John F. Campbell Esq
With the Author's compliments

Read carefully May 11 1876
J. F. Campbell.

CONTRIBUTIONS TO THE STUDY

OF

VOLCANOS.

ON THE FORMATION OF LAKES IN VOLCANIC DISTRICTS.

The latter part of this is too strong by half. Rivers of water do dig holes. Rivers of ice also dig holes, and when they melt these basins are "lakes" There are plenty of glacier lakes but all lakes are not glacial

THE
GREAT CRATER-LAKES
OF
CENTRAL ITALY.

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 $10\frac{1}{4}$ 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.

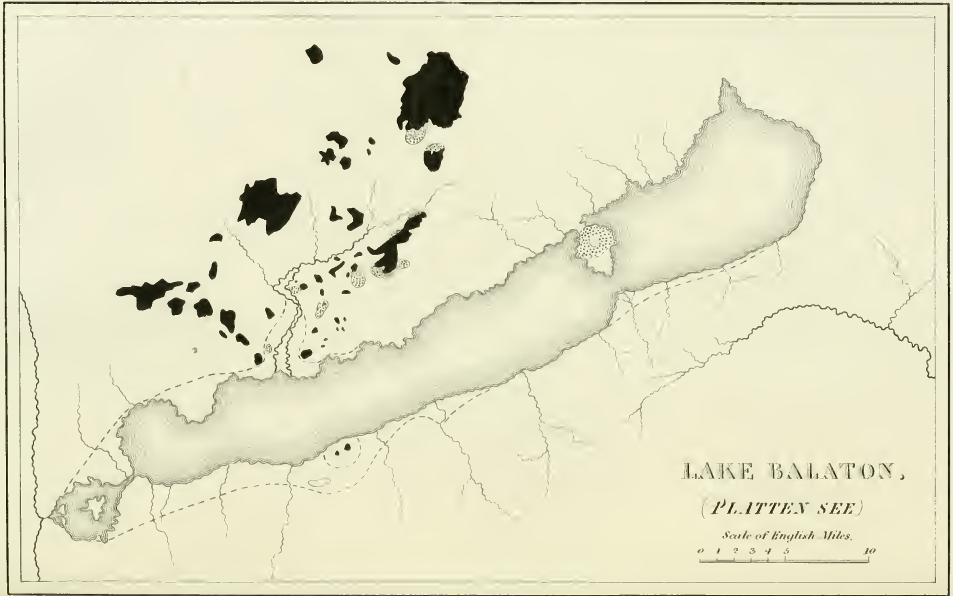
But as we have already pointed out, the wide and little elevated crater-rings of Albano, Bracciano and Bolsena present a totally different kind of architecture to the solid structure of Etna. They are in fact almost wholly built up of loose tuffs; masses of solid lava, whether in currents or dykes, being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

— — — — 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 sub-aerial 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.

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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.