J. W. Judd, del. J. W. Lowry, sculp[t]

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

II.—Contributions to the Study of Volcanos.

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

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 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.

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 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

[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.

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 *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

[1] Mr. Scrope has called my attention to the interesting circumstance that in both

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 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, show-

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.

ing 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 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 subter-

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

ranean 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.

The zoological position of *Hesperornis* is evidently in the *Odontornithes;* but the insertion of the teeth in grooves, the absence of a keel on the sternum, and the wide difference in the vertebræ require that it be placed in a distinct order, which may be called *Odontolcæ,* in allusion to the position of the teeth in grooves.

The two orders of birds with teeth would then be distinguished as follows :—

Sub-class, ODONTORNITHES (or AVES DENTATÆ).

A. Teeth in sockets. Vertebræ biconcave. Sternum with keel. Wings well developed. Order, ODONTOTORMÆ.

B. Teeth in grooves. Vertebræ as in recent birds. Sternum without keel. Wings rudimentary. Order, ODONTOLCÆ.

In comparing *Ichthyornis* and *Hesperornis*, it will be noticed that the combination of characters in each is very remarkable, and quite the reverse of what would naturally be expected. The former has teeth in distinct sockets, with biconcave vertebræ; while the latter has teeth in grooves, and yet vertebræ similar to those of modern birds. In point of size, and means of locomotion, the two present the most marked contrast. The fact that two birds, so entirely different, living together during the Cretaceous, should have been recovered in such perfect preservation, suggests what we may yet hope to learn of life in that period.

The geological horizon of all the *Odontornithes* now known is the Upper Cretaceous. The associated vertebrate fossils are mainly Mosasauroid reptiles and Pterodactyls.

A full description with plates of all the known *Odontornithes* is is now being prepared by the writer.

YALE COLLEGE, NEW HAVEN, *Oct.* 18*th*, 1875.

EXPLANATION OF PLATE II.

FIGS. 1–4. *Ichthyornis dispar*, Marsh. Twice natural size.
FIG. 1. Left lower jaw; top view.
„ 2. Left lower jaw; side view.
„ 3. Cervical vertebra; side view.
„ 4. Same vertebra; front view.

FIGS. 5–9. *Hesperornis regalis*, Marsh.
FIG. 5. Left lower jaw; side view; half natural size.
„ 6. Left lower jaw; top view; half natural size.
„ 7. Dorsal vertebra; side view; natural size.
„ 8. Same vertebra; front view; natural size.
„ 9. Tooth; four times natural size.

II.—CONTRIBUTIONS TO THE STUDY OF VOLCANOS.

By JOHN W. JUDD, F.G.S.

SECOND SERIES.—THE ANCIENT VOLCANOS OF EUROPE.

IN the preceding chapters we have endeavoured to throw light upon some of the more salient characters of volcanos—the features of their architecture, the nature of their products, and the peculiarities of their attendant phenomena. In doing so, however, we have preferred to select our illustrations from some of the less familiar, though, as we hope to have shown, by no means less interesting volcanos of our continent; and have of set purpose avoided the oft described examples of Vesuvius, Etna, the Auvergne, and the Eifel.

Before we turn our attention to the evidences which are found of the existence of volcanos in the same area during former geological periods, it will be instructive to pause, in order to take a brief review of the existing distribution of volcanic agencies in Europe.

Excluding Iceland, there are in Europe five volcanos known to be still active. One of these, Stromboli, is in a state of permanent eruption, while the other four—Etna, Vesuvius, Vulcano, and Santorin—may be the seat of a paroxysmal outburst at any moment. To these we ought perhaps to add the *mud-volcanos* of Sicily, Transylvania, and Wallachia. Some other volcanos, like the Solfatara of Naples and the Büdos Hegy in Transylvania, still discharge considerable quantities of heated gas and vapour, and are presumed (though perhaps erroneously) to be approaching the stage of complete extinction. Nor, in taking a survey of the volcanic phenomena of Europe, ought we to omit to notice those innumerable sources of hot water and gas, which perhaps collectively relieve the earth's crust of more heat than escapes from it during all the outbursts of volcanic violence, though in a manner so much less impressive. These hot springs, rising probably in the lines of old volcanic fissures, have determined the positions of the health-resorts which are found in such abundance in certain parts of the Continent.

But a large number of mountains and hills exist in Europe which, although exhibiting few, if any, symptoms of igneous activity at the present time, yet in their structure and materials present so many points of analogy with the active volcanos which we have enumerated, that no one can for a moment hesitate in assigning to them a similar mode of origin. Such are the innumerable extinct volcanos in the districts of Southern and Central Italy, the Auvergne, the Eifel, the Grecian Archipelago, the Island of Sardinia, and that lying on both sides of the eastern end of the chain of the Pyrenees. Besides these, several more isolated volcanic cones exist in Europe, such as that of Orgiofhof in Moravia, and the well-known Kammerbühl and Eisenbühl in Bohemia. Among these extinct volcanos every possible gradation may be traced, from such as present the most perfect and unweathered cones and craters, the complete extinction of some of which (as, for example, those of the Campi Phlegræi and Ischia) we are by no means assured of, to mere shapeless heaps of volcanic materials.

Besides the active and extinct volcanos, however, there are many masses of rock in Europe which in character and composition betray unmistakable evidences of their igneous origin; such are the so-called "traps" and many of the granitic rocks. Although the connexion of these with volcanic, or indeed with any kind of igneous action, was long strenuously denied, yet a more complete knowledge of such rocks, and a juster conception of the true nature of volcanic action, has now removed all doubts upon the subject from the minds of geologists, who now recognize and reason upon the evidences of volcanic activity in the earlier periods of the world's history with no less certainty than concerning those of the present day.

