clear, therefore, that the fumaroles on the outside and on the submerged portions of the volcano, though similar in character, were more numerous and violent in their action than at the present day. This is, of course, no more than might be expected so shortly after a prolonged series of violent eruptions.

In 1768, Sir William Hamilton passed by Vulcano, but did not land on it; the volcano appears at this time to have lapsed into a state of quietness, for he compares it to the Solfatara of Naples, and his artist, Signor Fabris, gives a drawing, in which clouds of vapour are represented as steadily rising from it, in much the same manner as at the present day. Brydone assures us that in 1770, when he watched the island for a whole night, neither Vulcano nor Vulcanello emitted any glow of light, but only threw out volumes of white "smoke."

In 1771, according to Deville, and again in 1775, as recorded by Dolomieu, great eruptions of Vulcano took place. During the latter the great stream of obsidian on the north side of the cone is said to have been produced. Spallanzani, it is true, has thrown doubt on this statement of Dolomieu, on the ground that he could obtain no confirmation of the fact from the inhabitants of Lipari; it must be remembered, however, that Dolomieu visited Vulcano only six years after the eruption took place, while Spallanzani was not there till seven years later.

It seems to me extremely probable that the filling up of the crater, which had made so much progress at the time of M. de Luc's visit in 1757, had probably continued till 1775, when the liquid lava was able to overflow the crater-rim. Dolomieu's observations on the state of the crater in 1781 seem to be quite in accord with this view. The sides were then so steep that he was unable to enter the crater, but by means of a telescope he could distinguish two small pools, into which large stones slowly sank when rolled from the edge of the crater. That these were full of incandescent lava is proved by a fact that Dolomieu records, namely, that the vapours of Vulcano were by night resplendent with *placid flames* (evidently the reflected glow of a surface of lava like that of Stromboli) that rose above the mountain and diffused their light to some distance.

The great Calabrian earthquake of 1783, which was violently felt in all the Lipari islands, does not appear to have been attended by any change in the condition of Vulcano. But in March, 1786, according to the unanimous testimony of all the islanders, as carefully collected by Spallanzani only two years afterwards, a most violent eruption took place. At first a series of subterranean thunderings and roarings were heard over the whole of the islands, but accompanied in Vulcano by frequent concussions and violent shocks. Then the crater threw out a prodigious quantity of sand mixed with immense volumes of smoke and "fire" (incandescent matter). This eruption continued for fifteen days, and so great was the quantity of sand ejected, that the circumjacent places were entirely covered with it to a considerable depth. This eruption in its characters and effects may be justly compared with the Vesuvian outburst of 1822, which was witnessed by Mr. Scrope and so graphically described by him.

Two years after this great outburst of Vulcano, Spallanzani, to whose intelligent observations on this and other volcanos geologists are so greatly indebted, visited the island. Such was the terror inspired by the recent eruption, that he could not induce any Liparote to accompany him into the crater. A resolute Calabrian, banished for his crimes to Lipari, was at last prevailed upon, by the offer of a large reward, to make the venture. Spallanzani describes the bottom of the crater as being oval in form, perhaps one-third of a mile in circumference, and covered with sand like the sides. The walls were almost perpendicular, and so high that Spallanzani judged them to exceed a quarter of a mile. It was only on the south-east side of the crater, where some of the materials had slipped from the sides, and formed a sloping talus, that access was possible.

In the centre of the bottom rose a small hill, about 45 feet in diameter, from every part of which a dense white smoke arose, its surface being encrusted with salts. On the west side of the crater-floor a mouth 30 feet in circumference gave off a column of dense white smoke with a loud roaring noise, and the explosions from this aperture had evidently blown away part of the adjacent crater-wall. Such was the heat and sulphurous stench proceeding from this "bocca" that it was impossible to approach it closely; its sides, however, could be seen to be coated with stalactites composed of sulphur and various salts. A spring of water, also depositing stalactites, was seen issuing at a height of about eight feet from the floor of the crater. All over the interior of the crater, and at many points around it, innumerable fumaroles poured forth jets of vapour, and in many places it was only necessary to stamp with the foot in order to produce fresh ones. The gas issuing from these apertures, the sides of which were intensely hot, sometimes extinguished a candle brought near them; but at other times the gas itself became ignited, and burned for several minutes with a bluish-red flame. At night several bluish flames could be seen rising from the bottom to the height of half a foot or sometimes higher; and these were most numerous and conspicuous in the central eminence.

Spallanzani describes the heat at the bottom as being so great as to burn his feet, causing him to seek refuge on the large blocks of lava scattered about. The odour of sulphuretted hydrogen was so strong as greatly to affect his respiration; it was in consequence very difficult to walk round the crater, and quite impossible to cross it near the middle. The action of the acid vapours on the fragments of glassy rock was very marked; and in one case Spallanzani was able to observe the commencement of change produced in a piece of black lava, which he jammed into the mouth of a fumarole and re-examined after the lapse of 32 days.

These clear descriptions of the great Italian philosopher enable us to refer without doubt to the grand eruption of 1786 the production of the existing vast crater of Vulcano; and this crater, it is probable, did not undergo any material changes, except in the number, position, products, and violence of discharge in its fumaroles, till the eruptions of 1873–4. That the signs of activity should have been much more marked two years after the great eruption than they afterwards became is no more than might have been expected. The amount of igneous action going on in 1788 was sufficient to cause an obscure red glow over the crater by night.

The southern and extinct portions of the island of Vulcano were inhabited and cultivated at a very early period. But during many of the more violent eruptions, which shook the whole island and covered it with thick deposits of ashes, the inhabitants would doubtless be driven away. This was certainly the case during the violent outbursts of the 18th century, when the island appears to have been wholly uninhabitable. At what period the people of Lipari found that the neighbouring volcano constituted, in its abundant chemical deposits, a great source of wealth, is not known. It is said, however, that at one time the collecting of these valuable products was abandoned, on account of the alleged injury done to the vines of Lipari by the sulphurous vapours. On the work being resumed by permission of the King of Sicily, furnaces for the purification of the sulphur are said to have been established in the Fossa Anticcha. The great accession of activity beneath the mountain, which heralded the series of outbursts of last century, made itself felt by an increase of heat in the soil, and abundant disengagements of suffocating gases, and this once more caused the cessation of the industry. As the terrors produced by the grand eruption of 1786 died away, and the crater began to gradually cool down, the inhabitants regained boldness sufficient to enable them again to visit the crater habitually, and at last to form habitations for themselves near the tempting but dangerous source of wealth, by excavating miserable homes in the old tuff cone of the Faraglione.

After the work of extracting the various chemical products had been carried on in a desultory manner for a considerable time, the crater was purchased a few years ago by a Glasgow firm for the sum of £8000, and regular chemical works established in the island. The collecting and preparation of the materials for exportation now employs about a hundred workmen, the whole of whom are Italians; but the necessary capital and machinery for carrying on the operations are supplied from this country.

Since the last grand eruption, and the lapse of the volcano into comparative tranquillity, its crater has been visited and examined by many geologists. Dr. Daubeny, who visited the island in 1824, observes:

"The operations of this volcano appear to be going on with much greater vigour than those of the Solfatara, and exhibit, perhaps, the nearest approximation to a state of activity during which a descent into the crater would have been practicable.

"Nor can I imagine a spectacle of more solemn grandeur than that presented by its interior, or conceive a spot better calculated to excite in a superstitious age that religious awe which caused the island to be considered sacred to Vulcan, and the various caverns below as the peculiar residence of the god.

"To me, I confess, the united effect of the silence and solitude of the spot, the depth of the internal cavity, its precipitous and overhanging sides, and the dense sulphurous smoke, which, issuing from all the crevices, throws a gloom over every object, proved more impressive than the view of the reiterated explosions of Stromboli, contemplated from a distance, and in open day."

At the present time the well-made road, leading by a series of zig-zags to the summit of the mountain, and the excellent viaduct over which this road is conducted into the interior—the trains of laden asses and mules passing along the same—and the groups of busy workmen scattered over the floor of this strange workshop, perhaps detract somewhat from the feeling of awe which the place would naturally inspire. What has been lost by the lover of the picturesque and wonderful, however, has been gained by the student.

Daubeny and Abich both availed themselves of the especially valuable opportunities afforded by Vulcano for making observations on the gases evolved by volcanic vents. M. Charles Ste.-Claire Deville and M. F. Leblanc, however, made a series of much more systematic experimental inquiries here in 1855-6. And still later, in 1865, M. Fouqué has continued these studies, and carried them much farther. To the results obtained by these eminent French chemists we shall have occasion to refer again in the sequel.

It is clear from the foregoing sketch of the history of Vulcano, fragmentary and imperfect though it necessarily is, that all the usual phenomena of a volcano in the *paroxysmal phase* are exhibited by it. As far as our accounts enable us to judge, it would appear that scarcely a century elapses without one or more violent outbursts; that sometimes the eruptions are continued with moderate violence during many weeks, months, or years, while at others the accumulated force is dissipated in a furious outbreak of comparatively short duration; and that, after these periods of intense activity, the mountain sinks into a state of comparative repose. All the usual phenomena of volcanic action are admirably illustrated in Vulcano—the shifting of the igneous vent along the line of subterranean fissure,—the formation, from time to time, of new craters,—the gradual filling up of these by the growth of small cones within them, leading as it would appear to grand paroxysmal outbursts, by which the crater is again relieved of its contents,—the decline of the volcano into the *solfatara stage*,—and the opening of parasitical vents, and sometimes of cones and craters, upon its flanks.

Since the last grand eruption in 1786, Vulcano has been in a state of almost complete repose, and even its gaseous emanations appeared to be gradually declining in abundance and violence. Some writers had in consequence been somewhat rashly led to speak of it as a spent volcano. As if to make a protest against any such assumption, the volcano a little more than a year ago resumed its activity: and we may now perhaps infer that, having recovered from the exhaustion produced by its last terrific effort, during which the present vast crater was formed, it is now recommencing that series of moderate eruptions by which the crater will be once more filled and the vent so clogged that it can only be cleared by another great paroxysm.

Fortunately for geologists, Signor Ambrogio Pinconi, the very intelligent manager of the chemical works in Vulcano, kept a diary of his observations on the crater during the late outbursts, and several times, indeed, at considerable personal risk, ventured into it while the eruption was actually in progress. During the continuance of the eruptions, the operations of the labourers in the crater were of course suspended; but the first explosions were so sudden that, before the workmen could make their escape, three of them sustained serious injuries. From the entries in Signor Pinconi's journal, a copy of which now lies before me, and the notes which I made on the spot only two months after the eruption had ceased, I have drawn up the following account of it.

On the 7th September, 1873, signs of renewed activity began to be displayed in the crater of Vulcano, and a series of small eruptions took place within the crater. These continued with varying intensity and many interruptions until the 24th of October. On the 22nd January, 1874, the activity of the crater was renewed, and continued till the 5th of February.

During these eruptions rumbling sounds were heard, which were compared to a fusillade alternating with discharges of cannon. These noises were audible at Lipari, which is situated at a distance of 6 miles from the crater.

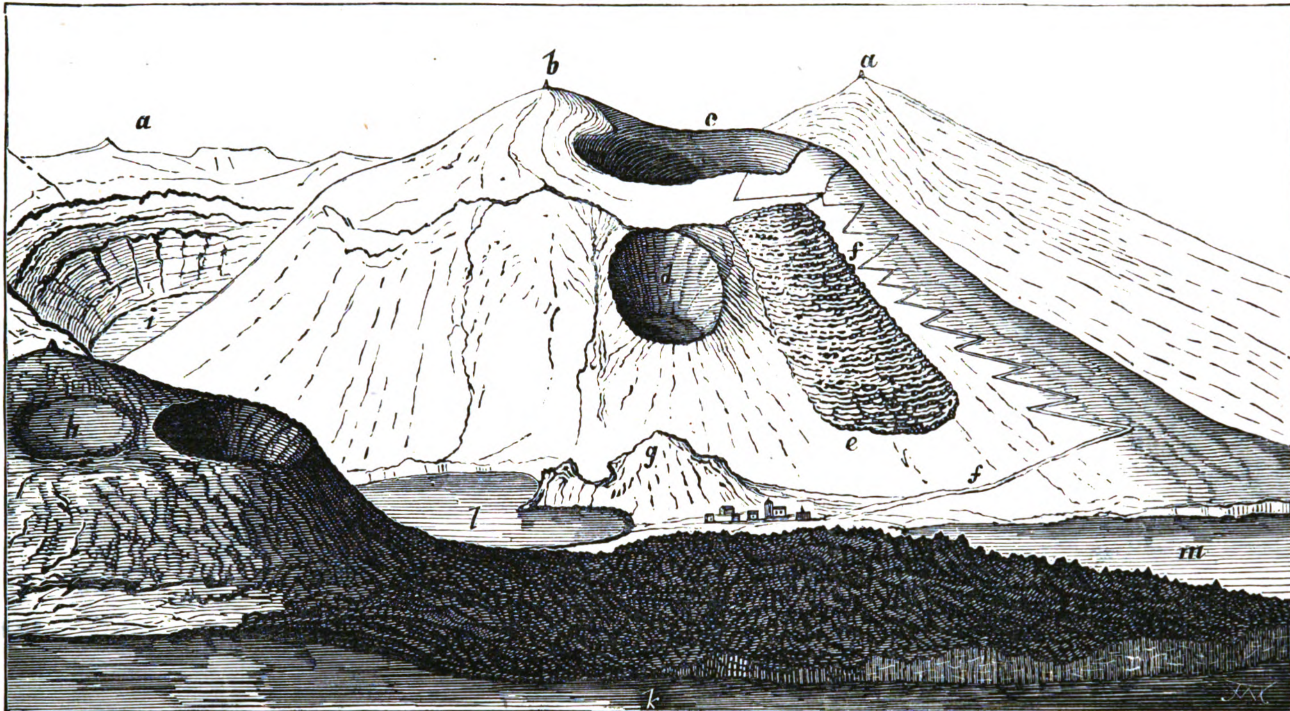
Several fissures were opened on the northern side of the bottom of the crater, and from these clouds of vapour were discharged and considerable numbers of stones thrown out. Some of these were of very considerable size; but the majority of them were, by repeated ejections, reduced to small fragments. Most of the stones fell back within the limits of the crater; but a few of them fell outside of it, and are seen scattered all over the sides of the cone. Some of these stones are 8 to 10 lbs. in weight; they are composed of highly siliceous rock (quartz-trachyte), and can be distinguished from the products of earlier eruptions by their pale-green colour and unweathered appearance. The fragmentary materials accumulated in great quantities around the orifices of ejection, and would doubtless have given rise to the formation of small cones on the bottom of the great crater, had not the large quantities of materials shaken down from the adjoining crater-wall caused the whole to assume the form of a great bank or talus, leaning against the northern side of the circular cavity.

On ascending to the top of this pile, which rises to the height of more than 100 feet above the bottom of the crater, I was able to see that from four still open mouths, ashes, lapilli and larger fragments of rock had been discharged, giving rise to the formation of a line of cones, the regularity of the building up of which had been greatly interfered with from the cause alluded to. From these open mouths considerable quantities of vapour were still (April 11, 1874) issuing.

Among the blocks of obsidian and quartz-trachyte, usually with highly contorted internal structure, which strewed the floor of the crater and had been ejected during the recent eruptions, were many which weighed several hundred-weights.

Considerable quantities of white ashes were ejected during these eruptions, and fell both in the islands of Lipari and Salina.

While these eruptions were taking place within the crater of



SKETCH OF THE GREAT CENTRAL CONE OF VULCANO, WITH VULCANELLO IN THE FOREGROUND, AND THE OLDER ENCIRCLING CRATER-RINGS IN THE DISTANCE, AS SEEN FROM ABOVE PUNTA DELLA CREPAZZA, IN LIPARI.

aa. Outer crater-rings culminating in Monte Saraceno. *b*. Highest point of the central cone. *c*. Great crater. *d*. Small crater, called the Fossa Anticcha. *e*. Obsidian lava-stream of 1775. *ff*. Road leading into the crater. *g*. The Faraglioni, with the "Fabbrica" near it. *h*. Vulcanello, with two of its craters seen. *i*. The Atrio between the outer crater-rings and the central cone. *k*. Lava-streams proceeding from Vulcanello. *l*. Porto di Levante. *m*. Porto di Ponente.

Vulcano, no change was detected in the state of the small fumarole which exists in the most recent of the craters of Vulcanello.

During the whole period of these eruptions, however, Stromboli was in a state of extraordinary activity, and it is said that outbursts of the two mountains occurred almost simultaneously.

On the other hand, I was assured that no correspondence could be discovered between the state of activity of Vulcano and the nature of the weather at the time.

Having sketched the history of Vulcano, so far as we have materials available for the purpose, it will now be interesting to consider its present state, and to discuss the origin of its various features.

As pointed out by Spallanzani, an admirable view of Vulcano and Vulcanello may be obtained from any of the high grounds in the southern part of Lipari. In order that the description of the island may be more readily followed, I have given, in Plate VII., a sketch taken from the mountain above Punta della Crepazza in Lipari, showing the great central cone of Vulcano, with its series of encircling older crater-rings in the distance, and Vulcanello and the Faraglione in the foreground.

The southern half of the island is made up of a series of semicircular ridges, each of which exactly resembles, on a small scale, the well-known Somma. These old crater-rings, for such they evidently are, consist of alternations of lava-streams and beds of agglomerate, the whole interpenetrated and bound together by innumerable dykes. On their outer sides these ridges slope gradually down to the sea; but towards the interior of the island they present bold precipitous cliffs. In these, as in the cliffs of Somma, the characteristic features of volcanic architecture can be admirably studied; and equal facilities are afforded to the geologist, where the sea has eaten into these old cones, as is especially the case on the south-west of the island. (See Fig. 4, page 15.)

These crater-rings, which culminate in Monte Saraceno (1581 feet in height), la Sommata, Monte Aria, and many other peaks considerably more than 1000 feet above the sea-level, are four in number, and are separated from one another by semicircular, flat-bottomed valleys, which are called Pianos. The whole of this southern part of the island is thickly covered with volcanic sand, produced in part by the decomposition of its rocks, but to which the ejections of the central cone are making constant additions. Consequently the island is almost a desert, a few fishermen only living on its southern shores, while some vine-growers maintain a hard struggle with the elements in sheltered nooks in the deep Pianos. No roads or even foot-tracks can be kept open, where every storm raises and redistributes the covering of volcanic sand; and in this the traveller sinks to the knees at every stride, while the few cultivated patches have to be protected from the dust-clouds by fences of reeds.

It is clear that the southern part of Vulcano has been the site of the formation of at least four volcanic cones, the central axes of which have been situated on a line directed N.W. and S.E.; and that the eruptions to which each new cone has owed its origin have, at the same time, destroyed the northern portion of the pre-existing one. The oldest crater-ring is composed of ordinary trachytic lavas, exhibiting all the characteristics and variations found among the products of the second period of eruption in the Lipari Islands; but the newer ones are found to present materials becoming continually more basic in composition, till at last they approximate to basalts and dolerites resembling those of Stromboli. The structure of this part of the island will be made clearer by a reference to the accompanying plan of the island, Fig. 10.

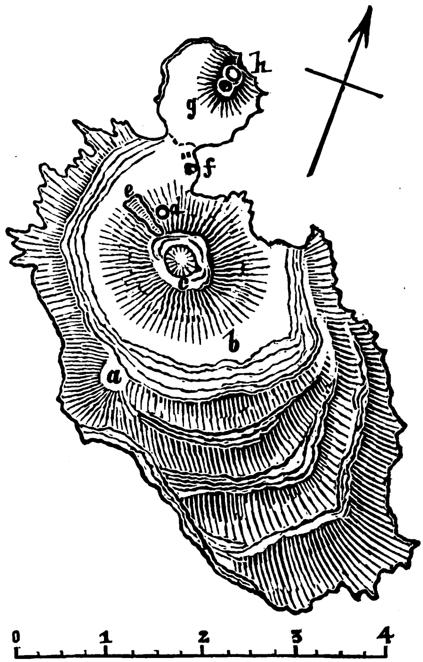


Fig. 10.—Plan of the Island of Vulcano, based on the map published by the Italian Government.—*a*. The four outer crater rings, culminating in Monte Saraceno. *b*. The Atrio surrounding the modern cone. *c*. The great crater. *d*. The smaller crater of the Fossa Anticcha. *e*. The obsidian lava-stream (of 1775). *f*. The Faraglione della Fabbrica. *g*. Lava-fields of Vulcanello. *h*. The cone of Vulcanello with its three craters.

Encircled by the four older crater-rings just described, and separated from them by a semicircular valley ("Atrio") deeply covered by volcanic sand, rises the active cone of Vulcano. This is not, as a glance at the sketch will show, a simple cone with a summit crater like that of Vesuvius, but a truncated conical mountain, in which the present crater occupies an excentric position. No one examining the upper part of the mountain can fail to perceive there the vestiges of a number of craters which have been successively formed and destroyed; and that the position of the central axis of eruption must have been subject to constant variation. These conclusions are confirmed, as we have seen, by those accounts of the state of the mountain in earlier times which have come down to us.

The highest point of the active volcano is situated on the north-east of the crater, and is 1266 feet above the sea-level. The lowest point of the crater rim, that over which the road is carried by which access is gained to the interior, is 882 feet high, while the floor of the crater is 532 feet above the sea-level.[1]

[1] There exists a remarkable discrepancy between some of the estimates of the height of the floor of the crater of Vulcano above the sea-level. Deville states it to be 837 feet, while Mr. Mallet gives it as only "a few feet," stating the depth of the crater to be from "1100 to 1200 feet." My own measurements with the aneroid were

The floor of the crater of Vulcano is about 200 yards in diameter; but its level area is much encroached upon by the talus that leans against its sides, and especially by the series of irregular cones which were thrown up on its northern edge during the late eruptions. The walls of the crater, which rise to heights of from 400 to 600 feet above its floor, are in their lower part vertical, but higher up slope outwards at an angle of about 45°. The diameter of the crater-rim is about 600 yards. The sides of the crater of Vulcano exhibit a series of admirable sections of the masses of agglomerate composed of materials of all sizes, often well stratified, and sometimes exhibiting the series of anticlinals all round the crater, which has been described by Mr. Scrope as so characteristic of the structure of volcanic cones. Some portions of lava-streams and dykes of vitreous lava can also be detected in the sides of the grand crater; but it is evident that the mountain has been mainly built up by fragmentary ejections.

The floor of the great crater of Vulcano, and also of the little crater of the Fossa Anticcha, to be hereafter noticed, is covered by a hard, compacted mass of pumiceous materials, which, when stamped upon or struck with any heavy body, gives forth a dull sound; this, as in the case of the well-known Solfatara of Nàples, is vulgarly supposed to indicate the existence of vast cavernous hollows below the mountain. A much simpler explanation of the phenomenon has been suggested by Mr. Scrope (see Trans. Geol. Soc., 2nd series, vol. v.); and that there is no foundation for the popular notion is shown by the fact that many masses of compact tufaceous materials give forth, when struck, precisely the same *rimbombo* sound, even when situated at a distance from any crater.

All over the sides and bottom of the crater of Vulcano fumaroles are seen discharging acid vapours and gases. Many of these are of insignificant proportions; but very large ones exist on the north-western rim of the crater and at a number of points at its bottom. The sides of the fissures from which the vapours issue are sometimes red-hot; Fouqué found that zinc was melted by the jets of issuing gas, and Mallet that the temperature of the lips of the principal fissure was in 1864 "sufficient to melt brass wire, but not sufficient to fuse a similar wire of bronze." It is not surprising therefore to find that, with this elevated temperature, the more inflammable products of the fumaroles are ignited directly they reach the atmosphere. This would seem to be the origin of the feebly-luminous flames, usually of a blue colour, which are seen at night playing over some of the fumaroles; the existence of these will not of course be thought to give any support to the popular notion of masses of red flame rushing out of a volcanic crater during eruption, which has been clearly demonstrated to be an optical illusion. Around all

repeated on three different occasions, and varied only between 497 and 535 feet The estimate given in the text is that of M. Salino, and appears to be derived from the official survey. Possibly some irregularity in the action of Mr. Mallet's barometer may account for the very inaccurate results which he was so unfortunate as to obtain, not only on this occasion, but in other observations about the same time at Stromboli.

the larger fumaroles are crusts of salts, usually of a white or pale yellow colour, but sometimes exhibiting a bright red tint, communicated to them by the sulphide of arsenic (Realgar).

The distinguished chemists, who at the instance of the French Academy have studied the gases discharged from volcanic vents, have accumulated a large body of valuable information on this interesting subject. Vulcano affording such remarkable facilties for their investigation, has received much attention from MM. Charles Sainte-Claire Deville, Leblanc and Fouqué. Their conclusions it would be impossible to detail, much less to discuss the bearings of upon geological questions, in the present sketch. Some of the more important facts obtained may, however, be briefly noticed.

The elements which have been detected among the gaseous emanations of Vulcano are as follows:—oxygen, hydrogen, nitrogen, chlorine, iodine, sulphur, selenium[1] (first detected by Stromeyer in 1825), phosphorus, arsenic, and boron; and the presence of bromine is suspected though not proved. The most remarkable circumstance is the abundance of boron in these emanations; this element not being an ordinary product of volcanic action, though found so abundantly in the hot springs of Tuscany.

It has been clearly shown that the nature of the gases evolved varies with the temperature of the fumaroles. This fact is illustrated by the following table, in which I have placed side by side a number of the analyses made by M. Fouqué:

	a.	*b.*	*c.*	*d.*	*e.*	*f.*
Sulphurous and Hydrochloric acids.	73·80	66·0	34·0	27·19	7·3	0·0
Carbonic acid............	23·40	12·0	28·0	59·62	68·1	63·59
Sulphuretted Hydrogen	traces	10·0	12·0	0·0	10·7	traces
Oxygen	0·52	2·4	4·8	2·20	2·7	7·28
Nitrogen..................	2·28	9·6	21·2	10·99	11·2	29·13

a. was from a strongly acid fumarole, with a temperature of 360° C., which deposits sulphide of arsenic, chloride of iron, and chloride of ammonium towards its centre, and boracic-acid and sulphur at greater distances.

b. was from a similar fumarole, but with a temperature of only 250° C.

c. was similar to *a* and *b*.

d. deposited similar salts to the former, but its temperature was only 150° C.

e. was from a slightly acid fumarole, with a deposit of chloride of ammonium, sulphur, and boracic, acid, and a temperature of only 100° C.

f. was similar to *e*.

[1] The mixture of sulphur and selenium deposited here received from Haidinger the name of "Volcanite."

Sulphur appears to be deposited round volcanic fumaroles through the action of sulphurous acid and sulphuretted hydrogen on one another. The production of the large quantities of chloride of ammonium can scarcely be explained, however, unless we admit with Daubeny that nitrogen, under conditions of high temperatures and pressures, exhibits a chemical activity, very different indeed from its inert character under ordinary circumstances.

The quantity of volatile matter issuing from the fumaroles of Vulcano varies from day to day, and new fissures are being continually opened, while old ones become closed. Signor Pinconi assured me that, after the recent eruption, the fumaroles discharged with enormously augmented violence, and that they produced, at the time of my visit, at least four times the quantity of salts deposited before the eruption. Two condensing chambers had just been erected over the largest fumarole for the artificial condensation of the vapours, but sufficient time had not elapsed to test the success of this method of collection. At present, the crusts composed of boracic-acid, sulphur, and sal-ammoniac are dug up round the fumaroles and conveyed to the outside of the crater by an excellent road carried over a viaduct. The sulphate of alumina. which is also largely collected, is produced by the action of the acid vapours on the pumiceous tuffs and agglomerates composing the mass of the mountain. At the "fabbrica," near the Faraglione, the products are roughly separated by simple machinery, sent from England for the purpose; but the salts are forwarded to this country for purification.

The cone of Vulcano is made up of agglomerates, often well stratified; the materials being much altered through the permeation of the mass by acid gases and vapours, and often exhibit brilliantly variegated tints. Half way down the slope of the mountain, on its northern side, is the little crater called Fossa Anticcha or Forgia Vecchia, the floor of which has a diameter of about 60 yards, while acid vapours are discharged by several fumaroles at its sides. In the sides of this crater, and in a great fissure near it, the characteristic quaquaversal dip of the materials in volcanic cones is well exhibited. The ejected materials are often seen forming beds dipping at angles of from 25° to 30°. (See Fig. 11.) The date of the formation of the crater called the Fossa Anticcha is quite unknown. It is clear that it existed at the time of Spallanzani's visit to the island, and he imforms us that at some earlier period the collection and purification of the products of the mountain had been carried on in it.

The lava-stream on the north-west side of the cone of Vulcano is composed of obsidian passing into Liparite, and exactly resembles those of the last period of eruption in the adjacent island of Lipari, which were described in the last chapter. Two points in connexion with this lava-stream are, however, worthy of especial notice. Firstly, although of great thickness, it has evidently consolidated on a slope of 35°, thus affording a striking illustration of the baselessness of the opinions maintained by Elie de Beaumont and M. Dufrenoy on this subject, by means of which they sought to support the exploded theory of "Elevation-craters." Secondly, in its wonderfully contorted internal structure, its rent and rugged surface, and especially in the manner in which, on reaching a somewhat less steep slope, its materials have been piled up into a high ridge, this current affords a most striking illustration of the extremely imperfect state of fluidity in which the vitreous lavas of Lipari were poured forth. (See Fig. 11.)

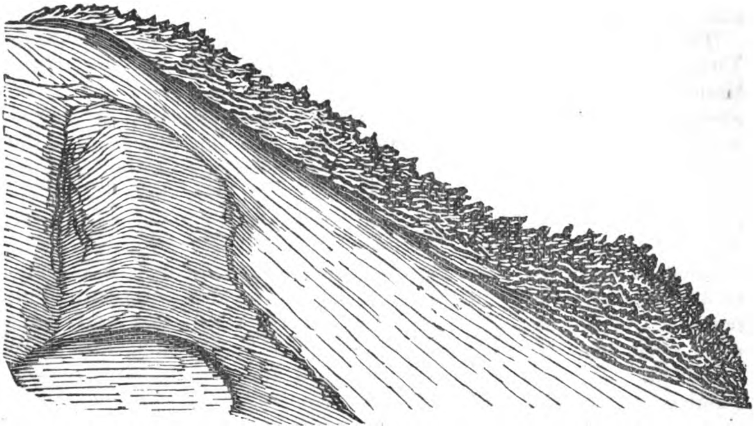


FIG. 11.—Profile-sketch of the obsidian lava-stream (of 1775) on the north-west side of the cone of Vulcano, with the stratified tuffs seen in the side of the Fossa Anticcha below.

The present fresh appearance of this lava-stream, uncovered as it remains by fragmentary ejections, is strongly confirmatory of the very recent date, that of 1775, which Dolomieu assigns to it. On the south side of the cone of Vulcano is another lava-stream, evidently of far older date, and almost completely buried under ejected materials. All the solid ejections of the existing cone of Vulcano appear to have consisted of the most highly acid rocks—Liparite, obsidian, and pumice—like the materials of the later eruptions in Lipari.

Between Vulcano and Vulcanello rises the mass of volcanic tuffs, evidently the denuded fragment of a cinder cone, which is known as the Faraglione. In a grotto in this mass, the sides of which continually drop with water abounding in acids and various salts, the most beautiful stalactites of sulphate of alumina, and various compounds of lime, iron, and occasionally of copper are formed. In this grotto I collected the brillant crystals belonging to the cubic system, of the hydrated compound of ferric and ferrous sulphates, called "Voltaite," a mineral first discovered by Scacchi in the Solfatara of Naples. Around the Faraglione, fumaroles discharging vapour with sulphuretted hydrogen and carbonic acid gases at an elevated temperature occur, while others are found giving off the latter gas only at the ordinary temperature of the atmosphere; these latter have been justly compared by Deville to the Grotto del Cane, at the Lago Agnano, near Naples.

The isthmus joining Vulcano and Vulcanello, and composed of fragmentary matters ejected by the volcanos, appears to have been formed in the sixteenth century. It is doubtful if Vulcanello be really the island which was thrown up in the second century before Christ. Its three craters have evidently been formed at very different periods (see Fig. 6, p. 19), and the newest of them still contains one or two active fumaroles; in the time of Spallanzani it was clearly in a much more active state. Some of the older lavas of Vulcanello were of basic composition.

Such is the structure of Vulcano, which exhibits, as we have seen in its various features clear evidences of a vast series of paroxysmal eruptions, repeated, at not very distant intervals, during the whole of the historical epoch.

In our next chapter we shall describe Stromboli, a volcano offering in its features, its modes of action, and its products, some remarkable and very suggestive points of contrast with Vulcano.

The Lipari Islands.—Stromboli.

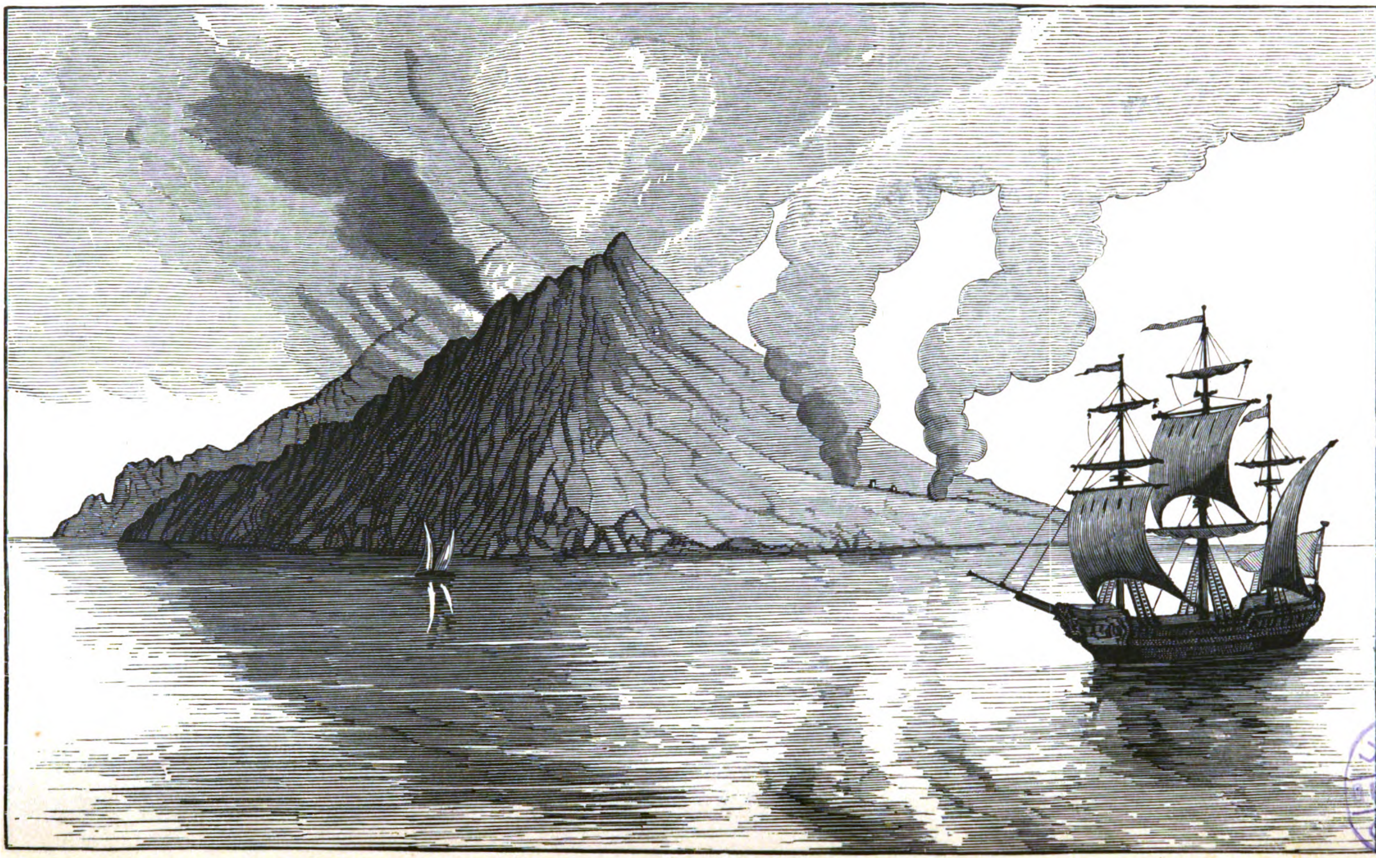
Presenting as it does the only example of a volcano in the phase of permanent moderate activity to be found in Europe, Stromboli must always have the strongest claims on the attention of geologists. Here may at all times be witnessed, in perfect security, those explosions produced by the disengagement of vapour in the midst of masses of liquefied rock, which, following one another at longer or shorter intervals, and taking place with greater or less violence, constitute a most striking feature in nearly all volcanic eruptions; and the causes, sequence and attendant phenomena of these outbursts can in the case of this volcano be most conveniently studied.

As might be anticipated from the less striking character of its action, Stromboli is less frequently mentioned by ancient writers than Vulcano; yet, as early as the fourth century before Christ, it is spoken of as being in a state of eruption, and references to it occur in the writings of Aristotle, Callias, Diodorus Siculus, Strabo and Cornelius Severus. Most interesting to the geologist, however, is the notice of the mountain by Pliny, who in the first century of our era describes it in terms which are still applicable to it at the present day.

But if the ancient accounts of this volcano are somewhat meagre, we are nevertheless fortunate in possessing the means of tracing very completely its history in modern times; during the last one hundred years numerous sagacious and trustworthy observers have visited the volcano, and given clear and accurate accounts of its condition. Their descriptions enable us to define the true character of the operations going on within its crater, to determine how far these operations are constant in their action, and to ascertain the limits of variation in the intensity, succession and results of its outbursts.

The general characters of the phenomena presented by Stromboli —"the lighthouse of the Mediterranean"—are well known to be as follows. The mountain, which is of conical form, rises directly from the deep waters of the Mediterranean to the height of more than 3000 feet above its surface, as the sea between the Liparis affords soundings of from 300 to 700 fathoms, we must remember that the several islands are only the upper portions of great volcanic cones; at least one-half of the height of these, and by far the greater part of their bulk being concealed beneath the waves. Stromboli is completely made up of volcanic materials, and presents, not only some obscure traces of a greatly ruined crater at its summit, but numerous indications, in craters and lava-streams, of lateral outbursts on its flanks. But the most striking and interesting feature about the mountain is that on its north-western side there exists a crater in a state of constant activity, which, besides giving off vapours and gases,—either in explosive puffs, in continuous blasts, or in quietly issuing wreaths,—discharges at more or less regular intervals showers of scoriæ and volcanic ashes. Occasionally, also, small streams of lava flow from the crater itself or at some lower point on the mountain; and that a reservoir of incandescent material exists within the crater, is proved by the fact that, at night, the clouds of vapour and dust above the mountain reflect a fiery glow, either at the moment of the explosion and for a short interval afterwards, or, during times of more intense activity, almost continuously.

With regard to the position and relations of the several parts of the mountain, we have numerous measurements of accurate observers to guide us; and the recently published map of the Italian Government enables us to verify their various barometrical and other determinations. The active crater of Stromboli (Cratère la Fossa) is situated rather more than 600 feet below the summit of the mountain, that is, at a height of considerably more than 2000 feet above the level of the Mediterranean. The diameter of the crater is about 400 feet, and its bottom, which is several hundred feet below the rim on its southern or landward side, appears to be bounded by a crater-wall of but little elevation towards the sea. From this depressed portion of the crater-rim a long slope, called the Sciarra del Fuoco, leads down to the sea, with so steep an incline (35°) that all materials ejected from the crater are unable to rest upon it, but roll down into the sea. The Sciarra of Stromboli constitutes one of the most striking features of the mountain; its length from the crater to the sea-level is more than 1200 yards, and the breadth of its seaward edge is about 1000 yards. The walls bounding the inclined plane of the Sciarra, and which gradually converge towards the crater, are steep cliffs, seen to be composed of lava-streams, agglomerates, and dykes, presenting their usual relations with one another; indeed, the whole may be regarded as a miniature representative of the grand Val del Bove of Etna. Its general appearance is well seen in the view (copied from Abich) given as an illustration to Mr. Scrope's paper in the Volume of this Magazine for 1874, page 532. On the slope of the Sciarra may be observed several well-marked ridges of lava, which are either lava-streams that have flowed down it, or great dykes, formed by lava rising through fissures which have been produced in it during paroxysmal eruptions. We may remark that the Italian word "Sciarra" seems to be derived from the same root as our northern



View of Stromboli in 1768, as seen from the South-west. (*From Hamilton's Campi Phlegræi. Plate* xxxvii.)

term "Scaur," and to have nearly the same significance. Having thus briefly noticed the salient features presented by Stromboli, the reader will have less difficulty in following the descriptious of the state of the volcano at different periods as borne witness to by various observers.

About the year 1744, according to an account received by Spallanzani, the volcano threw out such an enormous quantity of scoriæ as to cause a "dry place in the sea," which remained for some months as a hill rising above the waters, and then gradually disappeared. The probable interpretation of this is that, during a more than usually violent paroxysm of the volcano, a lateral cone was formed on the submerged flanks of the mountain, and, rising above the sea-level, was gradually destroyed by the action of the waves, in the same manner as in the well-known case of Graham's Isle.

In 1768, that able observer of volcanic phenomena, Sir William Hamilton, returning from a visit to Etna, was becalmed for three days among the Lipari Islands. Hamilton, at this time, not only saw the usual explosions of red-hot stones, but noticed that "some small streams of lava issued from its side, and flowed into the sea." A drawing by Signor Fabris, who accompanied Sir William Hamilton on this occasion, shows that, not only was the crater at this time in a state of rather violent activity, but that two lateral outbursts were taking place low down on the south-western flank of the mountain, not far from the hamlet of Ginostra. A copy of this drawing of Stromboli, made in 1768, is given in Plate VIII.

In 1770, according to Brydone, the volcano was more than usually active, and a submarine eruption took place near it. This author correctly describes the crater as situated at 200 yards below the summit of the mountain, but declares that while its action sometimes resembled that of Vesuvius (then in a state of moderate activity), "the explosions of which succeed one another with some degree of regularity, and have no great variety of duration," yet, at times, "a clear flame issues from the crater of the mountain, and continues to blaze, without interruption, for near the space of half an hour." Brydone had never seen a similar illumination of Vesuvius, except when the lava had risen to the summit of the mountain. In the descriptions of Brydone, then, we have evidence that in Stromboli and Vesuvius the usual features of their action were *temporarily* reversed: the former was passing through a violent paroxysm, while the latter exhibited a succession of subdued and almost rhythmical explosions. This is a most significant circumstance, and one which affords a complete refutation of the view that a *fundamental difference* exists between the nature, modes of action, and causes of the phenomena presented by these two volcanos.

Between the years 1766 and 1781, Dolomieu was twice in the vicinity of Stromboli during a time of sudden storm. He then saw the volcano making rapid explosions at intervals of two or three minutes, and throwing out stones, which fell into the sea at a distance of more than 200 feet, while the glow of light above the crater was very brilliant, and continued incessantly.

Very striking, however, were the differences in the state of the volcano which were noticed by the same distinguished observer when, in the calm and sultry weather of July, 1771, he visited the island, and ascended to the crater. Then the slight ejections of stones, which never rose more than 100 feet above the crater, while very few of them fell outside its rim, took place at regular intervals of seven or eight minutes; and the glow of light above the crater was seen only at the moment of the explosion, or for a few seconds afterwards.

In August, 1788, Spallanzani saw "the fires of Stromboli" at a distance of 100 miles, the explosions at that time taking place at very irregular intervals. On the 1st and 2nd of October, in the same year, during very stormy weather, he found the eruptions of the mountain were so violent, that the whole island and the sea around were lighted up at times by them; the houses were shaken by the violent concussions of the air; and ashes fell in the inhabited parts of the island, two miles distant from the crater. Yet the islanders assured Spallanzani that much more violent outbursts sometimes took place. On the 3rd of October, when the weather fell calm, much slighter explosions were seen to take place at intervals of not more than two or three minutes. On the night of the 4th, when Spallanzani visited the crater, the ejections were found taking place in the same rapid manner, but with very varying degrees of intensity. The account given by the great Italian philosopher of what he witnessed within the crater is most graphic and interesting. On its western side a very great number of fumaroles were seen discharging jets of steam, while deposits of yellow salts were being formed round their orifices; but on its eastern side one large mouth poured forth a continuous column of vapour, about 12 feet in diameter. In the centre of the crater, however, still more striking appearances were exhibited, for here a funnel-shaped tube was seen containing liquid lava. This incandescent mass was agitated by two movements, "one intestine, whirling and tumultuous, the other that by which it was impelled upwards and downwards." This vertical motion, the utmost range of which was estimated at 20 feet, was sometimes slow, and at others more sudden; but, on its reaching a certain height, large bubbles were seen to collect on the surface of the glowing mass, and these, bursting with a sharp report, carried innumerable fragments of the liquid rock in a fiery shower into the air. After the explosion, the lava was seen to sink again in the tube, to recommence its rise after a short interval. On one occasion, however, Spallanzani witnessed a most interesting occurrence in the crater of Stromboli: the lava sinking lower than usual in the tube, while the fumaroles began to discharge with a deafening roar, their orifices at the same time becoming red-hot. This striking phenomenon soon ceased, however, the normal action of the crater being resumed; and Spallanzani was assured by his guides that this peculiar condition of the crater only rarely occurred, and was never of long duration. In connexion with this very remarkable circumstance, it may be well to recall the fact that, during the recent eruption in the crater of Vulcano, the fumaroles ceased to discharge, but that on its termination their activity was renewed with greatly increased violence.