As illustrating the stages by which geologists have been gradually led to the adoption of their present views, we cannot perhaps do better than to relate "the story of the Kammerbühl."

The Kammerbühl, or Kammerberg (see Fig. 1), which is situated a little west of the road leading from the ancient town of Eger to the modern health-resort of Franzenbad in Bohemia, and about a

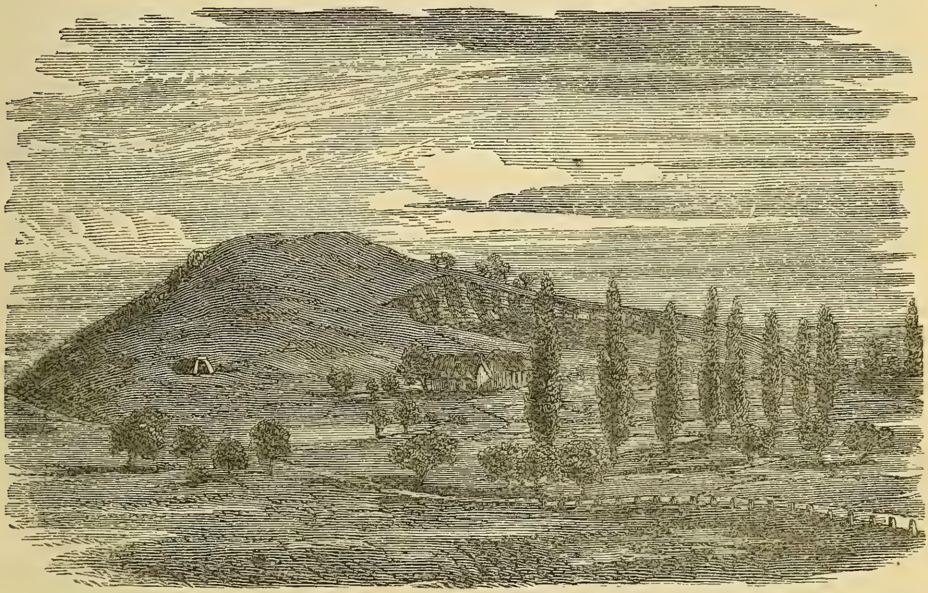


Fig. 1.—The Kammerbühl or Kammerberg, Bohemia, as seen from the South-west.

mile and a half from both places, was styled by Goethe "a pocket edition of a volcano." The interest which this object has excited among geologists arises neither from its magnitude nor from the perfection of its preservation, for in both these respects it is surpassed by hundreds of volcanic cones which might be mentioned in Italy, the Auvergne, and the Rhineland. But from its position, almost in the midst of the camp of the Wernerian school, it has been the object of many a fierce controversy, and it enjoys the probably unique distinction of being a volcanic cone of which the internal structure has actually been demonstrated by means of mining operations carried on within and around it.

The word "bühl" is an archaic German one, signifying a low hill, the distinctive appellation being derived from the district in which it is situated—the Kammerwald. The Kammerbühl stands upon a plateau composed of mica-schist with much quartz, the surface of which is about 1500 feet above the sea-level. The hill itself is a very small one, with gentle slopes, its elevation above the surrounding plain being only 126 feet; but it is conspicuous on account of its isolation. Its base is enveloped and concealed by the thick superficial deposits of recent date, for at no very distant period the whole country round must have formed a series of vast lakes and morasses, many portions of which are still undrained. The base of the hill is an irregular oval in form, about 500 yards long and

200 yards broad; and we can perhaps best give an idea of its true character by describing it as a slightly-curved ridge of cinders, stretching from north-west to south-east, in the former of which directions it presents its greatest elevation and steepest slopes, while in the latter it gradually and almost insensibly sinks into the plain.

On ascending the hill, it is at once seen to be composed of basaltic scoriæ, often containing olivine, mingled with larger or smaller quantities of fragments of the mica-schist and quartz of the platform on which it stands. But the best idea of the structure of the hill is obtained by means of the large artificial excavation that has been made in its southern part. This is a quarry about 200 feet long, 80 feet wide, and 30 feet deep, from which the scoriæ are dug for covering the roads. It is known as the Zwergeloch (Pigmies' Hole) from the tradition that it is the scene of nightly assemblies and revels of the dwarfs.

The sides of this quarry exhibit beautiful sections showing that the mass of the hill is composed of basaltic scoriæ of remarkably fresh appearance; but scattered among these are angular fragments of clay-slate, mica-schist, and quartzite, often exhibiting a burnt appearance, and not unfrequently of a bright-red colour. The whole mass is beautifully stratified (as is so commonly the case with the materials of volcanic cones), the varying colours of the different bands giving rise to a very striking appearance. Occasional beds occur, of varying thickness, which are almost wholly composed of fragments of the subjacent rocks; these we may refer without doubt to the action of sudden explosions tearing away the sides of the vent. Many of the scoriæ entangle numerous small fragments of the metamorphic rocks, but the proportion of these entering into the composition of the cone is not nearly so great as in the case of many of the Eifel. The scoriæ vary in size from that of a pea, or even less, up to a yard in diameter. A few well-formed "bombs"