Passing over the account of Ferrara in 1810, as well as some other descriptions of the features of the volcano in its ordinary condition of subdued activity, we will proceed to notice the admirably clear descriptions of an English naval officer, who, during the year 1813, was constantly cruising about these islands in a gun-boat, being employed in constructing the charts of the Mediterranean. The fact that he was not engaged in any special geological researches, and does not seem to have been acquainted with the writings of either Dolomieu or Spallanzani, gives his testimony on the subject all the value of that of a perfectly independent witness; and it will only be necessary to mention that this young officer subsequently became well known in the scientific world as Admiral W. H. Smyth, to satisfy our readers as to his competency and accuracy.[1]

Smyth, who ascended the mountain and spent a part of the night beside the crater, thus describes what he saw:—"When the smoke cleared away, we perceived an undulating ignited substance, which at short intervals rose and fell in great agitation; and, when swollen to the utmost height, burst with a violent explosion and a discharge of red-hot stones, in a semi-fluid state, accompanied with showers of ashes and sand, and a strong sulphurous smell. The masses are usually thrown up to a height of from 60 or 70 to 300 feet; but some, the descent of which I computed to occupy from 9 to 12 seconds, must have ascended above 1000 feet. In the moderate ejections, the stones in their ascent gradually diverged, like a grand pyrotechnical exhibition, and fell into the abyss again; except on the side near the sea, where they rolled down in quick succession, after bounding from the declivity, to a considerable distance in the water. A few fell near us, into which, while in the fluid state, we thrust small pieces of money as memorials for friends."

Valuable as is Smyth's evidence as to the nature of the phenomena displayed within the crater of Stromboli, his testimony to the fact that its eruptions are sometimes, and especially during stormy weather, of a much more violent character than ordinary, is equally clear, as the following passage will show:

"I was once going over, in my gun-boat, from Milazzo to Stromboli, when a furious south-east wind arose, and rendered it impossible to anchor before San Bartoli, where, on approaching, I observed the spray of the surf carried even to the houses: the only refuge to save us from being blown over to Calabria, then occupied by Murat, was to run almost under the crater in a nook of Schiarazza Point, where, for two nights and days, we rode in a state of partial security as to winds and weather; but certainly not without considerable danger from the incessant showers of red-hot stones that were hurled aloft from the crater with amazing rapidity, and most of which fell very near us, while some of them exploded in the air with a

[1] I am indebted to Mr. Warington W. Smyth, F.R.S., for giving me the date of his father's observations on Stromboli.

whizzing sound like the fragments of bomb-shells after bursting. The explosions followed each other in quick succession (not more than 5 to 10 minutes elapsing between) with a report like distant artillery; the moment of ejection was accompanied by brisk rattling detonations, and a full glare of fire, illuminating the storm at intervals, and presenting an awful and magnificent spectacle. At times, however, when the wind shifted a point or two, our admiration was checked, and we were obliged to run below, to avoid a thick cloud of minute sand and ashes, that instantly covered the vessel and filled her with a suffocating heat."

A little later Stromboli was visited by two English geologists, each of whom had paid particular attention to the character of volcanic action, and who were therefore well qualified to describe what they saw.

In May, 1819, Mr. Poulett Scrope ascended the mountain, and thus describes what he witnessed: "Two rude openings show themselves among the black chaotic rocks of scoriform lava which form the floor of the crater. One of these is to appearance empty; but from it there proceeds, at intervals of a few minutes, a rush of vapour with a roaring sound, like that of a smelting furnace when the door is opened, but infinitely louder. It lasts about a minute. Within the other aperture, which is perhaps 20 feet in diameter, and but a few yards distant, may be distinctly perceived a body of molten matter, having a vivid glow even by day, approaching to that of white heat, which rises and falls at intervals of 10 to 15 minutes. Each time that it reaches in its rise the lip of the orifice, it opens at the centre, like a great bubble bursting, and discharges upwards an explosive volume of dense vapour, with a shower of fragments of incandescent lava and ragged scoriæ, which rise to the height of several hundred feet above the lip of the crater. Many of the fragments do not reach so high. Part of them fall back within its circuit to be again rejected. A considerable proportion, however, falling on the steep talus already described on the north side of the vent, roll or slide down into the sea; and it is evident, from the crater continuing to retain its depth and form, that sooner or later, after perhaps repeated ejection, all must find their way there, to be distributed over the bottom of the Mediterranean."

As bearing on the variations in the intensity of action of the volcano, Mr. Scrope adds: "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 very soon be sealed up again, as the lava shortly after finds its way once more to the summit and boils up there as before."

A few years later (in 1824?) Dr. Daubeny visited Stromboli, but did not approach sufficiently near to the crater to observe its phenomena very minutely. He says: "The minor explosions were in general almost continuous, but that the greater ones, which alone were audible below, take place at intervals of about seven minutes: the latter are sufficiently terrific."

In 1825 Stromboli was visited by M. Biot, and in 1829 by M. Virlet and the commission despatched to the Morea by the French Academy. Each of these authors speaks of the explosions taking place at short intervals.

In 1831 the phenomena of this interesting volcano were studied at nearly the same time, but quite independently, by the two geologists who, in Germany and France respectively, have done more perhaps than any others for the promotion of the study of volcanic phenomena, more especially by combating errors, which in those countries so long retarded its progress. I refer to Friedrich Hoffmann and Constant Prevost. The former author has given us a detailed account of his researches, and the latter has borne witness to its substantial accuracy.

Hoffmann remained for three weeks in Stromboli at the end of 1831 and the beginning of 1832; he on three different occasions spent a considerable time on the edge of the crater, and minutely describes what he witnessed. He was convinced both from what he heard and saw, that the openings at the bottom of the crater vary in size, number and condition from time to time; shortly before his visit there were no less than seven openings in the crater, but when he examined it himself, there were but three: but these were seen to be quite distinct from one another both in position and in the nature of their action.

The largest of the openings occupied the centre of the crater floor, and gave forth vapours only, which produced yellow crusts on its sides. To the south-west of this, on the same level with it, and nearly under the crater-wall, another mouth about 20 feet in diameter was seen, which discharged abundant white clouds, and gave origin to constant smaller or greater explosions. In the interior of the glowing red throat of this chimney, a fluid column of lava could be seen moving up and down, and perhaps sinking to a depth of 20 or 30 feet below its summit. Through this column of liquid lava bubbles of steam burst with a noise which resembled that of a furnace when the door is opened; the puffs taking place regularly at intervals of about a second, and giving rise to the formation of globes of vapour, which, in issuing from the mouth of the aperture, carried up bladders of the liquid lava. This action continued often for more than a quarter of an hour, and then suddenly a louder detonation would be heard, which was followed by a violent escape of steam from the aperture and the ejection of a thousand fragments of glowing lava to a great height. Where the crater joins the steep slope of the Sciarra, a third and much smaller opening was seen, from which a little stream of lava, like a perennial fountain, was constantly issuing; it flowed down the Sciarra towards the sea, which, however, it did not reach, becoming solid before it arrived at the bottom; some portions, however, of the congealed mass were continually becoming detached and rolling down into the water. The position of this lava-stream on the Sciarra is represented in Hoffmann's drawing of Stromboli.

On the 25th of July, 1836, Abich visited the crater of Stromboli.

He saw in the midst of the crater a throat 60 or 70 feet in diameter, in which glowing lava could be perceived moving up and down; and several smaller openings were also visible by the side of it. Another mouth at the junction of the crater with the Sciarra discharged showers of stones at intervals of 6 or 7 minutes; the latter had formed a miniature cone about 20 feet high on the depressed edge of the crater-ring. The outbursts from this mouth were from time to time followed by the gushing forth of a little stream of lava from a cleft on the Sciarra, a little below the northern rim of the crater. The intervals between the explosions at the time of Abich's visit appear to have been very constant. Besides the larger mouths, there were numerous fumaroles within and about the crater.

In June, 1844, the crater of Stromboli was visited by MM. de Quatrefages, Edwards, and Blanchard. The first of these gives the following description of the state of the volcano at that time. The crater, which was well marked, presented several depressions, and *six very distinct* mouths were clearly visible in it. Two of these gave off steam exclusively. A third, on the right of the crater, produced an almost constant fountain of small, glowing fragments, which fell back within it; the action of this bocca was attended with a singular noise. On the right, three other mouths gave rise to intermittent explosions; two of these always acting simultaneously, at intervals of five or six minutes; while the sixth mouth appeared to be quite independent, and its much louder and more violent explosions occurred at intervals of 10 or 12 minutes. The stones thrown out by the latter rose to a height of more than 600 feet, those from the other two intermittent mouths to less than half that height. There was evidently a connexion between the first five apertures, for the action of the three constantly discharging vents was accelerated just before the explosions of the two smaller intermittent mouths; but the sixth and most powerful vent appeared to produce its explosions quite independently of all the others.

In the months of May, June, and October, 1855, and again in July 1856, Stromboli was visited by M. C. Ste.-Claire Deville. He fully confirms the great variations in the intensity of the explosions of the volcano. On the night of the 14th of October, M. Deville, profiting by a favourable condition of the wind, was able to examine the bottom of the crater. He found three open vents within it; one of these did not project any solid matter, but the vapours above it reflected a glowing light of varying intensity; the other two discharged stones with explosive outbursts. The largest of these mouths was in the midst of a little cone of scoriæ, near the centre of the crater, and it gave rise to an irregular succession of detonations, interrupted at intervals of about 15 minutes by explosions, producing magnificent "sheaves" of incandescent stones: the other opening was at the north-west angle of the crater, and gave rise to less violent explosions at intervals of about four minutes. On the upper part of the Sciarra, Deville saw, whenever the vapour drifted aside, an appearance, concerning which he was in doubt, whether it should be referred to a stream of lava, or an open fissure filled with incandescent material.

On the 2nd of July, 1856, M. Deville, accompanied by M. Bornemann, again ascended to the crater of Stromboli, and they record a most striking change in the condition of the crater. One very violent outburst took place, apparently from the mouth at the north-western side of the crater, but during the two days following only a series of very insignificant explosions occurred, sometimes almost uninterruptedly. They gave rise to only a feeble glow of light, and took place sometimes at the rate of three or four within the space of a minute.

M. Deville on several occasions carefully timed the intervals between the consecutive explosions in the crater as seen from the outside. On the night of the 31st of May, 1855, as witnessed from the sea, they were 15–3–15–17–11–15–16–3–4–8–16–4–5–3 minutes. On the night of the 14th October in the same year, as seen from the edge of the crater, they were 15–4–3–12–11–14–13–2–3–6–6–3 minutes. Of five successive intervals, noted in daylight on the 13th June, 1855, the longest was 21 minutes and the shortest 4 minutes.

In the latter part of 1864, Mr. Robert Mallet and Colonel Yule ascended to the crater of Stromboli. They were unable to see the floor on account of vapours which issued from the bottom and sides. Although the actual vents were not visible, Mr. Mallet was led to infer that the explosions took place from different points of its bottom, and he found the intervals between them to vary between 30 or even 40 minutes and 2 minutes. Each outburst "was preceded by several distinct low detonations, with intervals between each of from 4 to 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." The outbursts themselves are described as not being quite instantaneous in character, but as beginning with a hollow growl and clattering sound increasing to a roar, which endures for a few seconds to a minute or two, and then rapidly declines. Both the preliminary detonations and the shock of the outburst are stated to have sensibly shaken the ground on which the observers stood.

During the eruption of Etna in the beginning of 1865, Stromboli is said by the inhabitants of the island to have been in a state of extraordinary activity. The explosions were more violent than usual, liquid lava was emitted from the crater, and showers of ashes during several days covered the entire island. At the time when M. F. Fouqué visited the volcano, in the summer of the same year, it had, however, resumed its ordinary condition of subdued eruption.

In 1867, M. Jannsen made some spectroscopic examinations of the ignited gases within the crater of Stromboli; but his observations on this volcano appear to have been attended with considerable difficulty. In 1870, Dr. Julius Schmidt made some observations on the condition of the volcano.

On the 18th of April, 1874, after having on preceding days examined the lower portions of the mountain, I climbed up to the summit before sunrise, and descending thence a few hundred feet, spent five hours in examining the phenomena from near the edge of the crater. On this occasion, as in my other journeys in the Lipari Islands and Sicily, I was accompanied by Signor Pasquale Franco, of the University of Naples. During the ascent, I had a lateral view of the crater during one of the explosions, as seen from the side of the Schiarra; of this explosion I made the accompanying sketch (Fig. 12). On the north side of the crater a fissure is seen thickly encrusted with yellow salts, which is called the "Filo-della-solfre." The explosions appeared to me not to take place from the centre of the crater, but from near its north-western side.

Like all who have, during at least ten years past, examined the crater of Stromboli, I was prevented from seeing the interesting operations taking place at its bottom by the thick clouds of vapour, which were poured forth by innumerable fumaroles both within and around it. Seated near it, however, and occasionally getting glimpses of its interior when the wind drifted aside the heavy cloud of vapour, I was able to note the following phenomena.

A succession of loud snorting puffs like those of a high-pressure steam-engine, but quite destitute of their regularly rhythmical

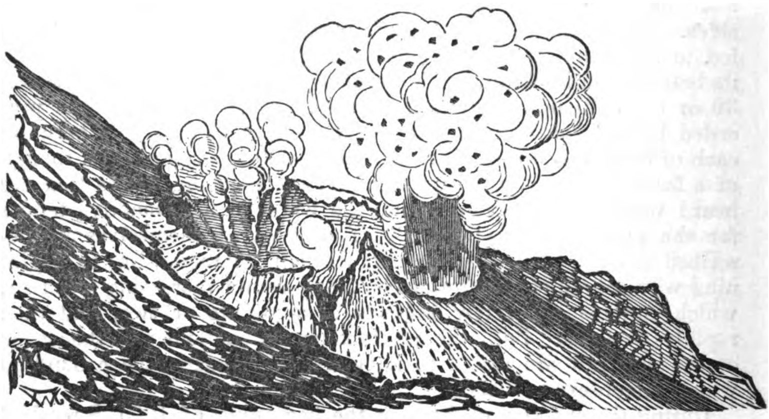
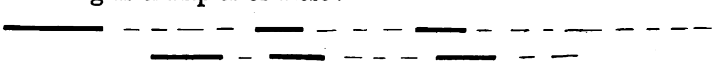


FIG. 12.—View of the active crater of Stromboli from the north side of the Sciarra, during an explosion.

character, were very distinctly audible. These were emitted continuously, but with most striking variations in their intensity, duration, and rate of succession. A long succession of slight short puffs would be followed by one or more longer and much louder ones. I attempted in my note-book to record the succession of these by means of lines, the length of which should represent the duration of the puff, and its thickness the intensity. I give the following as examples of these:—



and 

Sometimes the snorting sound would die away almost entirely, but at others it would burst out again suddenly with a loud series of sudden puffs.

From time to time violent outbursts of steam would take place at the bottom of the crater, carrying aloft fragments of lava, scoriæ, and ashes. So far as I was able to judge, these outbursts were not preceded by warnings of any kind, but occurred with the greatest suddenness. These outbursts certainly seemed to me to be quite independent of the puffing sounds, and, I can scarcely doubt, took place from a different mouth. The sound which accompanied the explosions was always sudden, but by no means violent. It did not in the least resemble the report of a cannon, but rather the rushing sound which is heard when a large number of rockets are discharged simultaneously. The noise of the falling fragments, falling upon and rattling down the sides of the crater and the Sciarra a few seconds after, was quite as striking as that of the explosion itself.

After watching the explosions for a considerable period, both on this and several other occasions, I found myself quite unable to correlate, in any way, the force and duration of the explosions with the intervals between them. I feel strongly led towards the conclusion that there were at least two orifices within the crater discharging independently. On several occasions two explosions were so close to one another, that I can hardly believe they took place from the same mouth. The observations of MM. Abich, de Quatrefages and Deville lend great support to this supposition.

I was informed by very intelligent residents in the island, namely the priest and his brother, whom I closely questioned upon the subject, that the most striking variations occur in the condition of the volcano. Sometimes, in summer, intervals of considerable length, occasionally extending to two hours, were declared to pass without any explosion. During the winter, however, it was said very violent outbursts sometimes take place. Large stones fall in the cultivated and inhabited portions of the island (and some of these I was shown); streams of lava flow down the Sciarra into the sea; and dead fish in great numbers are found floating around the island.

The succession of explosions which I witnessed on different occasions may thus be represented, using M for an outburst of moderate intensity, v for a violent, and V for an excessively violent one; s stands for slight, and S for very slight explosions. The intervals between them are given in minutes:—

On the 18th of April, 1874, commencing at 7·13 A.M.

M 6½,—M 4¾,—v 16,—M 4,—v 11,—s 2¼,—s 2¾,—S 5¼,—V 6¾, v 3¾,—M 7¾,—v 1½,—S 4,—M 9,—s ½,—s 2½,—M 3,—M 1¾,—s 2¼, S 4,—M ¾,—M 5¼,—M 4,—s 1¾,—S ¾,—M 1,—S 5½,—M 3½,— s 10½,—M 5,—v 5,—M 1½,—v 18½,—V 2¼,—M 2¼,—M 8¾,—V 5, M 5½,—s 2½,—S 6½,—S 1¼,—s 1¼,—S 6¼,—v 3¾,—M 3½,—s 1½,— S 8,—s ½,—S 2,—s 2½,—s 6,—M 3,—s 4,—v 1¾,—s 5½,—V.

On the 24th of April, 1874, beginning at 4·56 A.M.

V 10¼,—s 5¼,—s 1¾,—v.

On tbe 25th of April, beginning at 7·8 P.M.

v 30,—s 1,—V $3\frac{1}{2}$,—v 2,—S 1,—s $\frac{1}{2}$,—v $3\frac{1}{2}$,—M $2\frac{1}{2}$,—M $4\frac{1}{2}$,—M 2,—M $1\frac{1}{2}$,—S 1,—v $1\frac{1}{2}$,—M $8\frac{1}{2}$,—V $2\frac{3}{4}$,—S $4\frac{1}{4}$,—s 2,—v $2\frac{1}{2}$,—s $\frac{1}{2}$,—M 2,—V 5,—s 3,—M $1\frac{1}{2}$,—V 3,—M 6,—V 10,—M $1\frac{1}{2}$,—M 5,—V $1\frac{1}{2}$,—s $3\frac{1}{2}$,—M 3,—S $3\frac{1}{2}$.

Having thus given a *résumé* of the observations which have been made on the very interesting volcano of Stromboli during more than a hundred years, we may proceed to summarize those facts concerning its general features, and the nature of the operations going on within it, which these observations combine to establish.

With respect to the heights of the various parts of the mountain, the position and relations of its crater, and the depth of the sea around it, Mr. Robert Mallet has lately cast doubt on the accuracy of the statements of previous observers, and has published a series of "hypsometric measurements," which were made by him in 1864, "by means of a single aneroid," and of soundings made in positions which were "guessed" by himself and a friend. On the basis of these corrected measurements, Mr. Mallet has put forward a very novel and startling theory, namely,—that Stromboli is not an ordinary volcano, as every previous observer had supposed, but a singular combination of a geyser and a volcano!

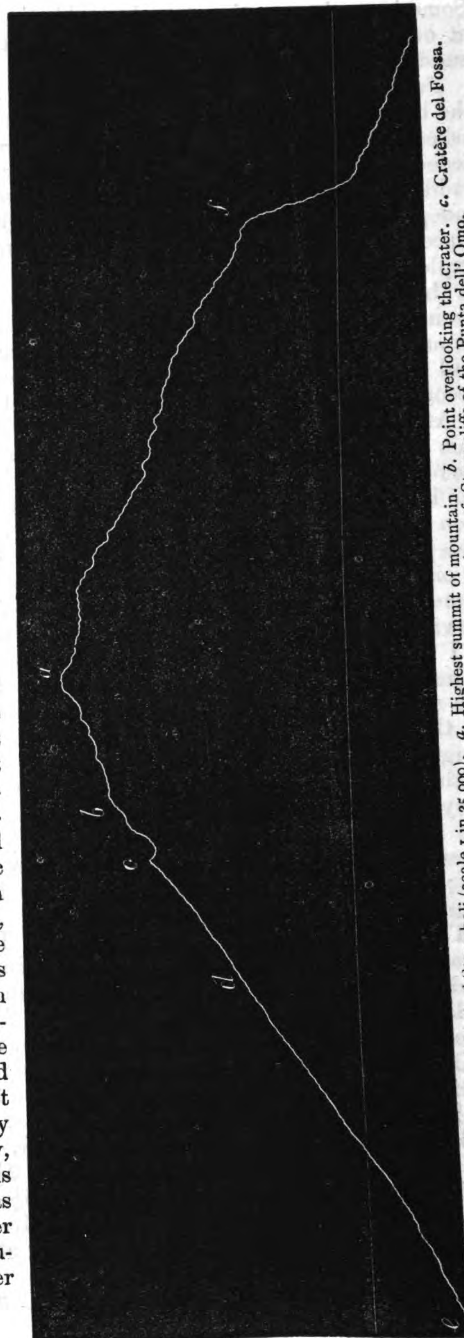


FIG. 13.—Section through the Island of Stromboli (scale 1 in 25,000). *a*. Highest summit of mountain. *b*. Point overlooking the crater. *c*. Cratère del Fossa. *d*. Sciarra del Fuoco. *e*. Steep submarine slope, forming its continuation. *f*. Steep cliffs of the Punta dell' Omo.

It is certainly to be regretted, not only on Mr. Mallet's own account, but for the sake of the credit of British science, that, during the ten years which elapsed between his obtaining these observations and his publication of the extraordinary theory which he has founded upon them, no attempt seems to have been made by this author, either to verify or check his measurements, although the most ample means existed, in numerous official publications, for so doing.