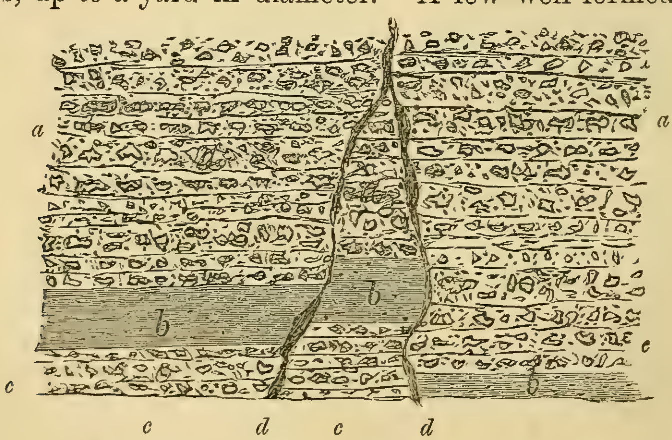


Fig. 2.—Section seen in side of the Zwergeloch.
a, a. Stratified Basaltic scoriæ.
b, b. Bands made up of fragments of burnt slate.
c, c. Stratified Basaltic scoriæ.
d, d. Pseudo-dykes occupying lines of fault.

occur, but do not constitute any large part of the whole, which consists mainly of very rugged scoriæ. A number of small faults or hitches in the mass, an interesting example of which is represented in Fig. 2, bear witness to the violence of the subterranean forces; and the appearance of chemical action on the materials near these and other vertical fissures indicates that they once served as channels for the escape of gases and vapours (fumaroles). Some of these fractures are occupied by loose materials and constitute *pseudo-dykes,* like those so frequently seen in the Neapolitan volcanos.

On the highest summit of the Kammerbühl there exists a small oval depression, about 15 yards in diameter and 7 feet deep. It has been supposed to represent the "crater" of the volcano; but this opinion is certainly erroneous, and there is no doubt that the depression in question has been occasioned by one or other of the numerous excavations which have been carried on in this hill, either for the purpose of discovering mineral treasures, or of satisfying scientific doubts. It is clear that the volcano of the Kammerbühl has suffered greatly from denuding causes, and that all its *external* features have been long destroyed. From what remains I should be led to infer that a series of several cinder cones in close apposition originally existed here, and that the one at the north-west end, which was the largest, was breached by a lava-stream.

The remains of this lava-stream are very clearly seen on the western side of the highest part of the ridge; its surface is highly scoriaceous, and only some of the more rugged portions rise above the grass-grown slopes of the hill. The remains of a quarry, from which rock was at one time obtained (it is said for millstones, and certainly for building purposes, as shown by the Roman tower in the old Castle of Eger), are seen in the midst of this lava-stream. By means of it we are enabled to see that the central and more solid parts of the lava constitute a true basalt, with much magnetite and olivine. This lava-stream cannot be traced far, and it appears to have been one of those of very imperfectly liquid character, adhering to the sides of the cone, but not extending itself on the level ground around it.

From the above brief description of the Kammerbühl, the reader may perhaps conclude that its true volcanic character is so obvious that no competent observer can ever have entertained a doubt upon its mode of origin. Such, however, is very far from having been the case. Although, as early as 1773, the Ritter von Born, in a series of letters to the Count von Kinsky, described the Kammerbühl as "an extinct volcano,"—yet the mischievous influences of the teachings of Werner subsequently manifested themselves in many attempts to prove that the lava of the Kammerbühl was, in common with the other patches of basaltic rock in Bohemia, "a floetz-trap rock," and the product of "aqueous precipitation."

In 1792 F. A. Reuss (the father of the recently deceased distinguished geologist A. E. Reuss) found the evidences of the action of fire in the materials of the Kammerbühl so overwhelming, as to lead him to put forward a new theory of its mode of origin. He argued that it was really the result of an "Erdbrand,"—a phenomenon of not uncommon occurrence in Bohemia, and resulting from spontaneous combustion taking place in beds of pyritous brown coal. It is of course unnecessary to point out the utter futility of such a mode of explanation; nothing, indeed, but the most desperate determination to escape, at all hazards, from the admission of anything like volcanic action, could have led to its being entertained even for one moment.

In the midst of the controversies of which the Kammerbühl had thus become the centre, it is to the illustrious Goethe, whose philosophic mind so successfully grappled with some of the most difficult problems of comparative anatomy, botany, and other sciences, that geologists are indebted for an able and independent examination of the whole question.

In 1809, and again in 1820, Goethe visited the Kammerbühl, and the result of his studies, as given both in Leonhard's Taschenbuch and the "Morphologie," was to place its true volcanic character beyond question. Subsequent writers on the subject, the list of which includes the names of Heinrich and Bernhard Cotta, Goldfuss, Bischof, Berzelius, Ehrenberg, Leonhard, Nöggerath, Sternberg, A. E. Reuss, and Jokely, have fully confirmed the correctness of the views maintained by Goethe.

But the most interesting part of the great German poet's contribution to this subject is that in which he suggested a simple means for removing once for all the doubts concerning the true origin of the Kammerbühl, and at the same time of applying to the Wernerian doctrines an infallible test. He showed that if, as "the Vulcanists" maintained, the basalt of the Kammerbühl came *from below*, a consolidated duct of the same material would probably be found in the midst of the cinder cone; and he suggested that mining operations should be carried on in the hill to confirm or disprove the presence of such a central core of basalt.

In 1834 the Count Caspar von Sternberg, whose contributions to fossil botany are so well known to geologists, determined to carry out the poet's suggestions. Already shafts and galleries had been sunk, in and around the Kammerbühl, with a view to the discovery of beds of brown coal. One such gallery is said to have been carried in 1776 to the distance of 360 feet; but of the details of these early explorations we have only very imperfect accounts. In 1820 Count Sternberg had himself caused a shaft 27 feet deep to be sunk in the midst of the Zwergeloch; and Heinrich Cotta had in 1826 put down two pits at the summit and base of the hill respectively, with a view to more fully determining the materials of which it is composed.

Count Sternberg's experimental works at the Kammerbühl consisted of a shaft on the south-west side of the hill carried down to the depth of 60 feet, and a number of galleries which were driven both from the bottom of the shaft and from the surface into the very heart of the hill. These old workings are now nearly filled with water, but the entrance to them is ornamented by a stone archway bearing the following inscription: "Den Naturfreunden gewidmet vom Grafen Caspar Sternberg, 1837." The result of these works was to fully establish the presence of a central mass of basalt in the midst of the hill; the presence of which had been affirmed by "the Vulcanists," and denied by "the Neptunians." From the results of these workings we are enabled to give the accompanying section of the Kammerbühl, Fig. 3.

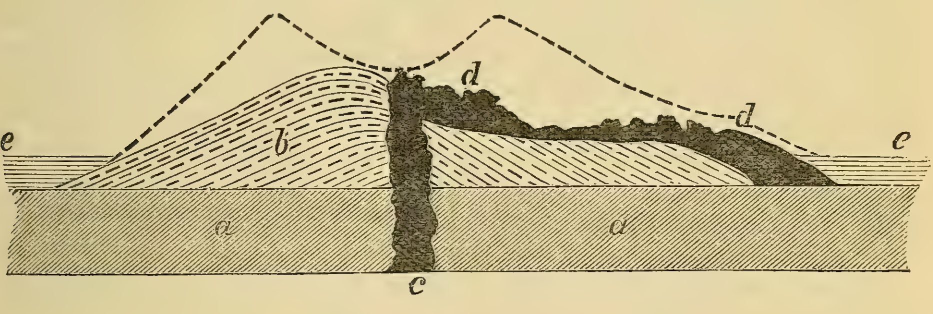


Fig. 3.—Section of the Kammerbühl in Bohemia.

a, a. Metamorphic rocks.
b. Basaltic scoriæ.
c. Solid mass of basalt rising through the centre of the volcanic pile.
d, d. Lava stream composed of the same rock.
e, e. Alluvial matter surrounding the old volcano.
N.B.—The dotted lines indicate the probable former outline of the volcano.

English readers will doubtless call to mind that a similar experimental test was at an earlier date suggested by Hutton, in the case of the veins of the Salisbury Crags, and was carried out by his friend Sir James Hall.

We have been led to dwell at some length on this story of the Kammerbühl, because that object forms such an interesting and instructive link between the undoubtedly extinct volcanos and the so-called masses of "trap-rock." All through Northern Bohemia, as well as in the districts of Silesia lying to the east, and in those of Bavaria to the west, isolated masses of basalt, like that occupying the centre of the Kammerbühl, occur by hundreds; and the same is found to be the case in the districts of Central Germany lying between the Thuringerwald and Hartz Mountains on the east, and the Rhine on the west. In many cases, as near Eisenach and Fulda, such masses of basalt are shown by quarrying operations to be truly intrusive, and are seen to have given off veins into and metamorphosed the surrounding rocks. Very interesting details concerning the physical and petrological features of some of these old volcanic ducts have recently been given by Prof. Möhl of Cassel.

If districts, like those of the Auvergne or the Eifel, which exhibit great numbers of small volcanic cones, were subjected to such an amount of denudation as would remove the sheets of lava and the piles of scoriæ, no trace would be left of the sporadic outbursts of igneous forces, but a number of isolated masses of basalt or other igneous rock, rising through the surrounding strata. Can we then doubt that areas (such as those we have above referred to) which present precisely these appearances were once surmounted by scattered cinder cones ("puys") and lava currents ("chières"), and that these have been removed by denuding forces?

Of the larger volcanic mountains much more striking and conspicuous evidences will of course remain, in hills of intrusive rock, and more or less isolated plateaux composed of lavas and alternating volcanic agglomerates. Such may be witnessed in the three great ruined volcanos of the Auvergne, those of the Siebengebirge, the Westerwald, the Habichtswald, the Vogelsberg, the Rhongebirge, in Central Germany, the Duppauer Gebirge and the Leitmeritzer Gebirge in Bohemia, and many similar masses in Hungary. Nowhere, however, can the phenomena presented by such a great ruined volcano be better studied than in the interesting Euganean Hills in the North of Italy. Here, as Prof. Suess of Vienna has so well shown, denudation has operated to such an extent as to bring to light in the most admirable manner the general ground-plan of a volcano,—which he believes must have rivalled Etna in dimensions,—besides revealing innumerable instructive sections of its mass. From the centre of this ruined volcanic pile numerous dyke-like masses of vast proportions, and composed of different varieties of lava, are found penetrating the beds of tuff in all directions; these of course marking the several fissures which were formed on the flanks of the cone, and injected with lavas during its gradual growth.

By examining the relation of such masses of rock, whether of larger or smaller dimensions, the volcanic origin of which has now been placed beyond dispute, to the various sedimentary and fossiliferous formation, they can be proved to have been erupted during every one of the epochs into which geologists have divided the vast periods concerning which the "records of the rocks" afford us any information.

The task of determining the geological age of a series of volcanic rocks is often, however, one of considerable difficulty; and hence most geologists, in constructing their maps, are content with merely indicating the extent and character of the igneous masses, and of perhaps showing also their relations to the sedimentary deposits, without attempting to classify them, as they do the latter, according to the period of their formation.