In order to give a distinct idea of the true relations of the different parts of the volcano, I have constructed a section (see Fig. 13) on the natural scale, passing from N.W. to S.E., through the Sciarra del Fuoco, the summit of the mountain, and the Punta dell' Omo. This section is based on the large map constructed by the Italian Instituto Topografico Militare, and on the splendid Chart of the Lipari Islands issued by the French Government, from the surveys made by MM. Darondeau, Gaussin, Boutroux, Manen, Larousse, and Vidalin in 1857 and 1858. In all its main details, too, the accuracy of this section is confirmed by the English and Neapolitan Admiralty Charts, and by the observations of Abich, Hoffmann, and other geologists.

Both of the official documents referred to give the height of the mountain as over 3000 feet. The elevation of the ridge overlooking the crater, which Mr. Mallet states as only 1200 feet, has been shown by repeated measurements, which I can myself confirm, as being only about 600 below the summit, or at least 2400 feet, that is, *twice* the amount given by Mr. Mallet!

The outer lip of the crater (or, in other words, the top of the inclined plane of the Sciarra del Fuoco) and the bottom of the crater are points quite inaccessible to the observer; but there nevertheless exist means of estimating their true elevation above the sea-level. Abich, who under-estimated the height of the summit of the mountain by about 200 feet, on the supposition that the inclination of the Sciarra was only 30°, fixed this point at 1645 feet above the sea-level. Mr. Mallet measured the slope of the Sciarra with the clinometer as from 34° to 36° with the horizontal, and I am convinced from my own observations that 35° is about a fair average. The exact position of the crater and its relation to the other parts of the island being given in the map of the Italian Government, we are thereby able to fix the elevation of this point as a little over 2200 feet. Mr. Mallet states it to be only 600 feet! Calculating from the positions of the several points as given on the map, this would make the slope of the Sciarra only 11°, which is not only quite at variance with Mr. Mallet's own measurements, but would be at once rejected by every one who had seen either the island itself or any drawing of it. With respect to the elevation of the bottom of the crater, which is probably liable to constant variation within small limits, I am in the same predicament as Mr. Mallet, having never succeeded in getting a sight of the crater-floor, owing to the clouds of vapour proceeding from the fumaroles. Several accurate observers who have seen it, however, declare it to be situated only a short distance below the outer lip. The estimate of at least 2000 feet, which most authors have given for the elevation of the bottom of the crater of Stromboli, we must, therefore, regard as certainly *below* the truth, while Mr. Mallet's statement that it "cannot be more than 300, or at most 400 feet, above the level of the sea," is altogether erroneous.

Lastly, Mr. Mallet's assertion that the Admiralty Chart indicates "that for some miles in the offing here the Mediterranean does not exceed 100 fathoms in depth," is to me simply inexplicable—since the English, French and Neapolitan Admiralty Charts all give numerous soundings of more than twice that amount, within a mile of the shores of Stromboli, while within a few miles of the island soundings of more than 700 fathoms occur.

Mr. Mallet's hypothesis of "the Mechanism of Stromboli" is based entirely on these grossly inaccurate "measurements;" and as it has already been criticized by Mr. Scrope in the pages of the Geological Magazine, I am spared the necessity of dwelling longer upon this painful subject.

Nearly every observer who has studied the phenomena presented by Stromboli, has been convinced that the permanent character of its action is connected with the existence of the steep slope of the Sciarra, which enables the ejected materials, sooner or later, to roll down into the sea, instead of accumulating around the vent and stifling its action for a time, only to lead to more violent paroxysms. The formation of the present crater, with the steep slope of the Sciarra leading down from it to the sea, was ascribed by Mr. Scrope in 1825 to some violent paroxysm, which had destroyed a large portion of that side of the mountain. This explanation is accepted by Hoffmann, and nearly every other geologist who has examined the question. Abich, indeed, not unjustly compares the destruction of one side of the mountain and the formation of an eruptive centre at a lower level, to the catastrophe which in the year 79 A.D. resulted in the blowing away of one side of the ancient Somma, and the rise of the modern cone of Vesuvius in its midst.

Let us now proceed to notice the character of the operations going on within this still active crater of Stromboli. These operations appear to have been, during the last 2000 years at least, of a comparatively *moderate* character. We have no record or tradition of the activity of the mountain becoming so violent as, in the case of Vulcano, to drive away the inhabitants, who have formed settlements (having a population in 1871 of 1,999) on the lower slopes of the island, at a distance of two miles from the crater. On the other hand, that the action is sometimes so energetic as to shake the whole island, to cover every part of it with showers of ashes, and to result in outflows of lava from the active crater and other portions of the flanks of the volcano, we have the clearest evidence.

With regard to the condition of the interior of the crater of Stromboli, we have also proofs of the occurrence of continual changes, similar to those which have been noticed in Vesuvius, and all other volcanos that have been systematically studied. That the bottom of the crater is a thin and variable crust, which covers a mass of incandescent and liquefied material, and that this heated mass communicates with the atmosphere by openings in the crust, which are continually changing in number, size, form, and position, no one can doubt who reads the account of the appearances presented by the interior of the crater at different periods. According to the nature of these openings, and their relations to the incandescent fluid mass beneath, they are found quietly giving off jets of vapour and gas,—violently discharging columns of steam,—permitting liquid lava to rise and fall within them, and to be dispersed by sudden and intermittent explosions,—or giving origin to small streams of lava. That, during the more violent eruptions, when the constant red glow above the mountain testifies to the existence of incandescent materials within the crater, and when abundant streams of lava flow down into the sea, the solidified crust forming the bottom of the crater is temporarily destroyed, we can scarcely doubt. Stromboli, indeed, appears to present, on a smaller scale, precisely the same characters with those seen in the volcano of the Ile de Bourbon, as described by Bory de St.-Vincent, and in the crater of Kilauea in Hawaii, as described by Dana and other observers.

That the more violent states of activity in Stromboli coincide with the winter seasons and stormy weather, and its periods of comparative repose occur during the calms of summer, is established, not only by the universal testimony of the inhabitants, but, as the foregoing accounts will show, by the actual observations of many competent authorities.

The very graphic accounts which we have quoted of the appearances presented by the liquid lava as seen rising and falling in the vent, agitated by whirling movements, and swelling up into vast bubbles which suddenly burst and give off clouds of vapour, are strongly suggestive of the same conditions as exist when any liquid or viscous material is heated, especially in a deep and narrow vessel, over the fire. In such cases, as vapour is being disengaged *within* the heated mass, the whole is kept in violent agitation; the small bubbles collecting into large ones force the whole mass upwards, and if the heat be not moderated, these bubbles burst on reaching the surface, and scatter the materials with explosive violence. That the lava of volcanos is a fluid mass containing imprisoned water, which, as it is relieved from pressure, flashes into steam, is now recognized by all geologists.

That the barometrical condition of the atmosphere must exercise a powerful influence on such a series of operations, as are seen to be going on within the crater of Stromboli, few probably would be bold enough to deny. Whether the notion, which, as we have seen, has prevailed in these islands from the earliest times concerning which history or tradition affords us any record, namely, that the state of the volcano enables the observer to *predict* the changes of weather, is a totally different question. Until we are able to appeal to an accurate series of meteorological observations, carried on concurrently with others on the condition of the volcano, the question must remain an open one. But every careful observer will willingly subscribe to the words of Spallanzani on the subject: "I should think myself justly to incur the imputation of rashness, should I venture to deny these facts, without having sufficient reason so to do; especially as they are so precise, so circumstantial, and said to have been observed upon the spot."

Stromboli consists, as we have already seen, of an older central cone, composed of trachytes, coated on all sides by thick masses of more recent basaltic lavas and agglomerates (see pp. 11 and 22). As in the case of Vesuvius and many other volcanos, very beautifully crystallized minerals (especially augite), which must have been formed *within* the vent, are ejected from its crater.

In bringing these sketches of the Lipari Islands to a close, I may notice an interesting circumstance, to which my attention has been drawn by Professor Suess, of Vienna. That geologist has recently published an important memoir, entitled "Die Erdbeben des südlichen Italien," and he has been good enough to point out to me that the lines of fissure, which, from a study of the seismic phenomena of Sicily and Calabria, he has inferred traverse those districts, point, like those which I have determined on totally different evidence, to the central submerged tract of the Lipari Islands.

The Island of Ischia.

Perhaps no district of equal area could be named in which so many instructive illustrations of volcanic action may be witnessed as the beautiful island of Ischia. Although only about six miles long by four broad, yet this island exhibits a great central volcanic mountain,—named "Epomeo"—surrounded by numerous parasitical cones and craters, which, alike in their features and their products, present the most interesting variations.

After the well-known descriptions which have been given of the island by Sir William Hamilton, Scrope, Daubeny, James D. Forbes, Scacchi, and many other observers, and the more complete treatises of Signor Ferdinando Fonseca and Herr C. W. C. Fuchs, dealing respectively with its palæontological and petrological features, any further account of its geology may seem to be unnecessary. But a study of the physical features presented by the island, aided by the light thrown upon them by the numerous valuable researches above alluded to, appears to me to lead to a more complete realization of the nature, mode of action, and succession of the forces to which the production of those features was due, than has as yet been published, and enables us to reconstruct, in a more complete manner than has been hitherto attempted, the geological history of the island. In the following descriptions, therefore, I shall pursue the chronological method, and, beginning with the oldest formations, gradually pass to those of more recent date, until we at last reach those the production of which is noticed in historical records.

The island of Ischia, like those of Vivara, Procida, and Nisita, is merely an outlying portion of the Campi Phlegræi of Naples; and the conclusions to which we are led concerning the nature and age of the tuffs and lavas of the island we are especially describing, are almost equally applicable to those of the whole district. The two principal volcanos of this area are Vesuvius (including under that name the more ancient Somma as part of the same mountain) and Epomeo; the former of which consists of a central cone within a semi-circular crater-ring, composed of trachytic-tuffs enveloped by lava and agglomerates of leucitic basalt, which have been the products of all its later eruptions; the latter is a ruined tuff-cone, surrounded by numerous parasitical vents, the lavas and fragmentary materials produced by which have all been of trachytic character.

A line drawn through Epomeo and Vesuvius would, if produced, strike the volcanic region of Monte Vultur in one direction, and that of the Ponza Islands in the other; and the numerous cones, crater-rings, and crater-lakes of the Campi Phlegræi all appear to be arranged along lines parallel to this series of grand volcanos.

We can scarcely doubt, therefore, that this linear and parallel arrangement points to the existence of a corresponding series of subterranean fissures, by means of which the igneous products, whether of recent date or belonging to older geological periods, were enabled to reach the surface.

The oldest portions of the volcanic rocks of Ischia are unquestionably the series of pumiceous tuffs of a greenish colour which make up the great central cone of Epomeo. That this tuff has been formed from an ordinary trachytic lava, through the distension and dispersion of portions of its mass at periods of eruption by the imprisoned gaseous and liquid materials, there is clear proof afforded in its general characters, and chemical composition. We may indeed call this tuff the "froth" of trachyte, and compare its relations to that rock with those which subsist between the wave and the wreaths of foam driven from its summit. The following analyses illustrate the composition of these tuffs of Epomeo, and prove its general identity with those of the Phlegræan fields, of which numerous analyses have been published:—

	Analysis of the Green tuff of Epomeo by C. W. C. Fuchs, 1872.	Analysis of the same by H. Abich, 1837.
Silica	54·69	54·57
Alumina	20·00	17·93
Ferric Oxide	3·13	} 5·49
Ferrous Oxide	2·26	
Lime	2·17	0·77
Magnesia	0·70	0·77
Manganese	0·02	—
Potash	4·77	5·23
Soda	0·28	6·40
Phosphoric acid	0·021	—
Water and loss	11·61	8·19
	99·65	99·35
Specific gravity	2·17	2·52

Concerning the conditions under which this green tuff of Epomeo was formed, we are fortunately not left in any doubt. It consists entirely, as we have seen, of pumiceous fragments, mingled with broken crystals of sanidine and numerous plates of black mica; these being the most common of the minerals included in the ordinary trachytes of the district. The mass is often found to contain, moreover, volcanic-bombs, and the proof of the tuffs having been the result of the ordinary explosive action of volcanos is, therefore, most complete. But mingled with these tuffs are found very numerous marine shells, specimens of which I collected up to a height of 1846 feet on the slopes of Epomeo, and they have been recorded as occurring even at still greater elevations. It would seem clear, therefore, that the tuffs must have been accumulated beneath the sea-level, but at such moderate depths as not to prevent the ordinary explosive action, and that disengagement of imprisoned vapour and gas, to which the pumiceous structure is evidently due, readily taking place. In opposition to the view put forward by some geologists,—namely, that lava when poured forth under water gives rise to a totally different series of products from those formed by subaerial volcanic action,—I may point to the fact that these undoubtedly marine tuffs of Epomeo, abounding in shells, offer no essential points of difference from the tuffs of Bagno Secco in Lipari before described, or those of Somma, both of which, as we have seen, contain numerous leaves and other remains of terrestrial plants, and were clearly of subaerial origin.

But in the case of the tuffs of Epomeo we have another interesting proof of its submarine mode of origin. The tuffs are sometimes interstratified with "marls," "clays," and white calcareous rocks of a chalk-like aspect. The interesting analyses of these, however, by Fuchs, show that they are all formed from the volcanic tuffs by ordinary aqueous erosion, aided to some extent by the passage through the mass of gases and vapours, and the ordinary action of organic beings living on the sea-bottom, especially of the mollusca, in separating the carbonate of lime. In illustration of this statement, we may quote the following analyses:—

	(a)	(b)	(c)	(d)
Silica	59·88	58·31	46·28	57·20
Alumina...	17·28	19·79	12·71	15·71
Ferric Oxide	5·06	2·86	4·46	5·51
Ferrous Oxide ...	2·30	2·11	2·14	2·64
Lime	1·69	0·70	11·27	1·16
Magnesia	0·80	0·81	2·17	2·68
Manganese	trace	—	—	—
Potash	6·43	6·29	2·58	3·19
Soda	2·97	2·88	0·82	1·01
Water	3·69	7·24	8·67	10·71
Phosphoric Acid ...	0·043	—	—	—
Carbonic Acid ...	—	—	8·13	—
	100·14	100·99	99·23	99·81

(*a*) represents the composition of the so-called marl of Epomeo, which is very largely dug, and both at Casamicciola and Naples, to which latter place it is largely exported, used for making tiles and pottery; (*b*) is the analysis of the concretionary nodules resembling the masses, often septariform, which abound in so many clays and marls; (*c*) a similar fine-grained white rock, but containing 18·44 per cent. of carbonate of lime; and (*d*) the composition of the residue of the same rock after the carbonate of lime, doubtless owing its presence to organic remains, has been removed by acetic acid.

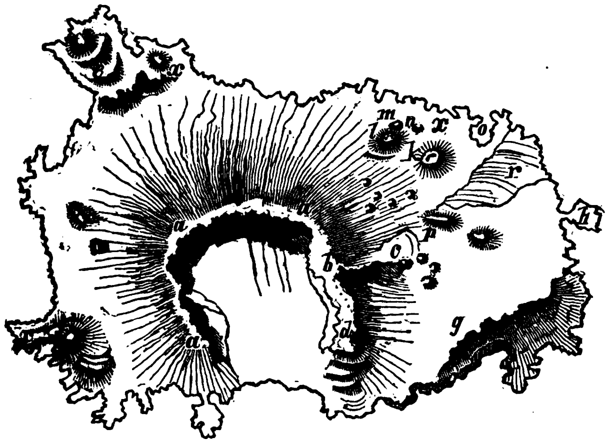


Fig. 14.—Plan of the Island of Ischia.

a, a, a, The semi-circular Crater-ring of Epomeo.
b, c, d, M. Vetta, M. Trippia, and M. Garofali; portions of lavas proceeding from central crater
e, f, g, h, Plateaux composed of old lavas.
k, Montagnone
l, Monte Rotaro
m, Monte Tabor
n, Castiglione
o, Lago di Bagno
p, The Cremata
r, Lava of the Arso
(*k*–*r*: Products of the most recent eruptions.)
x, x, x, Raised beaches.

The mountain of Epomeo or S. Nicola attains a height, according to the measurement of Scacchi, of 2608 feet. The mass of tuffs of which it is composed constitutes a great semi-circular wall surrounding a vast crater (see Plan of the Island, Fig. 14), about two miles in diameter, at the bottom of which are situated the villages of Fontana and Meropano. The depth of this great crater, of which the walls unsustained by the binding courses constituted by lava-streams, or the buttresses formed by dykes, are in a state of great ruin from denudation, is about 2000 feet. At its eastern extremity the great wall bounding the crater on its northern side is 2215 feet above the sea, and several of its highest peaks are in this part over 2500 feet; on the west and south-west this crater-wall is found to gradually decline in elevation, until above Serrara it is only 1276 feet. On its south, south-east, and eastern sides the crater-rim has been almost completely destroyed, owing to causes which will be presently noticed.

On its outer slopes the great cone of Epomeo is made up of fine-grained, well-stratified tuffs, dipping outwardly from the centre, and alternating with beds of so-called clay, marl and chalkymarl, produced by aqueous and organic agencies from the igneous products. But in its central parts, and within the great crater, the mass is composed of much coarser materials, and includes angular blocks and bombs of large size.

The causes of the destruction of the vast crater of Epomeo we have not far to seek. Its walls being wholly built up, as we have seen, of loose tuffs, it is evident that the weight of any great mass of lava rising through the vent would inevitably, if it did not force an exit for itself nearer the base of the mountain, carry away the weakest side, and thus breach the crater. That the crater of Epomeo was thus breached on its eastern side we have very clear evidence. It is true that the great streams of lava which have flowed from this side of the crater down the slope have been cut up into a number of isolated plateaux by aqueous erosion, but a comparison of the slopes and elevations of these surviving portions furnishes us with the clearest evidence of their former continuity. Thus Monte Vetta exhibits the great bed of trachyte, which is nearly 200 feet thick, at an elevation of 1651 feet; in Monte Trippia it rises to 1341 feet; while in the hill of Moscardine it is only about 900 feet. In Monte Garofali we find another great mass, perhaps a portion of the same sheet. And all have a similarly inclined position dipping from the great central crater of Epomeo.

All the lavas of Ischia, from the oldest to those more recent ones which we shall hereafter describe, are of trachytic character; but although their ultimate chemical composition is almost identical, they nevertheless offer some very interesting peculiarities with respect to the minerals into which their elements are combined. The trachytes of Ischia are made up of a crystalline base composed of both orthoclastic and plagioclastic felspar, throughout the mass of which large and brilliant crystals of sanidine, with smaller ones of sodalite, hornblende, mica, mellilite, magnetite, and ilmenite are scattered in various proportions. Sometimes the whole passes into a compact rock; at others we find a stony base containing the sanidine and other crystals; while occasionally the base becomes vitreous and the rock passes into a porphyritic obsidian ("obsidian-porphyry" or "pitchstone-porphyry"). Sometimes again, as in the case of the quartz-trachyte or Liparites of Ponza, Lipari, etc., the true trachytes of Ischia exhibit compact and vitreous portions combined in alternating bands.

As examples of the composition of the coarsely crystalline light-coloured trachytes of Ischia, we may cite the following analyses from Fuchs and vom Rath:—

	Monte Vetta.	Scanella.	Scarrupata. I.	Scarrupata. II.	Marecocco.
Specific gravity ...	2·45	—	I.	II.	2·43
Silica	61·87	59·12	62·95	65·75	61·49
Alumina...	18·33	21·46	18·26	17·87	20·02
Ferric Oxide	3·23	2·68	4·46	4·25	3·11
Ferrous Oxide ...	2·51	2·72	—	—	2·72
Lime	2·11	2·16	0·84	1·33	1·88
Magnesia	0·65	0·84	0·63	0·52	0·52
Potash	6·51	7·66	6·06	3·48	7·13
Soda	5·07	3·78	7·17	5·36	3·39

I have omitted from these analyses the small proportions of sodic chloride, phosphoric acid, etc., which they contain.

As examples of the compact and dark-coloured trachytes, we may notice the following:—

	Monte Campagnano.	Monte dell' Imperatore.	Punta della Cima.
Silica	63·06	61·05	61·55
Alumina	18·32	18·35	17·81
Ferric Oxide ...	3·22	4·21	3·01
Ferrous Oxide ...	—	2·12	2·60
Lime	2·53	2·05	1·69
Magnesia	0·93	0·90	0·47
Potash	7·52	5·28	7·51
Soda	3·08	5·94	4·08
Specific gravity ...	2·48	2·53	2·46

These trachytes are all apparently of considerable antiquity. That of Monte Vetta forms, as we have seen, a number of isolated plateaux, once a connected lava-stream, which breached the great crater of Epomeo on its western side. The other lavas also form plateaux of ancient date, which flowed from some portion of Epomeo, or from lateral cones on its flanks. The original points of outburst of these lava-streams can now, however, be no longer traced, so greatly have they suffered from denudation. Some of these lavas, like those of Scarrupata and Monte Vetta, are remarkable for containing sodalite, as shown by vom Rath. Others, like those of Monte Marecocco, etc., are distinguished by the presence of mellilite. The compact lava of Monte Campagnano in places becomes vitreous, and passes into obsidian, and it occasionally exhibits a banded or ribboned structure, veins of vitreous alternating with others of stony lava.

These lava-streams frequently cap masses of tuff, and are sometimes interbedded with such materials. In some cases these tuffs are made up of fragments of trachyte distended by gas; in others they are decidedly pumiceous, and have been evidently formed from a glassy rock. As an example of the former, we may cite the trachyte tuff of Punta S. Angelo; of the latter, the pumice-tuff and pumice of Monte Vico:—

	Trachyte-tuff of Punta S. Angelo.	Pumice-tuff of Monte Vico.	Pumice of Monte Vico.
Silica	53·71	54·02	60·06
Alumina	16·35	18·18	16·42
Ferric Oxide ...	2·82	3·64	3·01
Ferrous Oxide ...	2·19	2·23	2·33
Lime	1·38	2·01	1·37
Magnesia	0·55	0·79	0·40
Potash...	6·73	3·86	8·05
Soda	2·53	1·71	3·20
Water...	14·43	14·30	5·27

The whole of the rocks which we have now described as occurring in Ischia are of such ancient date that they have suffered very greatly from the denuding action of subaerial forces. The lavas which now cap the highest hills must have originally flowed along the bottoms of valleys, the sides of which have been since removed. Streams have cut ravines hundreds of feet in depth through the hardest lava-beds, leaving isolated portions of them forming high plateaux; the sea has eaten into the coast-line, causing the hardest and most solid masses to project as great promontories; and landslips, probably resulting from earthquakes (to which the district is particularly liable), have done much in bringing the central cone of Epomeo into its present ruinous condition. But vast as are the changes which have been produced by denuding forces upon these older portions of the island, yet that these latter have all been formed within a period which is, *geologically* speaking, very recent, is shown by the fact that, with one or two exceptions, all the fossil shells found in the tuffs (now raised to a height of 2000 feet in Epomeo) are still living in the neighbouring Mediterranean.