But it is evident that, as we make progress in our study of the earth's crust, we must not be satisfied until we can refer each of the outbursts of volcanic forces to its proper place in the geological history of the district; nor until our maps indicate the *ages* of the igneous as well as those of the aqueous deposits. Then only indeed will they truly deserve the title of "geological maps," and we shall be in a position to reason from them concerning the sequence and relations of geological events—whether of the slower movements which affected the earth's crust, during the quiet accumulation of sediments, or of the more sudden and violent ones, that heralded, accompanied and followed the paroxysmal outbursts of the volcanic forces.

It will be useful then to inquire what are the means which the geologist possesses for determining the date of formation of different igneous deposits.

The loose masses composed of scoriæ, tuffs, or ashes, which are accumulated during a volcanic outburst, are usually among the first of its products that yield to the wasting effects of denudation; and hence the organic remains, which are not unfrequently overwhelmed by or enveloped in such materials, have in too many instances totally disappeared. Occasionally, however, in consequence of their being covered up by masses of hard lava, or through being buried under subsequent sedimentary deposits, such fossiliferous volcanic agglomerates, tuffs or ashes have been preserved, and furnish us with direct palæontological evidence of the period of the outbursts by which they were formed. Sometimes, indeed, owing to the process of silicification having gone on in the mass, the fossils contained in such igneous rocks are unrivalled for their beauty and admirable preservation. As examples of such we may mention the terrestrial plants, insects, shells and bones of Saros Patak, and other localities in Hungary, of Lipari, Somma and Ardtun; the lacustrine shells, plants, fishes and mammals of Bohemia and the Auvergne; and the marine plants, shells and fishes of Ischia and the Vicentine.

But in too many cases, unfortunately, this direct palæontological evidence of the date of a volcanic outburst is altogether wanting, and the geologist is compelled to fall back upon less direct, though not necessarily less conclusive, evidence. Foremost among such we must mention the mode of association of the igneous rocks in question with sedimentary deposits, the age of which is known.

Here, however, we must point out that the *mere association* of igneous masses with a particular geological formation affords no proof whatever of their contemporaneity; and geologists have not unfrequently been led into the most serious error through too hastily assuming such to be the case. Thus in the West of Scotland the basalts are so constantly associated with the Jurassic rocks, that every one was at first led astray concerning their age by this accidental connexion; and it was only by the discovery of Miocene plants in their tuffs, and of their superposition to the highest Cretaceous rocks, that the fallacy of the inference as to their Jurassic age was made apparent. So also in Bohemia, as I had an opportunity of observing under the guidance of Prof. Fritsch of Prague, many isolated masses of basalt are found in the midst of outliers of Chalk; in this case, also, the association is purely accidental, the basalts being unquestionably of late Tertiary age, while the masses of Chalk around them appear to owe their preservation to a certain amount of induration produced in them by the igneous intrusion.

Thus it becomes clear that, in reasoning on the age of igneous rocks, we must convince ourselves not only of the *fact*, but of the *nature* of their association with the sedimentary rocks.

Where igneous masses are found clearly overlying sedimentary deposits, or where they penetrate between the aqueous beds in sheets, producing alteration both in the strata above and below them; or where they traverse the sedimentary formations in dykes, or enclose portions of the latter, whether as entangled fragments caught up in lava, or as ejected masses enclosed in the agglomerates; or again where alteration has clearly been produced in the sedimentary rocks in the vicinity of the igneous; then in all these cases the latter are undoubtedly of *more recent* date than the former.

But where, on the other hand, the fossiliferous sedimentary rocks overlie the whole of the igneous rocks occupying the depressions produced in them by denudation, or where the former contain pebbles derived from the latter, then we may confidently pronounce the igneous masses to be the older of the two.

It is evident that if the relations of a series of igneous rocks be thus studied, we may often, by excluding certain geological periods as certainly more recent, and others as undoubtedly more ancient, arrive at an approximate date for the outbursts by which they were formed.

If, however, the igneous masses, whether lava-streams or tuffs, are seen to be interbedded with a series of fossiliferous sediments, the former having clearly produced alteration in the *underlying* strata, while those superposed to them are unaffected,—then we are perfectly safe in inferring that both the igneous and aqueous rocks were produced during the *same* geological period.

There are undoubtedly cases in which we are unable to apply either of the methods which we have noticed above, whether direct or inferential, to the determination of the age of a series of volcanic deposits. In such cases, however, the analogies or relations of such igneous masses with others of which the date can be determined, may be sufficient to warrant us in assuming with a high degree of probability that they were formed during the same period.

Some geologists have maintained the opinion that the chemical and mineralogical features of volcanic rocks afford in themselves sufficient evidence of the date of their formation. But we cannot admit, in the present condition of our knowledge, such to be the case; there are certainly rocks of the most widely different age, but which, having been subjected to similar processes of alteration, are now quite undistinguishable in character by any test which we are able to apply. We shall not, however, be misunderstood as upholding *the converse* of this position, and asserting that all igneous rocks of former geological periods are identical in character and composition with those being formed at the present day. On the contrary, we are driven to the conclusion that while many facts seem to point to the identity of character of ancient and modern igneous rocks, there are not a few others which may be cited as tending to prove that, alike in their ultimate composition and their component minerals, the igneous rocks exhibit remarkable peculiarities in their distribution, both in space and time.

As the result of the studies carried on by geologists concerning the age and relations of the igneous rocks in different districts, no fact comes out more strikingly than that of the constant shifting of the centres of volcanic action. We find unmistakable evidence of the alternation in the same area of epochs characterized by great volcanic outbursts, with others in which the gradual deposition of sediments was clearly not interfered with by any such cause.

Thus, in those portions of Northern Europe which have been best studied by geologists, there is ample proof that the three periods of the Lower Silurian, of the Upper Palæozoic (extending from the Devonian to the Permian), and of the Miocene, were all marked by the most violent outbursts of volcanic forces; while in the intermediate periods few, if any, traces of such action can be discovered. But when we pass to other areas, we find the most violent outbursts taking place in what are with us periods of quiescence, and *vice versâ*. Nothing is more certain than that, during the middle portion of the Tertiary period, the districts of Western Europe must have been the scene of volcanic violence, on a scale perhaps far surpassing what is now seen in South America or the Indian Archipelago; and that ever since that period a gradual decline of the volcanic forces has been taking place in our area.

Seeing, then, that it is absolutely certain that in a district long unmarked by volcanic disturbances these powerful subterranean agencies may make their appearance, gradually attain their climax, and then die away, the following questions present themselves as being of the greatest interest to the geologist: What are the circumstances and attendant phenomena which mark the first appearance of volcanic activity in an area hitherto quiescent? What are the several stages through which the manifestation of igneous forces successively passes in reaching its climax? And what are the symptoms that work their gradual decline and extinction?

With these there presents itself another problem, namely, that of the relation of the violent actions attending volcanic outbursts to the perhaps equally powerful, but more slow and extended, movements which take place in adjacent areas not exhibiting any manifestations of the volcanic phenomena.

On all these questions we think important light is thrown by the study of the volcanic rocks of Central and Southern Europe, and of their relations to the great central rock masses of the Alpine system; and to these we shall proceed to direct attention in subsequent chapters.

(*To be continued in our next Number.*)

III.—Sketch of the Geology of Ice Sound and Bell Sound, Spitzbergen.

By Professor A. E. Nordenskiöld, of Stockholm.

Part II.

(*Continued from the January Number, page* 23.)

THE Fossil Plants from Bear Island have been described by Prof. Oswald Heer; there are 18 species (see Quart. Journ. Geol. Soc. Lond. 1872, vol. xxviii. pp. 161–173. pl. iv.), namely:—

1. *Calamites radiatus*, Brgn.
2. *Cardiopteris frondosa*, Goepp. sp.
3. ———— *polymorpha*, Goepp. sp.
4. *Palæopteris Roemeriana*, Goepp. sp.
5. *Sphenopteris Schimperi*, Goepp.
6. *Lepidodendron Veltheimianum*, Sternb.
7. ———— *commutatum*, Schimp.
8. ———— *Carnegyianum*, Heer.
9. ———— *Wijkianum*, Heer.
10. *Lepidophyllum Roemeri*, Heer.
11. *Knorria imbricata*, Sternb.
12. ———— *acicularis*, Goepp.
13. *Cyclostigma Kiltorkense*, Haught.
14. ———— *minutum*, Haught.
15. *Halonia tuberculosa*, Brgn. ?
16. *Stigmaria ficoides*, Sternb.
17. *Cardiocarpum punctatum*, Goepp. et Berg.
18. *Cardiocarpum ursinum*, Heer.

III.—Contributions to the Study of Volcanos.—Second Series.

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

On the Volcanic Outbursts which preceded the Formation of the Alpine System.

Of all the physical features of our continent, that which most powerfully arrests the attention is the noble chain of the Alps, with its wide-spreading system of subordinate mountain-ranges; and among the series of grand events, which by the researches of the geologist are demonstrated to have taken place on this our own portion of the globe, there are none more striking and conspicuous than those manifestations of subterranean forces to which the vast mountain-masses in question owe their origin.

As we now know, the great centres of crystalline rock, which for the most part constitute the axial portions of the Alpine ranges, do not represent any *primitive* formation—portions of the surface of a melted globe, as it originally cooled, or deposits of an ocean still in ebullition,—as old writers on geology used to imagine; but, on the contrary, they are found to consist in great part of sediments formed during different geological periods, which, long subsequently to their deposition, were, by the action of tangential mechanical strains, folded and crumpled, and by the agency of chemical forces developed in their midst, were transformed into their present highly crystalline condition. The sedimentary rocks out of which these crystalline masses have been formed were, as we now recognize, deposited during different Palæozoic, Mesozoic, and Tertiary epochs; and the forces by which they have been metamorphosed and have acquired their present elevated, contorted, and even inverted positions, have for the most part operated during what the geologist regards as comparatively recent periods; indeed, the most powerful of all the series of movements to which the Alpine chains owe their origin must have taken place during the latter half of the Tertiary epoch. The highly crystalline rocks of the central portions of the Alpine chain are not the *oldest* formed portions of their masses, but the *youngest*—and are the result of the extreme metamorphism of the most violently disturbed portions of sedimentary deposits, some of which are of as recent date as the Tertiary, and of the intrusion into their midst of aqueo-igneous masses. The growth of the Alpine chain was not, as formerly supposed, an *exogenous* one—resulting from the successive deposition on the flanks of a granitic axis of layers of gradually less crystalline character—but an *endogenous* one; masses of pre-formed sediments being upheaved along certain lines, and at the same time folded, crumpled and crushed, while they had a crystalline structure induced in them and liquefied masses from below thrust into their midst. So recent, geologically speaking, have been those manifestations of subterranean force to which the Alpine system owes its origin, that the greater part of the present elevation of these seemingly "everlasting hills and perpetual mountains" is unquestionably due to causes which have operated since the period of the deposition of the clays and sands on which London is built!

It is not our purpose to discuss in these chapters the general phenomena connected with the formation of the Alpine chain. This has recently been done in a most able manner by Professor Suess of Vienna, in his "Die Entstehung der Alpen." Our object will be rather to study the relations between the manifestations of subterranean force which have, during such comparatively recent geological periods, resulted in the striking mechanical and chemical changes in the Alpine strata, and those others which have produced the numerous volcanic outbursts within and around the Alpine system. And we believe that these studies of the orographic features of our own continent will lead us to conclusions, similar to those arrived at by Darwin from his observations in South America—namely, that the causes of the elevation of continents and of the upheaval of mountain chains are but different modes of action of the same forces which give rise to volcanic outbursts.