At various points, however, around this old extinct volcano of Epomeo, and especially on its north-eastern side, we find a number of cones and lava-streams, which by their fresh appearance are seen to be clearly of much more recent date; and of some of these the formation is recorded in historical documents. The relations of the ruined central volcano of Ischia, with its lava-streams cut up by denuding action into isolated plateaux, to the surrounding cinder-cones and lavas, are precisely similar to those which were so long ago shown by Mr. Scrope to subsist between the three great volcanos of Central France and the numerous "puys" which surround them. The series of efforts to which the Italian group of volcanos owes its origin must evidently have taken place within a much shorter geological period than those of Central France, which go back as far as the Older Miocene period; while the latter are, however, apparently quite extinct, the former are probably only passing through an interval of repose separating periods of paroxysmal violence.

Of the later-formed volcanic vents ("puys") of Ischia, the principal are Montagnone, Monte Rotaro with Monte Tabor, the Castiglione, the beautiful lake-crater known as the Lago del Bagno, and the modern cinder-cone of the Cremate, of the formation of which in 1301 we have the clearest historical records.

Montagnone is a very perfect cone rising to the height of 1084 feet, and presenting at its summit a crater of oval form, the bottom of which is 760 feet above the sea-level. The cone is almost completely made up of trachytic scoriæ and blocks of trachyte of all sizes. Trachytic lava of extremely viscid character appears also to have flowed from it, one narrow stream carrying away the eastern side of the crater and flowing down towards Bagno, while a wider current has broken down part of its northern side and cascaded down a steep slope, exhibiting a remarkable banded structure where the tension of the very imperfectly liquid mass has evidently been most violent. Neither of these streams, however, was able to flow far, nor to spread itself beyond the slope of the mountain. Many of the Ischian lavas, indeed, appear to have been exuded in a condition of such extreme viscosity that they accumulated immediately around the vent in vast hummocky masses; and in some cases it is difficult to decide whether we are dealing with the highly scorified surface of a solid mass of lava, or the agglutinated fragments of similar materials. Several active fumaroles still exist about Montagnone, and if we may be permitted to judge from the much less weathered condition of its rocks, almost destitute of soil and vegetation as they are, we should pronounce this cone to be of even more recent date than Monte Rotaro.

This latter cone is situated on the western side of Montagnone, and is so contiguous to it that in their lower portions the slopes of the two hills blend with one another. The highest point of the beautiful cone of Monte Rotaro is on its S.S.W. side, and is 982 feet above the sea; the lowest point of the crater-ring, on its western side, is 677 feet; while the floor of the crater is only 570 feet. Nothing can be more striking than the contrast between the appearance of Rotaro and Montagnone, the latter being remarkable for the barrenness of its bristling surface of lava, while the former is completely clothed with the most luxuriant trees and shrubs. The interior of the crater of Rotaro, especially, presents the most picturesque appearance, offering some analogy with the well-known much-larger crater of Astroni, near Naples. The extraordinary fertility of the soil formed by the decomposition of the volcanic rocks, combined with the sheltered situation, and perhaps also the subterranean heat (for hot vapours issue from the rocks at a number of points), have caused the ordinary shrubs of the Mediterranean area to assume a luxuriance unknown to them elsewhere. It is even said that the abnormal development of certain forms growing in this natural hot-house is so great as to make the species in some cases difficult of recognition.

The cone of Monte Rotaro is made up of an agglomerate containing blocks of all sizes of the ordinary sanidine-trachyte, more or less scoriaceous, and sometimes becoming pumiceous. Among the blocks are many composed of sanidine-trachyte with a vitreous base (pitchstone-porphyry), the glass being of a jet black colour, and the brilliant white crystals of sanidine scattered through it giving the rock a most striking appearance. When the glassy base of this "pitchstone-porphyry" or porphyritic obsidian is distended by gases, it passes into pumice, which still contains entangled among its fibres the fine crystals of sanidine, showing clearly that these latter must have been formed *within* the volcano, and not during the progress of the cooling of the lava.

It must of course be borne in mind that, as was clearly pointed out by Abich, we have two distinct series of obsidians and pumices, the one corresponding to the *quartz*-trachytes, and the other to the *ordinary* trachytes. Of the first of these we have already given many illustrations in describing the Lipari Islands; of the latter we can perhaps nowhere study more interesting examples than in Ischia. All volcanic rocks may pass into the vitreous condition, but their tendency to do so seems to be directly related to the proportion of silica which they contain. Thus by far the most abundant obsidians are those which correspond to the highly acid lavas, the quartz-trachytes or Liparites; next in order, but far less abundant, are the obsidians like those of Ischia, which are of the same chemical composition as the ordinary trachytes; while the basic lavas only very rarely assume the glassy condition (tachylite, etc.). The following analyses of an Ischian pumice by Abich, and of the "obsidian" of Monte Rotaro by Fuchs, may be compared with those of the more acid glasses of Lipari, which analyses have been already given on page 62.

	Pumice of the Island of Ischia.	Obsidian of Monte Rotaro.
Silica	62·29	60·77
Alumina	16·89	19·83
Ferric Oxide	—	4·14
Ferrous Oxide	4·15	2·43
Lime	1·24	1·63
Magnesia	0·50	0·34
Potash	3·98	6·27
Soda	6·21	4·90
Water, etc.	3·89	0·24
Specific gravity	2·4172	2·44

The bottom of the crater of Monte Rotaro is a small level plain about 70 yards in diameter; around this the walls of the crater rise to heights varying from 400 to 100 feet. The irregular height of the crater-walls appears to be the result of denudation; for though several lava-streams have issued from it, notably one on its southern side, yet the crater seems to have been reformed subsequently to the outflow of the last of them. Indeed, as we shall now proceed to show, the streams of lava of the latest eruptions of Monte Rotaro appear to have proceeded from its base, and not from its summit, the crater remaining unbreached.

On the northern slope of Monte Rotaro are situated two small ruined cinder-cones, which bear to that volcano the same relation which it does to the central mass of Epomeo. These smaller and more modern vents are Monte Tabor and the Castiglione. (See Fig. 15.) The little cone of Monte Tabor is made up of an agglomerate of

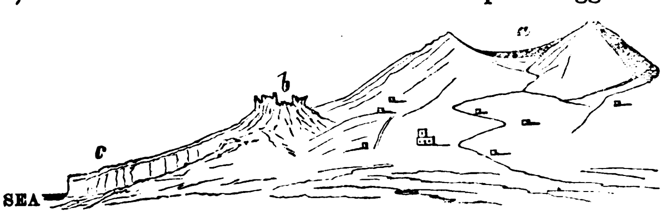


FIG. 15.—MONTE ROTARO with MONTE TABOR at its foot, as seen from CASAMICCIOLA. *a*, the crater of Rotaro. *b*, the ruined cone of Tabor. *c*, the lava-stream flowing to the sea and well exposed in a series of quarries.

blocks, some of which are of great size, and are always more or less scoriaceous. Mingled with the scoriæ are many fragments of the ordinary tuffs of Ischia, and of the same peculiar trachyte which has flowed from the cone. These are often burnt to a bright-red colour. Near the south foot of Monte Tabor an old "stufa" occurs. Monte Tabor is evidently the remains of a small cone thrown up at the time of the issue of a lava-stream from the foot of Monte Rotaro, by the flow of which its northern side was swept away, while many of its lighter materials have also been removed by atmospheric denudation.

The lava-stream which flowed from the cone to the sea is very extensively quarried, and thereby favourably exposed for study. The rock consists of a sanidine-trachyte of a pink, reddish, greyish, bluish, or greenish tint. The pink colour of certain parts of the rock is due to numerous crystals of Mellilite (Humboldtilite). The sanidine crystals of this rock are usually small, and some of oligoclase are scattered through the basis of the rock. The other minerals contained in the rock are magnetite, hornblende, mica, and a little augite. This interesting rock has been analysed by Fuchs with the following result:—

Silica	62·17	Soda	4·76
Alumina	20·83	Phosphoric Acid	0·024
Ferric Oxide	2·26	Chlorine	0·25
Ferrous Oxide	2·16	Loss	0·25
Manganese	trace		
Lime	1·68		101·23
Magnesia	0·45		
Potash	6·40	Specific gravity	2·45

The upper surface of this lava-stream is composed of a scoriaceous, almost pumiceous mass, containing porphyritic crystals entangled in it, and often also inclosing blocks of lava and fragments of the older tuffs which have been borne along in its flow. Where it first issues, this upper scoriaceous portion of the lava-stream is not less than 15 feet thick, but it gradually diminishes to a few feet only towards the end of the current.

A little to the east of Monte Tabor another and smaller vent has been opened, which has given rise to another lava that has flowed down to the sea. At its source is the still active stufa known as Acqua Castiglione al mare, the water of which has a temperature of from 160° to 170° F. The lava of Castiglione is a trachyte of darker colour than that of Monte Tabor, and, like it, is exhibited in sections in the cliffs of the island.

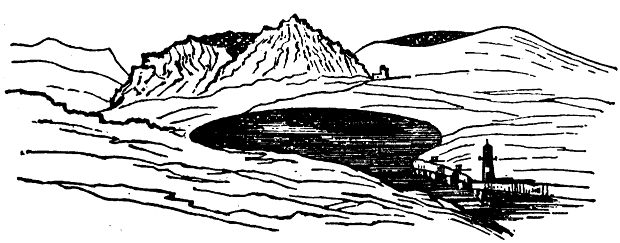


Fig. 16.—The Crater-lake of Lago del Bagno, Ischia, with Montagnone and Rotaro in the distance.

The Lago del Bagno is evidently a small crater-lake; it is of regularly circular form, and about a quarter of a mile in diameter. It has clearly been formed, like the similar craters occupied by lakes in the Campi Phlegræi, by explosive action. A few years ago the tuffs forming the northern margin of this lake were cut through, and the sea-water being thus admitted, a most beautiful basin was formed, within which ships can lie in perfect security; this natural basin now affords by far the best port in the island. (See Fig. 16.)

The recent date of the cones, craters, and lava-streams just described, is proved by their very fresh appearance. It is probable that some at least of them were produced during the outbursts, accompanied by such terrible earthquakes that the inhabitants were compelled for a time to abandon the island, which we know from historical accounts to have frequently taken place. Great eruptions are recorded as having occurred in Ischia about the year 470, between the years of 400 and 352, and in that of 89 B.C., and between 79-81, 138-161, and 284-305 A.D. After an interval of nearly a thousand years, the great outbreak of 1301 took place. The attempts which have been made to identify the various recorded outbursts before the long period of rest, with existing cones and lava-streams, are, it seems to me, at best very conjectural; but that the eruption of 1301 gave rise to the crater known as the Cremate, and the lava-stream of the Arso which flows from it, there is not the smallest room for doubting.

The Cremate is situated in a deep valley in the east side of Epomeo, and constitutes a perfect example of a small volcanic cone which has been breached by the outflow of a great current of lava. By descending the interior slopes of the crater, we find its walls to be composed of the scoriæ derived from the same peculiar trachyte which constitutes the Arso lava-stream. These scoriæ are black cinder-like masses (weathering to a reddish colour), completely filled with the entangled crystals of sanidine and other minerals which occur porphyritically imbedded in the solid lava. Sometimes the lava blocks have a vitreous base, and resemble "pitchstone-porphyry," and in these cases the scoriæ derived from them have a pumiceous character. Alternating with the great masses of agglomerate, the blocks of which are of all sizes, some being very large, are a number of subordinate lava-currents, of the same petrological character as the principal lava-stream. The great lava-current of the Arso has risen from the bottom of the crater of the Cremate, and, sweeping away its western side, has flowed down to the sea, along the line of valley between Bagno and the city of Ischia, a distance of about a mile and a half. The highest point of the Cremate is 763 feet above the sea, the bottom of its crater 528. From this lowest point the lava has boiled up to the height of 597 feet, and here forms a number of ridges composed of blocks set on end and scattered about in the wildest confusion. Thence following the course of the valley, and widening as it approaches the sea, the lava-current forms an extremely rugged *Cheire*, the surface of which is only very scantily clothed with broom, while numerous trees of the well-known Italian stone-pine have sprung up here and there in its hollows. At a number of points nests of specular iron and other products of sublimation from the cooling lava are found, and one vent still exists from which hot vapour continues to issue.

The accounts of the great eruption of 1381 which have come down to us are of a very meagre character; that of Pontanus having been written in 1538, and that of Marenta in 1559.

The products of this last eruption in Ischia present many features of the highest interest to the geologist. The rock of the Arso lava-stream is decidedly more basic in character than any other rock in the island. It does not, however, fairly fall within the class of lavas intermediate between the trachytes and basalts, to which Abich gave the name of "trachy-dolerite," and to which more modern writers apply the term "andesite." The basis of this lava is of a very dark grey, almost black colour, and consists of an amorphous dark-coloured magma, in which crystals of orthoclastic and plagioclastic felspars are imbedded. Scattered in great abundance through the mass are large crystals of sanidine, which, as Fuchs has shown, present some very anomalous characters. With these occur, sometimes in great abundance, crystals of hornblende, augite, mica, and magnetite, and irregular grains of olivine. A very similar rock occurs, as we have seen, in several of the Lipari Islands.

In illustration of the composition of the peculiar lava of the Arso, I may cite the analyses made of it by Abich and Fuchs, and that of the cinders of the Cremate by the latter author.

	Arso lava. Abich.	The same. Fuchs.	Cinders of Cremate. Fuchs.
Silica	60·80	57·73	54·83
Alumina	17·21	17·85	20·17
Ferric Oxide	3·55	4·44	4·77
Ferrous Oxide	1·29	3·90	3·86
Lime	1·43	3·65	4·12
Magnesia	2·07	1·77	1·93
Potash	7·77	7·65	7·38
Soda	4·64	3·77	3·04

The specific gravity of the Arso rock is according to Fuchs 2·61. Abich estimated the mineralogical composition of the Arso lava to be as follows:—

Felspar	84·45
Olivine	3·61
Augite	9·22
Magnetite	2 72

Ischia contains a great number of hot and mineral springs, at many of which those baths have been erected for which the island is famous. Some of these springs also give off large quantities of carbonic acid and other gases, and a number of stufe from which dry steam issues also occur. These numerous hot springs, etc., testify to the activity of the forces still at work beneath the island; so that a new outburst of these forces, which have now been otherwise dormant for nearly 600 years, may at any time take place.

The effects of subterranean forces in changing the elevation of different parts of the island within periods which are geologically very recent are manifested in the raised beaches of Lacco, Punta St. Alesandro and Punta dell' Imperatore. All of these yield great numbers of shells of the species still existing in the Mediterranean, which are found up to heights of 130 feet above the sea-level.

Alike in the composition of its lavas and tuffs, and in the periods during which its several volcanic formations originated, we find the closest analogy between the island of Ischia and the adjacent Campi Phlegræi; and the study of the former throws much light upon the structure of the latter.

In Ischia we see proofs of a great volcanic cone rising gradually above the sea-level, and, when it had reached its present limit of size, becoming extinct, while lateral outbursts took place on its flanks. Finally, around the ruins of the central pile, sporadic eruptions gave rise to smaller cones and craters, and even these in some cases had their lateral or parasitical cones. The points of resemblance and difference in the course of events and the succession of products in the three great volcanos of southern Italy—Epomeo, Vesuvius, and Vultur—are worthy of the most attentive study and consideration at the hands of the geologist.

The Ponza Islands.

If the line passing through those three grand centres of volcanic action—Vultur, Vesuvius, and Epomeo—be produced to the westward, it will strike the very interesting igneous masses of the Ponza Islands. These insignificant islands, which, from the early Roman times down to the present day, have figured in history only as places of banishment for criminals, possess for the geologist the very highest interest. This is due not only to the wonderful characters of the rock-masses which compose them, but also to the admirable manner in which these are exposed to our study by the extreme denudation to which they have been subjected.

In 1785 Sir William Hamilton visited these islands, and, being greatly struck by the remarkable features which they present, not only gave a short account of them in the "Philosophical Transactions," but wrote to Dolomieu, calling his attention to the importance of making a fuller examination of them. The illustrious French philosopher spent some time in them during the following year, and as the result of his studies his "Mémoire sur les Iles Ponces" was published in 1788. In the year 1822 Mr. Poulett Scrope made that careful survey of the whole of the islands, which enabled him to lay before the Geological Society in 1827 his well-known memoir upon them,[1] in which so many points of the highest interest in connexion with the characters of the igneous rocks are for the first time discussed. Lastly, in those very valuable investigations concerning the microscopic structure of rocks and minerals, which laid the foundation of a new and important branch of geological science, Mr. Sorby in 1858 largely employed the very remarkable rocks of Ponza, which the researches of Dolomieu and Scrope had shown to present such interesting characters.

After the detailed description of the Ponza Islands, accompanied by elaborate maps and sections, contained in Mr. Scrope's paper, the accuracy of which I have had the opportunity of verifying, anything like a general memoir upon them would at the present time

[1] Geol. Trans. ser. ii. vol. ii.

be quite unnecessary. There are, however, certain features presented by the rock-masses of Ponza which appear to throw important light upon some of the at present "open questions" of geology. These it may be desirable to call attention to in the present sketch.

The Ponza Islands, which lie off the entrance to the Gulf of Gaeta, form two small groups of islets and rocks, which are evidently the highest points of submerged tracts of considerable size—for round the islands the depth of water increases very gradually, and the 200-fathom line is only reached at distances of about three miles from the shores; yet the part of the Mediterranean immediately around them affords soundings up to 700 fathoms or more, as in the case of the Lipari Islands.

About thirty miles west of Ischia rise the islands of Ventotiene and San Stefano. These are evidently two fragments, which have escaped denudation, of a great volcano composed of materials precisely similar in character to those forming the island of Ischia—namely, ordinary trachytes with the agglomerates and tuffs derived from them. The foundations of both the islands consist of masses of rock of great hardness and solidity, evidently, as shown by their highly scoriaceous upper surfaces, portions of vast lava-streams; and these are covered by thick masses of more or less stratified tuffs and agglomerates. Ventotiene is one mile and a half long, by half a mile broad, and it rises to a height of 470 feet above the sea-level. The form assumed by this island, on account of the inclined position of its masses of lava and tuffs, is familiar to all geologists from the sketch given in Mr. Scrope's "Volcanos," page 209. San Stefano is similar in character, but of smaller size, being less than half a mile in diameter, and rising to a height of only 272 feet above the sea; its form is illustrated in the accompanying sketch, Fig. 17. By an elevation of 200 fathoms the sea-bottom around these two islands would be converted into an island of conical form, having a diameter of six miles, and a height of nearly 1700 feet.

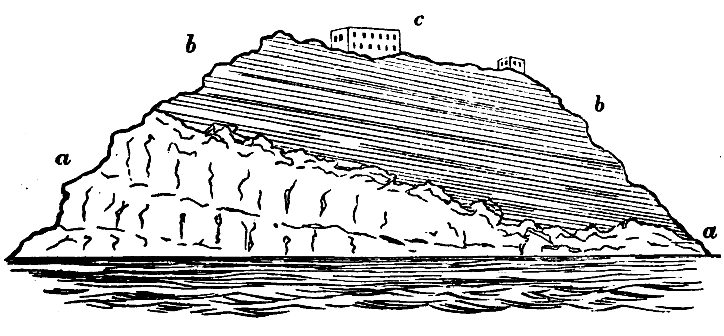


FIG. 17.—THE ISLAND OF SAN STEPHANO AS SEEN FROM THE SOUTH.
a. Trachytic lava-stream, with scoriaceous surface. *b*, Stratified tuffs. *c*, Prison and Barracks.

The same remark applies to the Botte Rock, between Ventotiene and Ponza, a projecting point of another, but much smaller, submerged mountain mass. It is composed of ordinary trachyte; and if elevation to the extent of 200 fathoms were to take place, a conical mountain of about two miles in diameter, and having the Botte Rock as its apex, would be exposed to view.

Twenty miles W.N.W. of the first of these old submerged volcanic cones is situated the other and principal group of the Ponza Islands, consisting of Ponza, Palmarola, and Zannone, with many smaller islets and rocks. The highest part of this group of islands, which are evidently the more prominent points of another submerged tract, is the mountain mass forming the southern part of the island of Ponza, and known as the Monte della Guardia, which rises to the height of 951 feet. This consists of a bulky bed of ordinary trachytic lava, resting upon stratified tuffs, both precisely similar in character to those of Ventotiene and Ischia. The form assumed by this mass of lavas and tuffs clearly indicates that it is the sole remaining fragment of another volcano, composed of the same materials as those to the eastward. (See Fig. 18.)

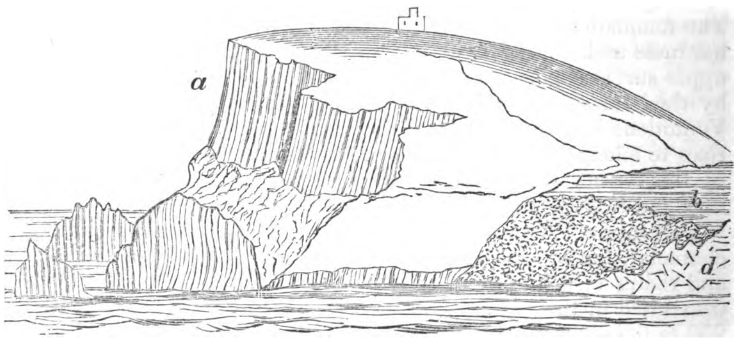


FIG. 18.—THE HEADLAND MONTE DELLA GUARDIA IN PONZA.
a, Columnar trachyte. *b*, Stratified tuffs. *c*, Pumiceous agglomerates. *d*, Intrusive masses of Quartz-trachyte.

In the case of the island of Ponza, however, this relic of an old volcano is seen to rest unconformably upon a still older series of rocks, which constitutes by far the larger portion of the entire group of the Ponzas. These rocks, although evidently of igneous origin, like those which rest upon them, nevertheless offer, alike in their chemical and mineralogical constitution and in their geological relations, a most remarkable contrast to the latter. While the overlying, and evidently newer, rocks are composed of ordinary sanidine-trachytes, with interbedded stratified tuffs, clearly the result of volcanic action at the surface, the latter are made up of highly siliceous pumiceous agglomerates, through the midst of which dyke-like masses of a rock of the same composition as granite, and approaching that rock in many of its characters, has been forced. (See Fig. 19.)

The remarkable features assumed by these older rocks of Ponza, as the result of the mechanical strains to which they have been subjected during their consolidation and crystallization, powerfully arrested, as we have seen, the attention of those pioneers in the study of Vulcanology, Hamilton, Dolomieu, and Scrope; and these rocks are still worthy of the most diligent and attentive study, both as regards their physical relations and their minute structure, by all who desire to investigate the nature, mode of action, and products of volcanic forces.

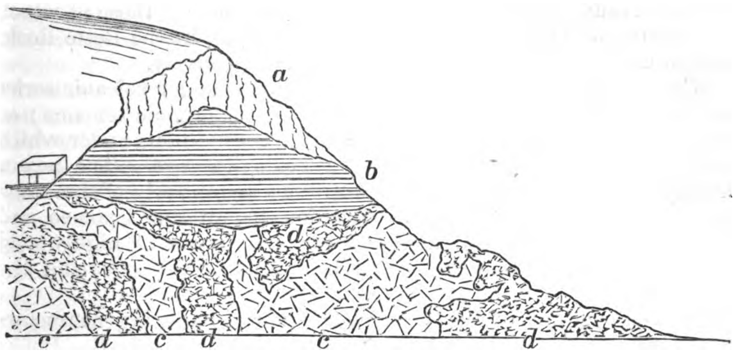


FIG. 19.—WESTERN SPUR OF MONTE DELLA GUARDIA, AS SEEN FROM THE NORTH SIDE OF LUNA BAY.

a, Trachytic lava. *b*, Stratified tuffs. *c*, Intrusive masses of quartz-trachyte with their edges passing into obsidian porphyry. *d*, Pumiceous agglomerates.

The great masses of pumiceous agglomerates, traversed by dykes and sheets of the peculiar quartz-trachyte which together constitute the greater part of Ponza, and the whole of Palmarola, are in Zannone seen in contact with sedimentary rocks of Cretaceous age (Hippurite limestones) resembling those of the nearest point of the mainland, Monte Circello. To the student of the older volcanic rocks those features of local metamorphism presented by the limestones of Zannone, which were first pointed out by Mr. Scrope in 1827, cannot fail to be of the highest interest. On the north-east side of the island the Cretaceous limestones exhibit precisely the same characters as at Monte Circello; but as we approach the igneous masses extruded through them, they are found becoming highly crystalline and by degrees passing into a dolomite. A specimen of this altered rock, which my friend Professor Guiscardi, of the Naples University, examined for me, was found to exhibit little or no effervescence upon the application of acid to it; but when powdered and heated with the acid, carbonic acid gas was at once disengaged.

But not only has the limestone undergone considerable changes near its junction with the igneous rocks, but these latter have also themselves been greatly affected, passing into a compact highly siliceous material, with a strikingly conchoidal fracture. It is interesting to notice that the intrusive rocks of similar composition in the Hebrides have undergone precisely similar changes near their contact with stratified masses.

We have thus evidence that in the Ponza Islands great eruptions of igneous rocks of the most highly acid class have taken place subsequently to the deposition of the Cretaceous rocks, and that after these earlier volcanic masses had suffered greatly from denudation, which appears to have removed all the cones and lava-streams, leaving only masses of agglomerates traversed by dykes and sheets intruded among them, a second series of volcanic outbursts took place. As the result of these latter, at least three volcanic cones, composed of similar materials to those of Epomeo and the older portion of Vesuvius and Somma, were formed—namely, those of which we see the relics in Ventotiene and San Stefano, in the Botte Rock, and in the Monte della Guardia of Ponza, respectively.

The volcanic tuffs (whether of the older or younger volcanic series in the Ponza Islands) have as yet yielded no organic remains; so that some doubt still remains, both as to the conditions under which they were formed, and their exact geological age. The newer trachytic lavas and stratified tuffs are not improbably of the same age as the rocks of identical composition constituting Epomeo and the nucleus of Vesuvius; the older series of rocks of highly acid composition belong to some period between the Cretaceous and the Pliocene.

It is on account of the peculiar and very interesting characters presented by these highly acid or siliceous rocks that the Ponza Islands have attracted so much attention from geologists. The ultimate chemical composition of these rocks is exhibited in the three subjoined analyses, for which we are indebted to Abich. They illustrate three of the most important modifications of character assumed by the rock.

	I.	II.	III.
Silica	73·46	74·54	75·09
Alumina	13·05	13·57	13·26
Oxide of Iron	1·49	1·74	1·10
Oxide of Manganese	trace.	0·10	—
Lime	0·45	0·34	0·18
Magnesia	0·39	0·24	0·16
Potash	4·39	3·68	8·31
Soda	6·28	4·86	1·67
Loss	—	0·20	—
	99·51	99·27	99·77
Specific Gravity	2·5398	2·5293	2·6115

I. is a porphyritic rock with crystals of mica and glassy felspar from Ponza; it represents the more granitic forms of the rock. II. is the interesting, curiously laminated, rock of Palmarola, "the banded and ribboned trachyte" of Mr. Scrope; it contains only traces of mica and hornblende. Abich regards these two rocks as made up of about 50 per cent. of orthoclase, 25 per cent. of free quartz, and 25 per cent. of albite. The small proportion of lime and the large per-centage of soda make it extremely probable that albite is a very important constituent of this rock. III. is a more porous rock from Zannone inclining to the vitreous structure, in which nearly the whole of the felspar appears to be orthoclase, while the free quartz amounts to 28·4 per cent.

The microscopic study of these rocks of Ponza brings to light many features of the highest interest. A series of specimens may easily be collected, exhibiting every variation from a vitreous rock to one of the most highly crystalline character; some of the examples of the latter, indeed, approach so closely in character to *granite* that it is questionable whether they ought not really to be assigned to that class of rocks.

Every attempt, like that of Gustav Rose, to give granite a purely mineralogical definition, has failed, in consequence of the variation, even in different parts of the same mass, in its constituent minerals. The several felspars may replace one another in an almost infinite number of ways, and different micas and hornblendes may be similarly substituted for one another, while accessory minerals may so increase in abundance as to become important constituents of the rock, without its in any way forfeiting the title to be considered a true granite. The *texture* of the rock, however, appears to afford surer ground on which we may base a definition, than the exact species of minerals which compose it. Normal granites consist of an aggregate, in which distinct crystals of orthoclase, and often of some plagioclastic felspar, with those of one or more species of mica or hornblende, have separated, leaving a base composed of quartz, exhibiting a greater or less tendency to form distinct crystals, and a crystalline mass of felsitic matter enveloping the perfect and imperfect crystals, and representing the "mother liquor" out of which these latter have been formed, portions of which are also entangled in their cavities. There are, however, granites in which the quartz appears to have more readily crystallized, and to have been among the first minerals separated from the mass.

Now the remarkable rock of the Ponza Islands has an ultimate chemical composition identical with that of many granites; its constituent minerals—orthoclase albite or oligoclase, quartz and mica or hornblende—are precisely those of ordinary granite; and hence it must be by its *texture,* if at all, that we must hope to be able to separate it from that class of rocks.

The study of this Ponza rock clearly proves that the minerals of which it is composed have had four different modes of origin.

I. They may have crystallized out from a liquefied magma, probably under great pressure, and long before it reached the surface. This is, I believe, the origin of the large crystals of mica, hornblende, felspar, and the smaller and less perfect ones of quartz, which are found scattered, often in great abundance, alike through the most vitreous and the most stony varieties of the rock. In proof of this fact of the formation of large crystals in the magma before its eruption I may cite the following facts.

1. In the masses of volcanic sand blown from the throats of volcanos, crystals (usually of course broken and damaged, but of precisely similar character to those embedded in the lava) abundantly occur. The perfect augite crystals ejected by Stromboli afford an interesting illustration of this fact.

2. Where the lava contains these large porphyritically embedded crystals, the scoriæ or pumice formed from it will be found to contain

the same crystals in a perfect condition, entangled in the meshes of the distended rock; clearly proving that these crystals were floating in the liquefied mass before its ejection. This fact is exemplified in many of the pumices and scoriæ of Ischia.

3. These crystals, when embedded in the rock, are often seen to be rounded on their edges and to have suffered other injuries. Sometimes the same crystal is seen broken into several fragments, which are more or less separated from one another. The mica crystals, owing to their perfect cleavage, have often especially suffered; their edges are "frayed-out," their laminæ separated by portions of the matrix which has been forced between them, and occasionally the plates of which they are built up are found to be twisted and crumpled in the most extraordinary manner.

4. Such crystals are all seen to be arranged with their longer axes in the direction of the flow, and around them the smaller crystals, formed by the devitrification of the enveloping mass, exhibit the *fluidal structure* and a peculiar packing or condensation around and behind them. Many of the sections indeed present an appearance which may be justly compared to the surface of a flowing stream, on which at the same time quantities of chaff and a number of pieces of wood are floating; the former representing the microliths, and the latter the porphyritically embedded crystals.

That those conditions of high temperature, great pressure, and the presence of large quantities of imprisoned water and gases, which exist deep down in a volcano, are eminently favourable for the formation of large crystals of various minerals, we have the clearest proof in the beautiful contents of those blocks which are torn from the deep underlying rocks of Vesuvius and ejected from its throat. That the same conditions should induce a similar separation of the materials of the liquefied mass itself, is no more than might be expected. On a future occasion I shall discuss the nature and origin of the condition of fluidity in igneous rocks, upon which so much light is thrown by the fact that crystals of minerals of very different degrees of fusibility are able, not only to separate, but to continue floating about in them.

II. When, as was shown by Mr. Sorby, a granite, like that of Mount Sorrel, is fused, it passes on cooling into a glass. But if the cooling be conducted slowly, *sphærulites* composed of acicular crystals in radial groups are formed in the mass. Now in some cases the matrix surrounding the crystals of the Ponza rock before described has assumed a vitreous condition, and it there becomes a porphyritic obsidian. In this obsidian every variation from the first appearance of crystalline structure to the formation of the most distinct sphærulites may often be observed.

III. If glass be heated to a point far short of that required for its fusion and slowly cooled, crystals of various minerals begin to make their appearance in the mass, which gradually passes into stone, or in other words becomes devitrified. The possibility of this passage from the glassy to the stony condition *without fusion* is a condition which must always be borne in mind by the geologist. The slowness with which large masses of such imperfectly conducting materials, as most lavas are, cool down, is familiar to all who have studied volcanos. It can hardly fail to happen, then, that many lavas which have solidified as glasses have, in the long intervals, during which they have been gradually parting with their remaining heat, become devitrified.

The glassy condition of rocks is clearly an exceptional and *unstable* condition for them to assume. The probable reason why no vitreous rocks of ancient date exist is not because similar conditions of volcanic action did not prevail in earlier periods of the world's history, but because the vitreous rocks have lost their peculiar characters by devitrification. In proof of this conclusion I may recal the fact, already described by me, of Old Red Sandstone lavas in Scotland exhibiting traces of sphærulitic structure, which appears to be in all cases connected with the existence of volcanic glass. Even a moderate degree of heat, if sufficiently prolonged, permits of the passage of a matter from the unstable colloid to the stable crystalline condition; and it is not improbable that pressure and other forces long sustained may be attended with the same result.

The Ponza rock often exhibits clear evidence that after solidifying in the form of a glass it has been subjected to devitrification.

IV. The passage through the rock of water, especially when this contains such acids as abound in volcanic regions, may completely alter the composition and internal characters of the rock. Certain minerals among its constituents may be attacked and removed in solution, while others assume a totally different crystalline condition and arrangement. Of such changes the rock of Ponza often exhibits the clearest evidence, its more basic materials being attacked and destroyed, and its quartz re-crystallized. As shown by Mr. Scrope, veins of quartz and true metallic lodes with cupriferous pyrites occur in this rock; and the quartz of these, as pointed out by Mr. Sorby, is quite different in character from that in the unaltered igneous rock. It contains "many fluid-cavities with water holding in solution the chlorides of potassium and sodium, the sulphates of potash, soda and lime, and free hydrochloric acid."

Let us now proceed to inquire what are the relations of this interesting rock of Ponza to granite, on the one hand, and to the ordinary highly siliceous lavas (quartz-trachytes or Liparites), on the other.

The geological relations of this rock have been so fully illustrated by Mr. Scrope that it is not necessary to dwell at any length upon the subject. Through vast masses of pumiceous agglomerates, evidently formed by explosive action, the solid rock of which we are speaking has been forced in dykes and sheets, which sometimes have a width of a few inches only, at others of many yards. The crushed and re-consolidated character of portions of the matter at the sides of these dykes, the remarkable banded and ribboned internal structure of the rock itself in many places, and the phenomena witnessed at the planes of contact of the dykes with the masses which they traverse, bear witness to the violent force and vast irregular pressures which accompanied their intrusion.

In no case does this more ancient rock of Ponza appear to have been extruded as lava, and to have consolidated under ordinary atmospheric pressure. Either the pressure of the superincumbent ocean, or possibly that of mountain masses of volcanic materials poured out at the surface and piled above them, has evidently influenced their mode of consolidation, and greatly modified their characters.

This conclusion is quite in accordance with the microscopical characters presented by the minerals which compose these rocks. The felspar crystals abound with cavities filled with stony matter; while the crystals of quartz, as pointed out by Mr. Sorby, contain fluid-cavities with air-bubbles, and present a most perfect resemblance to those of the true granitic rocks. The result of Mr. Sorby's most ingenious researches, however, was to show that while the quartz crystals of the Ponza rock must have been formed under a very considerable pressure (one of possibly not less than 4000 feet of rock), yet that the ordinary granites were produced under a pressure which must have been far greater.

Great, indeed, as are the points of resemblance between the rock of Ponza and many granites, both in chemical and mineralogical constitution, and in certain features of their microscopic structure, the real and important points of difference between these two classes of rock must not be lost sight of. These differences consist in the tendency which the *basis* of the rock constantly shows to assume the vitreous condition, and in the mode of arrangement and injured condition of its embedded crystals. In these respects the rock of Ponza approaches and even graduates into the ordinary highly siliceous lavas (Quartz-trachytes, Liparites or Rhyolites), such as those which we have described in the Lipari Islands.

Thus we are led to the conclusion that rocks like those of Ponza, and certain others in the Euganean Hills, Hungary, etc., which precisely agree with them in character, form a perfect bond of connexion between the granites on the one hand and the highly siliceous lavas (Liparites) on the other. For rocks of this character Richthofen has suggested the name of "granitic-rhyolite," or "Nevadite," and his definition of this rock, which constitutes great mountain masses in the western parts of North America, appears to be entirely applicable to the rock of Ponza. Whether geologists agree to accept this term or not, the fact remains of the existence of a series of rocks through which we can trace the passage, by the most insensible gradations, from *granite* to the variety of *lava* known as Liparite.

It has been shown by Delesse, Durocher, and other observers, that a rock of highly crystalline or granitic structure has a much higher specific gravity than the glass formed by its artificial fusion. As both mathematical reasoning and experiment have led Sir William Thomson and his brother to the conclusion that for those bodies which contract in consolidation pressure raises the point of fusion, while for those that expand it lowers it, we might by analogy be justified in inferring that, under great pressure, rocks would be unable to undergo that expansion necessary for their assuming the colloid or vitreous condition. I need not point out how this conclusion coincides with the observations of the geologist. We have the strongest grounds for inferring that in granite consolidation took place under enormous pressure; and we never find it assuming the vitreous structure. In the rock of Ponza the pressure was evidently far less, and the rock occasionally passes into a more or less glassy form; while in the *lavas* known as Liparites, where all superincumbent pressure is got rid of by their extrusion at the surface, the tendency to pass into the vitreous condition is, as we have seen, extreme. By the study of different portions of igneous masses we are able, therefore, to trace every stage in the transition from the most typical granite to the most perfect glass and pumice.

The relation of the glassy portions of the rock of Ponza to the ordinary crystalline varieties are, as pointed out by Mr. Scrope, worthy of the most careful study. In almost every case the dykes or intrusive sheets of crystalline rock are at their planes of junction converted for a greater or less thickness into a glassy material. Three different causes suggest themselves as possibly tending towards this result.

(1). The more rapid cooling of the liquefied masses on their outer surfaces.

(2). The enormous friction, of which we have the clearest evidence, between the intruded matter and the agglomerates through which they were forced. This might operate in two ways: by crushing up the solidifying particles, and rendering them easy of refusion; and by the actual development of additional heat from the friction. The probability of this kind of action having gone on is shown by the fact that not only are the dykes of solid rock converted into glass at their sides, but the masses of agglomerate themselves, near the lines of junction, also pass into obsidian.

(3). The smaller amount of resistance offered by the agglomerates to the expansion, which, as we have seen, takes place in the passage from the crystalline to the colloid state, would favour the production of obsidian on the outer surfaces of the intrusive masses.

It may well be conceived how, with the presence of such conditions as we have indicated, the most remarkable transitions of rock structure from the glassy to the crystalline may be produced; accompanied by the development of the most singular examples of brecciated, ribboned, and contorted appearances.

There are a number of other interesting features which have been already described as being exhibited by the Ponza rocks, to which want of space will prevent us from doing more than making the barest allusion in this sketch. Such are the interesting prismatic forms assumed by them on the smallest as well as on the largest scale; the remarkable globiform concretions in some of their vitreous masses; the changes undergone by them in consequence of the passage of water and acid gases through them; and the formation of crusts of carbonate of lime on their surfaces, and of calcareous sand-

The Great Crater-Lakes of Central Italy.

In no part of Europe, probably, can we find such striking examples of the effects which may be produced by single paroxysmal outbursts of vocanic force, as in the band of igneous rocks which stretches through nearly the whole length of the Italian peninsula, on the western side of, and parallel to the chain of the Apennines. Etna and many of the extinct volcanos of this continent constitute, it is true, mountains of vaster bulk than any in the district to which we have referred; but while the former were evidently built up by the accumulation of the products of igneous forces operating during long periods from the same centres, and with comparatively moderate violence, the enormous craters of the latter bear witness to the occurrence of single outbursts of these forces of far greater intensity.

The materials which have been ejected from the various centres of activity along this great volcanic band present many features in common; especially in the abundance of leucite and the group of minerals allied to it; there are also not a few points of peculiar interest in connexion with these rocks which have been very admirably treated by Professor vom Rath in his "Geognostiche-mineralogische Fragmente aus Italien." Without, however, staying to dwell upon these subjects, we shall proceed to notice the proofs which exist of the occurrence of those volcanic outbursts of extraordinary violence or duration to which we have referred, and which have resulted in the production of some of the most marked and striking of the physical features of the district.

The frequency of the occurrence of lakes in volcanic districts is a circumstance that is familiar to all geologists. Sometimes, as in the case of the Lac de Chambon in the Mont Dore, the throwing up of a series of volcanic cones in the midst of a valley has arrested the drainage, and given rise to the formation of a lake; in other cases, precisely similar effects have resulted from the influx of a great current of lava across a line of drainage. There are not wanting proofs, also, that those local subterranean movements to which volcanic districts are especially subject have frequently so altered the levels along a line of river-valley as to lead to the damming up of the stream, and to the consequent production of lakes. In all these cases the lakes have been formed by the joint action of aqueous and igneous forces. But there are also many examples of lakes the basins of which clearly owe their origin to the action of igneous causes alone. Such are the well-known Maare of the Eifel, and those numerous depressions common in almost all volcanic districts, which are evidently old craters that have become filled with water.

But lying to the northward of Rome we find two lakes of such vast proportions—the Lago di Bracciano being 6½ miles in diameter, and the Lago di Bolsena 10 miles—that we may at the first sight of them be fairly led to hesitate in referring their formation to the ordinary explosive action of volcanos. Dr. Daubeny, indeed, appears to have been so staggered by their enormous size, that he found it impossible to accept their volcanic origin. In the present chapter we purpose to notice those features presented by them which appear to place their mode of formation beyond question.

In seeking to illustrate the characters and to account for the production of these vast craters, it will be well to refer, in the first instance, to examples of a precisely similar kind, though on a somewhat smaller scale, the mode of origin of which it is not possible to doubt. Vesuvius presents us with a great encircling crater, that of Somma, which has a diameter of two miles and a half, and which was produced during the grand paroxysmal outburst of A.D. 79. There seems to be now no room for doubt that at the period of this grand eruption, concerning which we possess such interesting historical details, the original cone of Somma was completely gutted, and that vast cavity formed in the midst of which the existing cone of Vesuvius was subsequently built up. Here, then, we have an illustration of the effects which may be produced by a single eruption of a volcano, and may fairly employ it for comparison with others, concerning the formation of which we have neither historical records nor traditions to aid us, and which may possibly indeed have originated prior to the appearance of the human race upon the earth.

Such an example we have in the great volcano of Rocca Monfina, which presents so many points of analogy with Vesuvius that the geologist will have no difficulty in recognizing the mode of origin of the principal features of the former, though it has long been extinct, and its rocks have suffered greatly from the action of denuding forces.

The mountain group of Rocca Monfina exhibits a crater-ring of about three miles in internal diameter, that is to say, it is somewhat greater than the similar crater-ring of Somma, which surrounds the modern cone of Vesuvius. The materials which compose these older encircling craters of Somma and Rocca Monfina are almost identical, namely, leucitic basalts and the tuffs derived from them; but it is clear that while in the former the lavas form a very large proportion of the mass, in the latter they are quite subordinate to the tuffs, of which the volcano is mainly built up. In the centre of each of these old craters rises a more modern volcanic cone, but of very different characters in the two cases. While Vesuvius is composed of lavas and tuffs quite similar in character to those of Somma, the Montagna di Santa-Croce, which has risen in the midst of the old crater of Rocca Monfina, consists of vast hummocky masses of a peculiar rock—a "trachy-dolerite," with much mica. That the crater-ring of Cortinella (which embraces the mountain produced by later eruptions, in the same manner that Somma does Vesuvius) was formed by similar explosive action to that which we know gave origin to the latter, no one can doubt who observes the exact correspondence in all the characters of the two mountains. The only difference between them is this—that while Somma, after the great paroxysm which destroyed all the higher and central portions of its mass, continued to pour forth those similar leucitic lavas and tuffs by which the modern cone of Vesuvius was gradually built up, Rocca Monfina, by a change not uncommonly witnessed at centres of volcanic outbursts, began to originate materials of a different composition and mode of behaviour, namely, the more acid lavas of much less perfect liquidity which formed those great bosses in the centre of its crater constituting the mountain-masses of Santa-Croce.