We must here, however, carefully guard ourselves against an error into which some of the older geologists fell. Although the elevation of surrounding areas often precedes and accompanies the outbursts of volcanic forces, and the actual accumulation of ejected materials around igneous vents may result in the formation of mountain piles of the vastest dimensions, yet the origination of the principal mountain chains does not appear to be *directly* referable to volcanic action. On the contrary, a period of volcanic activity in a district would seem to be almost invariably followed by a greater or less amount of subsidence of the immediate area in which it takes place. Von Buch, when he came to study the interesting volcanic rocks situated in the very heart of the Alpine chain—namely, those of the Southern Tyrol—fancied that he had discovered in them the real cause of the elevation of the Alps. The fallacy of the views of Von Buch has, however, been fully shown by the proofs which have been since obtained, that the volcanic eruptions in question took place at a period long prior to that of the movements to which the origin of the Alps must be attributed.

But although the outbursts of these volcanic rocks of the Southern Tyrol were certainly not the *direct cause* of the elevation of the Alpine chain, it would be a great error on our part to hastily adopt the conclusion that the two series of events had no connexion with one another.

So far as we are able to judge from the characters of the faunas of the Silurian, Devonian and Carboniferous rocks of Southern Europe, there is no reason whatever for concluding that during these periods any kind of barrier to the distribution of organic life occupied the position of the existing Alpine chain. Indeed, the first indication of the existence of a line of weakness in this portion of the earth's crust is found towards the close of the Permian period, when a series of volcanic outbursts on the very grandest scale took place, along a line parallel to and nearly coincident with the main axis of the present Alpine range, and were continued with some interruptions till nearly the close of the Triassic period. Of the nature, products, and attendant phenomema of these pre-Alpine volcanic outbursts, we propose to give a slight sketch in the present chapter.

In studying the history of these early outbursts of the volcanic forces in the Alpine district, we have unfortunately some great difficulties to contend with. Throughout the greater part of the Alpine range, sedimentary rocks of younger date have been piled to the height of many thousands of feet above the volcanic products of the period we are considering. At three points, however, denuding forces have exposed them for our study—namely, near the Lake of Lugano on the borders of Switzerland and Italy, in the Southern Tyrol, and in the country about Raibl in Carinthia. At a number of intermediate points and at some others in the same line, but to the eastward of all of them, more partial exposures of volcanic rocks of contemporaneous date are found; these serve to indicate that, if we could remove the mass of superincumbent rocks of later date, we should probably discover beneath them a continuous range of volcanic masses along a line nearly coincident with that of the future Alps.

Of the several exposures of the pre-Alpine volcanic rocks, that which affords us by far the best insight into the nature and succession of the operations which took place, occurs in the district of the Southern Tyrol. The old volcanos of this country we shall now proceed to describe, and then afterwards briefly notice the features of some of the contemporaneously formed igneous masses at other parts of the Alpine system.

The greatest breach in the continuity of the Alpine chains is that which has been effected by the denudation of the river-systems of the Inn and the Adige, flowing northwards and southwards to the Danube and Po respectively; and it is at the watershed between these two systems of valleys that the lowest of the great Alpine passes—the Brenner—occurs. Now, it is just in this area of maximum denudation that the finest exposure of the pre-Alpine volcanic rocks is found.

The oldest of these is the well-known quartz-porphyry of Botzen, which by the earlier geologists was regarded as a granite. Although only very partially exhibited by the denudation of the vast overlying masses of the Triassic, Rhætic, Jurassic, Tithonian, Neocomian and Cretaceous rocks, it can be traced over an area of more than 1,000 square miles, and is found to constitute mountain-masses of more than 9,000 feet in height. It is probable, moreover, from the appearance of similar rocks at the bottoms of deep valleys, and at other points where the younger formations have been removed by denudation, that a belt of similar rocks extends below the southern limestone zone of the Alps, from the borders of Switzerland on the west to Carinthia in the east.

The rock of the quartz-porphyry of Botzen presents many variations in structure and appearance; while it sometimes approximates in its characters to the granites, with which class of rocks it was, as we have already remarked, identified by the older writers, it at other times closely resembles the recent Liparites of Hungary and other countries. The quartz is almost always distinctly visible, as more or less rounded grains, and these, with crystals of orthoclase felspar, are imbedded in a paste, which is sometimes micro-crystalline, at others more or less glassy, and occasionally exhibits a sphærulitic structure.

Closely associated with the quartz-porphyry of Botzen is a rock called by Tschermak "quartz-porphyrite," and which differs from the former principally in being composed of a *plagioclase* felspar instead of orthoclase. This rock is best seen in the San Pellegrino Valley lying to the south of the mountain of Monzoni, but it has also been detected at some other points in the district. It is usually of a greyish-green colour, and exhibits numerous large grains of quartz with smaller crystals of plagioclase felspar and biotite, imbedded in a compact dark-coloured base. The rock in question is of much interest as presenting us with an exact representative among the volcanic products of older date of the remarkable modern quartz-Andesites or Dacites, which are so largely developed in Eastern Europe. The view once held by petrologists, that the prevailing felspar in all rocks which contain free quartz must necessarily be an orthoclase, is now shown to be altogether untenable. Among granitic rocks we have the Tonalite of vom Rath (the so-called granite of the Adamello group), composed of a plagioclase felspar with much free quartz. Among the porphyritic rocks, or those with a texture intermediate between granites and lavas, and also among the latter class of rocks themselves, we find innumerable examples of rocks of similar mineralogical constitution,—both in the modern Hungarian Dacites and the ancient quartz-porphyrites of the Southern Tyrol.