Proceeding still to the northwards, we find, a little to the south of Rome, a third volcanic group, that of Monte d'Albano, composed of similar leucitic basalts and tuffs to those of Vesuvius and Rocca Monfina. In the centre rises Monte Cavo, which we may justly compare to Vesuvius; it is a volcanic cone, with a well-marked crater at its summit, upon the floor of which rise the remains of several smaller cones, now weathered down and grass-grown. Monte Cavo, like Vesuvius, is embraced by a great crater-ring, broken away on its western side by the later parasitical eruptions which have originated the craters of Vallariccia, Lago d'Albano, Lago di Nemi, and the craters about Frascati. But while the outer crater-ring of Somma has an internal diameter of only two miles and a half, and that of Rocca Monfina of three miles, the similar crater-ring of Monte Albano is not less than six miles in internal diameter; and it is, moreover, almost wholly composed of volcanic tuffs. In spite, however, of the difference of size, no geological observer can for a moment doubt that the exact identity of relation between Vesuvius and Monte Cavo, and their respective encircling crater-rings, points to a similarity in their mode of origin; and of what that was in the case of the former we have actually historical evidence.

North of Rome rises another volcanic group—that of the Lago di Bracciano. In this case we find a great circular hollow of almost precisely the same dimensions as that of Monte Albano, and composed of identical materials, namely, leucitic tuffs, with a few currents of lava. The circular mountain group that incloses the Lago di Bracciano only differs from that at Albano in the circumstance that no central mountain rises in its midst. The great hollow occupied by the Lago di Bracciano is nearly circular in form, and about 6½ miles in diameter. The surface of the lake is 540 feet above the level of the sea; while the highest point of its surrounding wall, the hill known as the Rocca Romana, rises to a further height of 1,486 feet. On its western side the inclosing ring of hills has been cut through by the River Arrone, which affords an outlet for the waters of the lake. It appears clear that the excavation of this river valley has effected a gradual lowering of the level of the Lago di Bracciano, in a manner similar to what was suddenly effected, by artificial means, in the case of the lakes of Albano and Nemi by the ancient Romans. A few scattered outbursts of the volcanic forces have evidently taken place in the immediate neighbourhood since the grand catastrophe by which the vast crater was formed; and numerous hot and mineral springs all around bear witness to the fact that the igneous forces are not even yet wholly extinct beneath it.

The Lago di Bolsena is less perfectly circular in form than the Lago di Bracciano; its length from north to south is 10¼ miles, and its breadth from east to west nine miles. The lake lies in the midst of a group of hills, wholly composed of volcanic rocks, which rise gradually from the plains to heights of from 1,200 to 1,500 feet above the sea. The surface of the waters of the lake is 962 feet above the level of the Mediterranean, and the ring of hills around it constitute heights for the most part from 300 to 500 feet above it. Some few points in this crater-ring are, however, of considerably greater elevation, as San Lorenzo on the north, Valentano on the south, and Montefiascone on the south-east, which are respectively at heights of 684, 780, and 985 feet above the level of the waters of the lake. The last-mentioned point, however, owes its great elevation to a later eruption, the town being built on the summit of a cinder-cone which has been thrown up on the very edge of the crater-ring, evidently at a period subsequent to its formation. Like that of Bracciano, the crater-ring of Bolsena is cut through by a river-valley, that of the Marta, which affords a means of escape for its waters on its south-western side; and it is clear that by the excavation of this channel the surface of the lake has been gradually lowered.

The lake of Bolsena differs from that of Bracciano in having two islands, known as Bisentina and Martana, rising in its midst. These are composed of volcanic tuffs, and present the peculiar quaquaversal dips so characteristic of cinder-cones. These are evidently the remains of two small cones, which have been thrown up on the floor of the great crater, by eruptions subsequent to the great paroxysm which produced its main features.

The series of craters which we have now described possess so many features in common that it is very instructive to notice such points of difference as exist between them, since these may serve to illustrate the various changes, both in the nature and products of their action, which volcanic centres may undergo.

In Somma we find a crater with a diameter of two miles and a half, the actual formation of which is described by historians; while the materials ejected in the course of its production still lie thickly over the ruins of buried cities. Within this crater a cone—that of Vesuvius—has grown up, and has been in great part destroyed and re-formed several times during the last eighteen centuries. In

Rocca Monfina a crater-ring of almost identical character, but of somewhat larger dimensions and older date, has had extruded within its area bosses of bulky crystalline rock, apparently of so viscid a character at the time of their emission as not to be capable of being scattered in scoriæ, or of flowing in lava-streams. To pass from these craters to those of Monte Albano and the Lago di Bracciano (of which the diameter is almost twice as great) may at first sight, perhaps, present some difficulty; but if the exact correspondence of all the features, except those of size, between Somma and Vesuvius on the one hand, and the outer ring and central cone and crater of Monte Albano on the other hand, be considered, no one can possibly doubt the similarity of their modes of origin. The contrast is sufficiently obvious between what must have occurred in the case of the latter volcanic group, where a central cone of vast dimensions has been built up by eruptions subsequent to the grand paroxysmal outburst that gave origin to the outer crater-ring and in that of the vent of Bracciano, which became quite extinct after its final grand effort. In the Lago di Bolsena a paroxysm, of such violence as to produce even a still larger crater, was followed by feebler outbursts, that only sufficed to form two small cinder-cones within its vast circuit.

It is not surprising that the vast size of these great lakes of Bracciano and Bolsena should have led some to entertain doubts as to the possibility of their having been formed in the same way as ordinary craters—that is, by explosion. But if a sufficiently large series of these objects be studied, it will, we think, be found impossible to draw any clear line of distinction between those of the most moderate dimensions and those which attain such vast proportions, or to ascribe to the latter any different mode of origin to that which has so clearly produced the former.

Without passing beyond the district with which we are now immediately concerned, the truth of this statement may be made clearly apparent. In the Campi Phlegræi we have several beautiful examples of crater-lakes, such as Agnano and Avernus. Both of these are less than one mile in diameter, and there is no more room for doubting their mode of origin than there is for questioning that of Astroni, which is a crater with a very small lake in its midst, or indeed of that of Monte Nuovo, the formation of which was actually witnessed only three centuries and a half ago. But in the immediate proximity of these are the precisely similar crater-rings of Pianura and the Piano di Quarto, which, although having diameters of three and four miles respectively, are nevertheless so precisely similar in character that it is quite impossible to assign to them a different mode of origin.

Again, the formation of the crater-ring of Somma is an event of which we have authentic records, and it is impossible to doubt that an eruption on even a still grander scale must have originated the precisely similar crater surrounding Monte Albano; while, if this be admitted, the analogous crater-rings of Bracciano and Bolsena cannot but be assigned to the operation of similar causes.

Indeed of the recent formation of a crater of even as vast dimensions as those which we have described as existing in Italy, we have an example in the grand eruption of Papaudayang, in Java, in 1772, by which a gulph no less than fifteen miles long by six broad was originated!

Accepting then the conclusion that even the vast circular lakes of the Italian peninsula have been formed by explosive outbursts, similar in character to, but of greater intensity or duration than some of those which have been recorded during the short periods to which history or tradition goes back, we may proceed to ask, what are the causes which have led to the production in different cases of very dissimilar structures by the same explosive action?—namely, of cones like Monte Nuovo and Etna, on the one hand, having comparatively small craters at their summits, and of vast craters like the Piano di Quarto and the Lago di Bolsena, in which the surrounding wall is of comparatively insignificant bulk and elevation. In making this distinction, however, it must be borne in mind that no strong line of demarcation exists between the two classes of objects. Between almost perfect volcanic cones, exhibiting at their summits quite insignificant craters and pit-craters with scarcely a vestige of a crater-wall, examples illustrating every conceivable stage of gradation may be cited.

It is clear that, as a general rule, the formation of volcanic *cones* must be assigned to the operations of comparatively moderate explosive force, either long continued or oft repeated; while that of pit-craters must be due to comparatively short, sudden, and violent outbursts.

That the cause which produces both classes of volcanic vents is no other than the expansive force of bodies of steam, which are disengaged from masses of incandescent lava rising through fissures towards the surface, is a fact now universally recognized. And to the geologist familiar with the appearances presented by such fissures, as filled with the now consolidated materials to which they gave passage, and exposed beneath what were once eruptive vents, through the removal by denudation of the overlying volcanic structures, a cause for the varying modes of action at different points of the same volcanic district may readily suggest itself.

The great fissures filled with consolidated materials, which penetrate older rocks in volcanic areas that have suffered great denudation, affect two very distinct modes of arrangement. They are either cracks which traverse the strata vertically, or fissures which have been formed through the yielding of the planes of least resistance among the strata themselves. The former, filled with consolidated lava, become dykes; the latter, intrusive sheets.

That the fissures of both classes sometimes reached the surface, and that, in such cases, they gave origin to volcanic outbursts, we have very unmistakeable evidence. But it is also clear that the action which would take place at the surface in the case of the two kinds of fissures would necessarily be very different. In the case of a vertical fissure, the smallest communication with the surface would lead to a local disengagement of vapour, and this relieving the pressure on the mass below, continually fresh supplies of steam would be liberated, carrying up fragments of the liquefied rock in which it was imprisoned as scoriæ or pumice, or forcing it out in streams as lava. Thus would naturally be built up, according to circumstances, a cone of cinders, a composite cone of cinders and lava, or a solid cone ("mamelon"), wholly formed by the welling out of the latter material. But in the case of a horizontal fissure, the result would probably be very different. Here the mass of lava, which, as we know, may be forced for many miles away from the volcanic centre, would have its imprisoned water retained by the superincumbent rocks till it reached a point at which, either from a decrease in the thickness or a diminution in the capacity for withstanding expansive force of the superincumbent rock, it began to be disengaged. Then an accumulation of vapour of the highest tension would begin to take place, and by its accumulated force, the repressive power of the overlying rocks being at last completely overcome, the latter, throughout a wide area, would be shattered to fragments and dissipated in one short, sudden, and violent outburst. But the mass of lava to which this outburst was due, having beneath it no further reservoir from which steam could be disengaged and rise to the surface, the first violent outburst would not be succeeded, as in the case of vertical fissures, by a series of similar explosions.

By the liberation of vapour in vertical and horizontal fissures respectively, then, it seems possible to account for the formation in the same district, as in the Campi Phlegræi, of the two very distinct kinds of volcanic vents, or for the appearance of either class almost alone, as in the Eifel and the Auvergne.

But though this explanation may suffice to account for the production of those smaller vents which occur in such areas as we have referred to, yet it is evident that the formation of enormous craters like those of Bracciano and Bolsena is a problem of a different and perhaps far more difficult character.

If, for example, we were to conceive of an eruption of so violent a character as to blow into the air all the central portion of Etna, so as to leave a crater of many miles in diameter, the result would be not very different from the vast lake surrounded by a rim of comparatively small elevation, which we witness in Bracciano and Bolsena. But here we are met by the fact that, in Italy, at least within the historic period, no such mountain as Etna has ever been so destroyed by a volcanic outburst as to leave only a basal wreck consisting of a wide and low crater-ring.

Etna is an admirable type of a *well-built* volcano. As shown in the splendid section of the Val del Bove, lava-streams, dykes, and agglomerates are combined together into a framework of the most solid character. As the structure has risen in height, the weakest portions of its flanks have successively yielded to the vast expansive forces below, and fissures being produced, these weakest parts have been successively repaired and strengthened, first by the injection and consolidation of lava in the fissures, and secondly by the piling up of materials above them. Thus the grand cone has grown, by the alternate strengthening of its flanks through lateral outbursts, and the renewal of ejections from its axial crater, as the vast chimney became sufficiently strong to sustain the pressure necessary to raise the materials to the lofty summit of the mountain. That this has really been the process of growth in Etna, no one who studies its enormous bulk, its numerous parasitical cones, and its clear sections, can for one moment doubt.

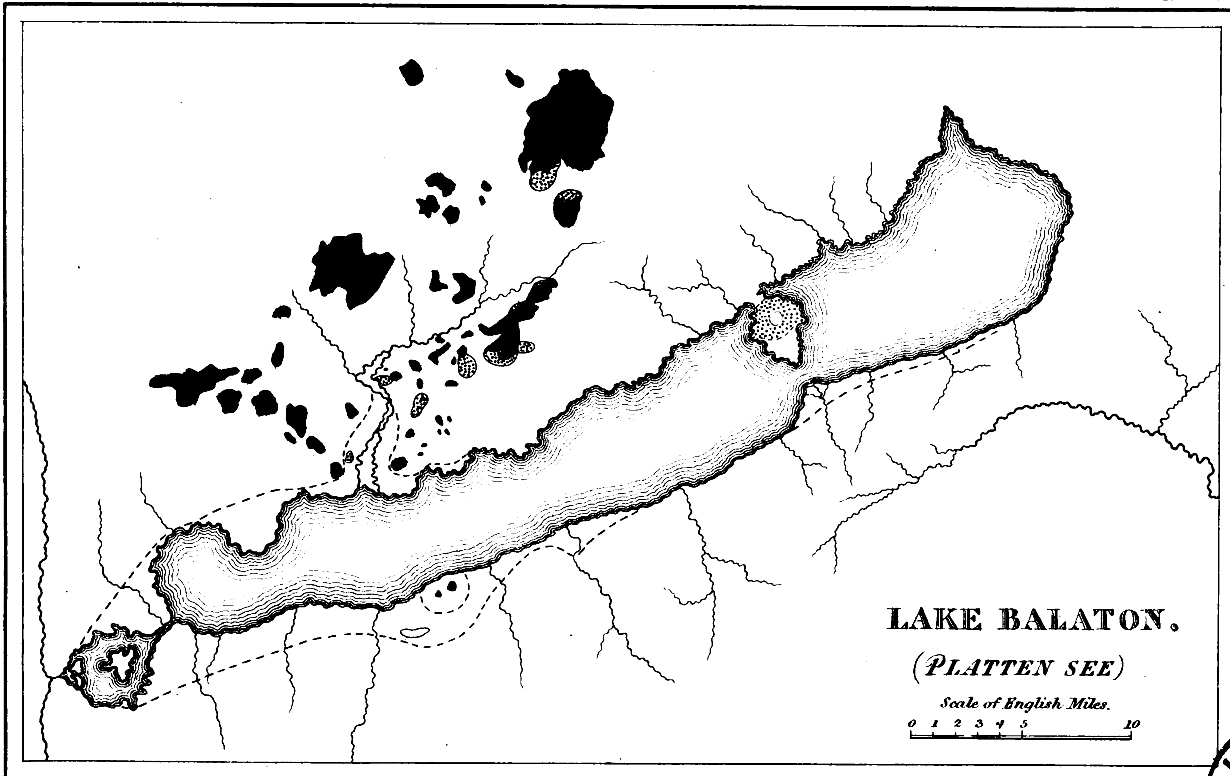
But as we have already pointed out, the wide and little elevated crater-rings of Albano, Bracciano and Bolsena present a totally different kind of architecture to the solid structure of Etna. They are in fact almost wholly built up of loose tuffs; masses of solid lava, whether in currents or dykes, being few, and forming but a very small proportion of their bulk.

The action of expansive forces within cones almost wholly composed of such loose materials would necessarily be very different from that which we have seen takes place in Etna. Lateral eruptions would become almost impossible, for as soon as any part of the flanks of the mountain began to yield to the rending force, the loose materials at the sides of the fissure would close in and fill the crack as rapidly as it was formed. That this is no hypothetical explanation of what takes place in such tuff cones is shown by the numerous beautiful pseudo-dykes, filled with fragmentary materials, which occur in the tuff-cones of the Campi Phlegræi, and the almost total absence in these cones of dykes of solid lava.

The expansive force of the vapour, gradually separated from the incandescent masses of lava below the mountain, being thus unable to open any safety-valve by producing a lateral eruption, would at last attain such tension as to enable it to dissipate the whole structure of the cone itself, composed as it is of loose and uncompacted materials. These by repeated ejection would be reduced to fine fragments, which would be deposited as tuff and ash over enormous areas all around the vents. The craters of Albano, Bracciano, and Bolsena are in fact surrounded by such deposits, which extend over a wide district around them.

Vast, then, as are the dimensions of the great crater-lakes of Central Italy, it is impossible to doubt that they have been formed by the same causes which have originated the numerous others of smaller size, but of similar character, within the same district,—namely, the explosive action of steam disengaged from masses of lava below them. Nor does it, in the case of these vast craters, seem possible to admit of their areas having been enlarged subsequently to their formation by any kind of erosive action. Not only is there no evidence whatever that these craters have been submerged beneath the ocean; but, on the contrary, the narrow rivers and valleys by means of which the waters of both Bolsena and Bracciano are carried off, as well as the loose cinder cones in the midst of the former, point to an exactly opposite conclusion. Neither does the action which Mr. Brigham points out as taking place within that vast lake of liquefied rock, Kilauea, namely, the encroachments of the mass of incandescent liquid upon its walls, by which these are slowly eaten back, appear to throw any light upon the formation of the great Italian craters; so very different in composition and behaviour are the lavas of Italy and Hawaii respectively. All theories of an engulphment of the central masses of the volcano completely fail to explain the regular circular form of these depressions, and their striking similarity to those of smaller size, which have evidently been produced by explosive action.

Nor, when we reflect on the small portion of the earth's surface, and the very short periods concerning which we have any records of the nature and results of the physical changes that have taken place upon it, need we hesitate to admit that paroxysms may have occurred which, though similar in kind, yet exceeded in their degree of intensity any which man may have had an opportunity of witnessing or recording.



J. W. Judd, del. J. W. Lowry, sc.

– – – – – Former limits of the Lake. ■ Basaltic Lavas. ░ Basaltic Tuffs.

On the Origin of Lake Balaton in Hungary.

(PLATE I.)

IN our last chapter[1] we referred to the frequency of the occurrence of lakes in districts which contain volcanos that are still active or have only recently become extinct.[2] In connexion with this subject, we must also call attention to the interesting circumstance that, wherever the geologist finds evidence of the former action of subaerial volcanos, there he almost invariably detects proofs also, that numerous lakes have been formed and successively filled up with sediments. Very strikingly is this fact illustrated among the great series of volcanic rocks, which, during a great portion of the Tertiary period, were being erupted in Central and Southern Europe; and which form an almost complete girdle surrounding, but lying at a considerable distance from, the great central masses of the Alps. We have in these districts the most unmistakable palæontological evidence that the periods of violent volcanic activity were also characterized by the repeated formation and filling up of lake-basins.

We have already shown how a study of the features presented

[1] See Geol. Mag. 1875, Decade II. Vol. II. p. 349.

[2] It has been suggested to me by my friend Mr. Scrope that this fact of the very constant connexion between volcanic action and the formation of lake-basins would be brought out very clearly and impressively by an estimate of the number of lakes which at present exist in the Auvergne, together with those which have in very recent times been filled up with alluvium. The large map of that part of the Auvergne included within the Department of the Puy de Dôme, prepared by the Abbé Le Coq, lends itself admirably to such a purpose, and I have obtained from it the following results. The area of the Department of the Puy de Dôme is only a little greater than that of the English county of Lincoln, yet its surface is studded over with the relics of no less than 276 lakes and lakelets. These may be classified as follows:

1. Crater lakes, either still existing or filled up with sediments, and clearly formed by explosive action	18
2. Lakes formed by the arrest of drainage in a valley by the flowing of a lava-stream into it, or by the throwing up of volcanic cones in its course	3
3. Lakes lying among the volcanic rocks and due either to the irregular accumulation of volcanic materials, to local subsidences, and other changes of level	81
4. Lakes lying in similar depressions among the rocks of the old granitic plateau, generally in the lines of drainage, and owing their formation to local changes of level in this formerly violently disturbed district	174
Total . .	276

In this estimate I have included only the smaller examples of lakes of very recent by the great circular lakes of the Italian peninsula leads us to the inevitable conclusion that they, in common with the numerous similar ones of smaller dimensions, owe their origin to the *direct explosive action* of volcanic forces,—and that they occupy, in fact, the bottoms of vast craters which have been formed by this agency.

But, as we have already remarked, it is not by such direct explosive action alone that the volcanic forces are capable of originating those depressions in the surface of the land which constitute lake-basins. Sometimes an ordinary river-valley may have a part of its course dammed up, either by the flowing of a stream of lava across it or by the throwing up of volcanic cones in its midst. And still more striking are the effects produced on the system of drainage in a district by the subterranean movements which so constantly precede, accompany, and follow the outburst of volcanic forces. By this agency true rock-basins, often of vast dimensions, are formed,—sometimes by local subsidence, at others in consequence of inequalities of movement along a line of river-valley.

It would perhaps be impossible to cite any clearer or more striking illustration of the formation of a rock-basin, capable of containing a lake, by the subterranean action of volcanic forces, than that of Lake Balaton (or the Platten See, as it is called by the Germans) in Hungary.

Among all the beautiful lakes which at the present time surround the Alpine system, there is none which equals in size Lake Balaton. It has a length of about 50 miles, and a breadth varying from 3 to 10 miles, its area being no less than 420 square miles. Its depth, however, unlike that of many of the Alpine lakes, is not very considerable, averaging only between 30 and 40 feet. Lake Balaton is, nevertheless, a magnificent sheet of water, and in picturesque beauty is scarcely, if at all, inferior to any of the more famous lakes of Southern Europe.

In certain of its features, however, Lake Balaton presents interesting points of contrast with the Alpine lakes, and to these it will be instructive to refer. It does not occupy, like them, a depression in one of the great valleys radiating from the Alps, nor has it, indeed, any visible natural outlet. A number of more or less considerable streams flow into it; but until the Roman emperor Galerius constructed a canal between it and the Sio, a tributary of the Danube, the waters of the lake had no communication with that or any other river. Nevertheless, these waters are almost perfectly fresh, and exhibit only the faintest trace of saline characters.

It is clear to any one who examines Lake Balaton that it occupies

date. The exact limits of the larger ones formed in the great river-valleys of the district it is now very difficult to define; and the patches of lacustrine sediment, filling innumerable depressions both of large and small size, of older date, are greatly obscured by later formed volcanic products or have been to a very great extent removed by denudation. I need only add that, as Le Coq well shows, the district of the Auvergne could never have been the seat of powerful glacial erosion, although the perpetual snow which may have clad the higher parts of the district during the Glacial Period may have contributed to the *preservation*, though not to the *formation*, of the lakes in question, in the manner pointed out in this paper.

a true rock-basin—that is, an actual depression in the surface of the land—and that its waters are not merely dammed up by superficial accumulations. The rocks which inclose it are, on its northern side, of Triassic and Rhætic age, and, on its southern, of older Neogene (Miocene) date—the latter being about the equivalents in time of the Molasse of Switzerland, which forms the shores of a great part of the Lake of Geneva and of so many other Alpine lakes. On all sides, but at different distances from it, the lake is encircled by hills of considerable but varying elevation, the bold spurs of the Bakony Wald coming down to its northern shores; while the alluvial flats of great extent on its banks, and the beaches at some elevation above its surface, testify to the former considerably greater extent of the lake.

Let us now inquire what evidence is afforded to the geologist, who studies its features, concerning the mode of origin of the great depression in the earth's surface in which Lake Balaton lies.

With respect to that agency which is so confidently appealed to by several Scotch geologists as having originated the greater portion of the rock-basins, in which lakes lie,—namely, the alleged power of a glacier to *excavate* a depression in the earth's surface,—it will only be necessary to mention certain facts concerning the position and features of Lake Balaton, to demonstrate the utter futility, at all events in this case, of any such mode of explanation. Not only does the district exhibit none of the usual evidences of powerful ice-erosion, but it is quite impossible to conceive how such action could have taken place here. The hills of the Bakony Wald, lying on the north of the lake, are certainly not of sufficient extent and elevation to have constituted the gathering ground of a great glacier, and the only possible source of such an agent must therefore be sought in the more distant Alps. Assuming for one moment that there existed during the Glacial Period an ice-river of sufficient dimensions to have extended from the Eastern Alps to Lake Balaton (though of this no proof has, so far as I am aware, been ever adduced)—such a glacier would naturally have followed the valley of the Mur or that of the Raab, in neither of which do great lakes exist, and could not have originated Lake Balaton, which lies on the plateau separating the basins of these two rivers. For an Alpine glacier to have excavated the bed of Lake Balaton, it must have been able with a very slight initial descent—the Eastern spurs of the Alps having a comparatively small elevation—to traverse a nearly level plain 100 miles in width, to have then surmounted a group of hills some 30 miles broad and from 1000 to 1200 feet in elevation, and after all this expenditure of force to have retained sufficient energy to dig in the midst of solid rocks a basin of vast extent. In short, Lake Balaton lies exactly in that position which is of all others the least favourable that it is possible to conceive for the action of the supposed excavating power of a glacier from the Eastern Alps; while the points at which the erosive action of such a glacier would naturally operate with greatest effect exhibit no traces whatever of the formation of rock-basins.

But in the case of Lake Balaton there is opportunely furnished to the geologist a means of applying to the theory of ice-erosion a ***crucial test.***

Right in the midst of the lake, and almost dividing it into two portions, rises the peninsula (once an island) of Tihany; this is a mass of considerable elevation, composed for the most part of loose basaltic tuffs, and evidently constituting the relics of an old volcanic cone.

Now, it is quite inconceivable that a glacier, which had sufficient excavating power to produce that great depression in the solid rocks among which Lake Balaton lies, could, nevertheless, have left standing right in its course such a mass of comparatively soft tuffs as constitutes the peninsula of Tihany. And it must therefore be clear to every one that, unless the volcanic outbursts which formed this mass can be shown to be of *later date* than the Glacial Epoch, the basin of Lake Balaton could not possibly have had its origin in ice-action during that period.

But concerning the geological age of the tuffs of Tihany we have the most unmistakable evidence in the fossils which they contain. These prove conclusively that the volcanic outbursts by which they were formed took place during the deposition of the 'Congeria Schichten'—which are placed by Karl Mayer on approximately the same horizon as our Coralline Crag. That the basaltic lavas and tuffs of the Bakony Wald were formed *long prior* to the Glacial Period there is not, indeed, the slightest room for doubting; and this conclusion is quite in harmony with the appearances of very extensive denudation which these volcanic rocks present;—the lava-streams being reduced to isolated plateaux, the tuffs in great part swept away, and the plugs of basalt, that have filled the throats of the old volcanos, in many cases left standing above the rocks they have penetrated.

Dismissing then on these conclusive grounds the theory of glacier-erosion, as certainly inapplicable to the case of Lake Balaton, let us inquire if the examination of the district does not suggest any other mode of origin for it. Such, we think, every geologist will at once recognize as indicated by the volcanic outbursts that have taken place, not only on its northern and southern shores, but also in the midst of its bed. The volcanic district of the Bakony Wald and Lake Balaton, which is illustrated in our sketch-map, Plate I. (the materials of which are derived from the Geological Maps of the Vienna Reichsanstalt and those of the Geological Institute of Hungary), is a portion only of a linear series of later Tertiary volcanos, which stretches south-westward from the Matra of Northern Hungary to the Danube, being produced on the opposite side of that river by the trachytic outbursts lying north-east of Stuhlweissenburg, and beyond the Bakony Wald in the opposite direction through Styria to the neighbourhood of Gleichenberg. It is impossible to doubt that the peculiar arrangement of this series of contemporaneous volcanic outbursts points to the existence of a line of fissure in the earth's crust at the time of their occurrence; and it is a very significant circumstance that the longer axis of the great depression in which Lake Balaton lies exactly coincides with this line of volcanic action.

We have already had occasion to refer in these chapters to the local subsidence which, as demonstrated by Darwin, so frequently follows the cessation or accompanies the decline of volcanic activity in a district; and which is so admirably illustrated by the Lipari Islands and Santorin among recent volcanos, and by that of Mull among those of more ancient date. In such a subsidence, therefore, we recognize a competent and obvious cause of the production of the rock-basin occupied by Lake Balaton. And the fact of such subsidence is confirmed, as in the analogous case of the island of Mull, by the exceptional state of preservation of the old volcano of Tihany.

We thus see that an examination of the phenomena presented by the largest of all the lakes in southern Europe leads us to ascribe its origin to the subterranean movements that have accompanied volcanic action. It is interesting to notice the circumstance that by far the largest lake in our own islands exhibits the clearest proofs of having been formed by the same agency. Some years ago, while studying the basaltic rocks of Antrim, I was strongly impressed by the conviction that Lough Neagh must clearly have been formed by subsidence taking place subsequently to the great development of volcanic activity in the district; and this view is abundantly confirmed, and indeed placed beyond the possibility of doubt, by the valuable observations made by Mr. E. T. Hardman, of the Geological Survey of Ireland, during his detailed examination of the district. In a communication laid before the British Association in 1874, Mr. Hardman shows conclusively that Lough Neagh (which must originally have had an area nearly twice as great as at present) existed *before the Glacial Epoch;* and that a series of post-Miocene dislocations, which he has traced during his survey, would lead to a subsidence of the tract occupied by the lake.

That the very remarkable valley of the Jordan occupied by the lakes of Merom, Tiberias and Asphaltites (Dead Sea), the latter of which is 1300 feet below the Mediterranean, is an ordinary river, valley, which once terminated in the Gulf of Akabah, but in the line of which great depression has taken place, seems now to be clearly proved by the officers who have conducted the Ordnance Survey of Palestine. And there appear to be grounds for connecting this great depression, which was once occupied by a single vast lake, with volcanic action in the district.

The three examples we have cited represent very fairly the three principal types of lake-basins which exist upon the earth—Balaton being an example of a vast but shallow depression without natural outlet,—Lough Neagh a smaller but deeper lake lying in a system of drainage,—and the Jordan gorge a depression in a line of river-valley, the bottom of which now lies far below the sea-level.

But in pursuing this line of reasoning we may perhaps go one step further. The interesting accounts that have recently come to hand of the explorations of Mr. Stanley in equatorial Africa suggest the probability that the noble lake of the Victoria Nyanza (which bids fair to prove a rival in size to Lake Superior in North America, and therefore to be the largest sheet of fresh-water in the world)[1] may also lie in a basin formed by volcanic subsidence. It is now apparent that this lake is no mere marsh, or collection of lagoons, as soundings *near its shores,* which are often exceedingly bold and even mountainous in character, have been found to indicate depths up to 275 feet. The fact of the existence of this and the neighbouring lakes *immediately under the equator* will be of course accepted as proving that they, equally with Lough Neagh and Lake Balaton, could not have been formed by the agency of ice during the glacial period. On the other hand, the frequent mention of basaltic rocks as occurring on its islands and shores, and the report of the existence of a number of active volcanos in its proximity, at least suggest that it may owe its origin to the action of the same causes which have formed the lakes in question. But for the final settlement of this question we must await the arrival of fuller details concerning this very interesting lake district of Central Africa.

We think that the foregoing remarks will be accepted by all as showing that rock-basins—even those of the very largest dimensions—may have had their origin in those changes of level resulting from the subterranean movements which have accompanied volcanic action,—and that, as a matter of fact, the largest lakes in the British Islands and in the Alpine regions of Europe, respectively, and not improbably the vast sheets of water in Central Africa also, have been so formed, and could not possibly be the result of glacier-erosion.

It would of course be very easy to multiply to almost any extent the examples of lakes which, like those of Van, Urumiah, etc., in the district south of the Caucasus, are clearly connected with the outburst of volcanic forces; or of others, like those of Nicaragua, Managua, Maracaybo, and Titicaca, etc., in the Equatorial part of the American continent, which no one can dream of as having been formed by the action of glaciers.

It may here, however, be necessary to point out that our argument lends no support whatever to the inference that, in those districts where the action of *volcanic* forces cannot be traced, lake-basins must be the result of other than subterranean agencies. On the contrary, we maintain that movements, precisely similar in character to those which take place in volcanic districts, are constantly occurring on every part of the earth's surface. It is probable, indeed, that the movements which are connected with volcanic activity are often of a more sudden and violent character than those which take place in non-volcanic districts, and that in consequence of this their effects are more strikingly manifest to us. But to suppose that the

[1] There is still some doubt remaining as to the dimensions of the Victoria Nyanza. If Mr. Stanley's map represents the true positions of points on its shores, then the lake would certainly be larger than Lake Superior. If, however, Captain Speke's determinations of positions be accepted as the more accurate, as Mr. Ravenstein advocates, then the African lake would be about one-sixth smaller than the American.

permanent effects produced in the case of the former are necessarily greater than in that of the latter, would be as unphilosophical as for a geologist to ascribe to sudden floods (the effects of which strike the most casual observer) a greater share in the excavation of valleys than to the unobtrusive but constant actions of atmospheric waste and ordinary transport by streams.

If we can demonstrate, in the first place, that in those districts where the effects of subterranean movement are most readily traced (namely volcanic areas) rock-basins have certainly been produced by this agency; and, in the second place, that movements similar in character and equal in extent occur in other districts, though in a manner which renders their effects less capable of detection by us,—are we not justified in accepting such movements as capable of explaining the formation of lake-basins in all cases, rather than in having recourse to a purely hypothetical cause?

And if this mode of viewing the subject be a legitimate one, what reason can be adduced for doubting that those great disturbing forces — which, during and subsequently to the Oligocene and Miocene periods, have given rise to such startling results in the contortion and even in the inversion of the rocks of the Alps, but which at the same time have produced only inconsiderable effects in the areas immediately surrounding them—*must* have originated, in different parts of the great lines of drainage descending from those mountains, such inequalities of movement as could not fail to result in the formation of lake-basins? Now it is a most striking and significant circumstance that a careful study of the deposits that were formed *immediately around the Alpine System* during the periods of most violent movement leads to the conclusion that, near the limits of the disturbed and unaffected areas, lakes were constantly being formed and filled up with sediments. Nor have we the smallest grounds for inferring that such movements have altogether ceased, and could have played no part in the origination of the existing lakes in similar positions; but, on the contrary, even the stoutest advocates of the glacial origin of these lakes admit that considerable movements must have taken place, both in the Alps and elsewhere, during and subsequently to the Glacial Period.

This is the view of the mode of origin of the great Alpine lakes which was maintained by the late Sir Charles Lyell, and which has been supported by the critical examination of a number of special examples by the Rev. T. G. Bonney. And the same opinion concerning the formation of these lakes is held by the distinguished geologists of Germany, Switzerland, France and Italy, who during the last thirty years have made such splendid additions to our knowledge of Alpine geology; with but one solitary exception, we believe, all the geologists who have especially devoted themselves to the study of these regions have rejected the hypothesis of the glacier-erosion of the lake-basins as both unnecessary and inadequate.

Of the various facts which have been adduced as lending support to the doctrine of the erosion of lake-basins by ice, the only one which can be said to afford a presumption in its favour is the abundance of lakes in districts which have been recently subjected to glacial erosion. But this fact, as was shown by the late Sir Charles Lyell, is capable of another and very simple explanation, without calling in the agency of so problematical a cause as the excavating power of ice. A very large proportion of the lakes and lakelets, found in glaciated districts, are in reality formed through the arrest of drainage by the peculiar and often seemingly capricious modes of accumulation of moraine matter. The smaller number of true rock-basins which remain, after eliminating the moraine lakes, appear indeed to owe their existence also to the action of glaciers, but in a very different manner from that maintained by the advocates of the doctrine of ice-erosion, or even from that suggested by M. de Mortillet.

In considering this question, it must always be borne in mind how rapidly the effects of subterranean forces on the drainage of a district are masked and concealed by the action of denuding causes. As we sail over the great Alpine lakes, we are constantly impressed by the fact that, even in the case of those of most profound depth, every tiny streamlet that descends from the surrounding mountains is pushing a delta boldly into its waters, while the larger streams have often produced alluvial flats of enormous extent, that have evidently been reclaimed from the area of the lake. To the eye of a geologist, indeed, almost every lake may be said to be *visibly filling up*; and the whole Alpine System is encircled by innumerable *extinct lakes*, belonging to various geological periods. The effects produced by local subterranean movements in the line of a river-valley—whether in creating an increased fall, and thus originating rapids and waterfalls, or in arresting the drainage at certain points, and thus forming lakes—must be regarded as bringing about a condition of *unstable equilibrium* in the valley; while the erosive and transporting action of the stream is continually tending to remove the temporary derangements in the system of drainage by the cutting back and levelling of the precipices over which rapids and cascades descend, and by filling up the beds of lakes or cutting through the dams that retain them. In those valleys, indeed, wherein the action of denuding forces more than counterbalances that of subterranean movement, the formation of rapids and of cascades on the one hand, and of lakes on the other, will be prevented.

In this admirably adjusted system of mutually antagonistic agencies—those namely of surface erosion and subterranean movement—the occurrence of a period characterized by glacial conditions will produce an interruption, which must be attended with very marked though temporary effects. The depressions which under ordinary circumstances would form the beds of lakes, and then rapidly be filled with sediments, would probably be occupied by inert masses of ice, over which the glaciers would flow in just the same manner as the waters of some of the existing Alpine rivers pass over the surface of the lakes that lie in their course, without producing any appreciable effect on the great mass of cold water that occupies their profounder abysses. This temporary arrest of the compensating effects of river action in a valley—while the antagonistic agent, subterranean movement, remained unaffected—would of course result in the formation and preservation of a greater number of lake-basins on the one hand, and of abrupt slopes on the other, than could be originated under ordinary conditions.

These considerations, taken in connexion with the frequency of the arrest of drainage by moraine matter, enable us to understand that frequency of lakes and tarns in glaciated districts, to which such importance has been attached by the advocates of the theory of ice-erosion.[1] But they also afford an equally simple explanation of certain facts, which are altogether inexplicable by and opposed to the theory of the excavation of rock-basins by ice—namely, the frequent absence of lakes in certain other glaciated regions and in situations where, according to that theory, the conditions were most favourable for their production. If, as we maintain, the formation and preservation of numerous lake-basins in a district is due to a favourable coincidence of subterranean movement with the suspension of the obliterating effects of river denudation through the occurrence of glacial conditions at the surface, then the abundance of such lakes in some glaciated regions and their paucity in others are alike accounted for.

It is, however, impossible to conceal from ourselves that the real obstacle to the reception of so simple an explanation of the formation of lake-basins, as that afforded by local changes of level due to differential subterranean movements along lines of drainage, and the consequent appeal to the hypothetical agency of the excavating power of ice, is the strange assumption that the production of the features of the earth's surface is entirely due to the action of denuding agents, and that subterranean forces have played no part whatever in the matter. We cannot but regard this doctrine—so boldly advanced by several modern writers on geology—as opposed to the fundamental and best established principles of the science, and as being not less mischievous in its tendencies, than it is unsupported by facts.

That differential movements of the most striking character have taken place in the earth's crust during every geological period, no one who examines the admirable detailed maps of the Geological Survey of the United Kingdom, and studies the effects produced by the numerous *faults* indicated upon them, can for one moment doubt. And yet every practical geological surveyor will readily admit that the dislocations of the strata, which he is able to detect, bear probably only a small proportion to those which actually exist. This is shown by the fact that while in formations exhibiting rapid alternations of thin beds, like the Coal Measures or the Oolites, in which faults are easily detected, they are represented as exceedingly abundant, in others, consisting of uniform masses like Mountain Limestone, Lias Clay or Chalk, where it is difficult to trace their effects, but very few are indicated. But even where no actual

[1] Mr. Scrope has called my attention to the interesting circumstance that in both the Scandinavian and North American regions, which exhibit such a vast number of lakes, we have unmistakable proofs that considerable movements of the surface of the land have been going on in comparatively recent times.

fractures of the strata occur, undulations and foldings of various degrees of curvature bear witness to the continual action of subterranean forces. And that the effects of these were felt at the surface is amply demonstrated by peculiarities in the mode of accumulation of the various sediments, which, as Darwin has so well shown, must ever be dependent on the rate of subsidence. Nor have we the smallest grounds for believing that these subterranean movements and the effects produced by them at the surface are one whit less powerful at the present time than during former geological periods. In proof of this we need only point to the numerous facts that have been accumulated, especially by Lyell and Darwin, showing that the present surface of the earth is subject to slow but powerful movements, sometimes wide-spread in their operation, but at others exceedingly local. The modes of reasoning by which geologists have arrived at these conclusions concerning the movements of the earth's surface are not less cogent and convincing than those which they adduce in support of their views concerning the effects of denuding agents. And it is quite possible to admit *to their fullest extent* the important part played by atmospheric waste in the moulding of the features of the earth's surface, without persistently shutting our eyes to the effects of those subterranean forces, concerning the operation of which we have equally convincing evidence.

The only mode of escaping from this mode of reasoning is by denying that local and differential movements, such as have so constantly produced bending and fracture in the strata, are still at work on the earth's crust; or, as Mr. James Geikie appears to do,[1] to assume that they can produce no effects at the surface. That faults do not produce "lines of cliffs" at the surface (except perhaps under peculiar and exceptional conditions) we are ready to admit—for the denuding forces are constantly at work masking and modifying the effects of the subterranean; and both are equally slow and all but imperceptible in their modes of action during the limited periods of human observation. But for the conversion of an ordinary river-valley in part of its course into a lake-basin, it is by no means necessary that any movement of so great and violent a character as to produce a fault in the subjacent rocks should take place. Any one who will examine the longitudinal section of a lake-basin *accurately drawn to scale*, such, for instance, as the instructive examples given by Professor Ramsay, must admit that an almost imperceptible curvature of the strata, to the extent of two or three degrees only, will suffice to produce even the deepest known lakes.

That lines of flexure and fracture must have had much to do in the original determination of the lines of drainage of a district, it is impossible to doubt. And that periods of violent movement in a district may have resulted in important modifications and vast alterations in its system of drainage, few will hesitate to admit. Where too, as in the case of Lough Neagh, the detailed mapping of the district by a competent observer brings to light faults, the position, effects, and age of which are exactly such as would result in the

[1] "The Great Ice Age," page 289.

surface movements necessary to produce the rock-basin in question, we are surely justified in inferring a connexion between the two sets of phenomena. But it by no means follows that where we are unable to detect a fault crossing the line of valley or a synclinal fold in its course, there subterranean movement could have had no part in producing a lake-basin in it. The amount of vertical movement necessary to originate even the deepest known lake-basins bears so small a proportion to the length of the valleys in which they lie that we do not hesitate to affirm that their effects upon the subjacent strata could not, save under exceptionally favourable conditions, be detected by the most experienced geological surveyors.

It is only by those who ignore altogether the operation of subterranean forces, in directing, controlling and modifying the effects produced by denuding agencies, that any difficulty has ever been experienced in accounting for the formation of lakes, or that the necessity is felt for assuming that *rivers of ice* possess a power, which it is on all hands admitted does not belong to *rivers of water* —that of excavating great basin-shaped depressions in their course. To those who believe that—alike in the present and during all former geological periods—the subterranean and subaerial agencies have been in unceasing action, side by side, and that the present features of the earth's surface are the result of the constant mutual interaction of these two classes of forces—the formation of rock-basins, far from being, as is asserted, an *abnormal* phenomenon, is one of the necessary consequences of the antagonistic agencies which we can demonstrate to be operating on the surface of our planet. If it be granted, in the first place, that meteoric agencies have the power of producing great lines of drainage (valleys) on the earth's surface—and, in the second place, that different portions of such lines of drainage may be subjected to unequal vertical movement—and of the truth of both these postulates we can produce equally unmistakable and convincing evidence—then it follows, inevitably, that cascades or rapids on the one hand, and lake-basins on the other—the results of converse relations of the two sets of forces—*must be* from time to time produced in these lines of drainage. And if all the existing lake-basins are to be assumed to have been produced by ice-erosion, we may surely be justified in asking—What has become of those which must have resulted from the action of the obvious causes to which we have just referred?

To sum up the argument of the present chapter—We have demonstrated that the basins of the largest lakes in our own islands, in the Alpine regions of Europe, and in equatorial Africa, respectively, *could not possibly* have been formed by the supposed excavating power of ice. We have also shown that in each of these cases there is the strongest ground for believing the districts in question to have been subjected to powerful subterranean movement; and that these were quite competent to produce the depressions in question.

But if it can be proved that in the case of lakes which happen to preserve evidences of the manner and date of their origin, the ordinary operations of denuding and subterranean forces are quite competent for their production—even when the lakes are of the very largest dimensions—where is the necessity for calling in the aid of a new and problematical agency to account for the formation of the smaller examples?

For ourselves, we must add—in the face of the strenuous efforts which have recently been made to resuscitate the doctrine of the erosion of lake-basins by ice—that an attentive study of the lakes of both the Scottish Highlands and of the Alps (districts which have been so confidently appealed to as affording the strongest support to the theory) has only served to confirm our conviction in the justice of the conclusion, on this subject, that has been arrived at by all except an inconsiderable minority of geologists—namely, that the agency in question is as unnecessary as it is hypothetical.