With regard to the epoch at which these quartziferous lavas of the Southern Tyrol were erupted, all geologists are now agreed that it must have been that of the Dyas or Permian.

In order to illustrate the ultimate composition of these quartziferous volcanic rocks, which during the Permian period were so abundantly erupted in the Alpine region, we may cite the following analyses:—

	(1)	(2)	(3)	(4)	(5)
Silica, with Titanic acid	76·14	73·10	74·62	67·98	66·75
Alumina	12·69	12·84	11·94	14·01	16·53
Peroxide of Iron	—	—	—	—	2·76
Protoxide of Iron	1·78	3·02	2·59	5·00	1·66
Protoxide of manganese	0·17	trace	0·23	—	—
Lime	0·51	1·22	0·73	2·47	4·71
Magnesia	0·32	0·44	0·31	2·41	2·64
Potash	5·81	4·32	5·29	3·55	1·82
Soda	1·82	3·33	2·93	2·25	2·86
Water	1·03	1·20	0·90	1·67	2·12
Totals	100·27	99·47	99·54	99·34	101·85

(1) is a typical example of the quartz-porphyry of Botzen from St. Ulrich in the Grödener Thal. The analysis, which is by Dr. Ruhe, was published by Scheerer.

(2) and (3) are analyses of somewhat similar rocks made by Scheerer and Ruhe respectively; (2) is the rock of Moena, which contains much pinitoid.

(4) is a rock, which is regarded by Tschermak as to a certain extent intermediate in character between the quartz-porphyries and the quartz-porphyrites. It is from the Travignolo Valley, and the analysis given is by Scheerer.

(5) the interesting quartz-porphyrite from the San Pellegrino Valley. The analysis, which is by S. Konya, was published by Tschermak.

With respect to the mode of formation of these vast masses of volcanic rocks in the Southern Tyrol, the only conclusion at which we can arrive is, that the highly siliceous materials which compose them constituted a lava of only very imperfect liquidity, and that, like many modern lavas of the same class, it quietly welled forth from volcanic fissures, building up vast dome-shaped mountains, the formation of which was attended with but comparatively little explosive action. Masses of tuffs, however, clearly resulting from the latter kind of action, do occur in association with these widely spread quartziferous lavas, and the manner in which they are found to alternate with beds of sandstone and conglomerate, as in the Grödener Thal, and at many other points, indicates that the outbursts by which these volcanic rocks were formed must have taken place either on the land or in shallow water. Richthofen has endeavoured to refer these Permian volcanic outbursts to a number of distinct periods, and it is certain that they must have extended over enormous intervals of time. Some idea of the scale on which these displays of volcanic activity took place may be gathered from the fact that, although they were certainly greatly denuded before the deposition of the superincumbent rocks upon them, and are now only very imperfectly exposed to our observation, yet the quartziferous volcanic rocks of the Botzen district constitute rock-masses more than 9,000 feet in thickness!

The eruption of the quartz-porphyry of Botzen, which, as we have shown, must be regarded as the first symptom of the existence of that line of weakness in the earth's crust, to which the formation, at a later period, of the Alpine chain must be ascribed, was followed by a prolonged period of subsidence. During this epoch the vast thickness of sediments which constitute the Alpine Trias was deposited, consisting of sandstones, limestones, and shales piled upon one another to the aggregate thickness of several thousands of feet. This quiet accumulation of sediments during the Triassic period was, however, interrupted by a number of volcanic outbursts on a far less grand scale than those which had taken place during the Permian period ; the remarkable variations in the thickness and mode of formation of the several divisions of the Alpine Trias also indicate the very local and interrupted nature of the movements which were taking place in the area, and prove the continued activity of those subterranean forces of which the manifestations at the surface by volcanic outbursts had become so much more feeble.

If, however, the volcanic outbursts of the Trias appear insignificant in extent when compared with those of an earlier period, they arrest the attention of the geologist much more powerfully than the latter, on account of the variety and interesting characters of the rock-masses produced by them ; and especially by the assemblage of beautiful crystallized minerals, which have resulted from the action of the igneous intrusions on the surrounding stratified masses.

There are indeed few localities in Europe more justly famous among men of science than the valleys of the Southern Tyrol. To those of the most varied tastes, the district offers equally powerful charms. The artist and lover of picturesque scenery is attracted by the remarkable contrasts afforded by the dark rugged igneous masses, surrounded by spires and precipices of glittering dolomite; the botanist finds a wonderfully varied flora growing upon its strangely diversified soils; the mineralogist recognizes it as an almost unrivalled locality for many beautiful crystallized forms; the palæontologist knows of no richer hunting grounds than the beds of St. Cassian; the granites and porphyries of the area are among the best-known types of the petrologist; and the physical geologist has learnt to regard it, ever since the days of von Buch, as a field in which a solution of some of the grandest problems of his science may be hopefully sought. Few districts of equal area can, perhaps, boast of a scientific literature so prolific; and a list of works relating to its geology alone, which was drawn up by Richthofen in 1858, and extends to ten quarto pages, would have to be very largely added to, in order to bring it up to date. The visitors' books of the little inns in the secluded valleys of the Southern Tyrol are collections of the autographs of scientific investigators; and nowhere perhaps in the whole world do the quiet and unobtrusive labours of men of science attract so large an amount of popular attention as in these remote valleys. The English geologist smiles to see in such a spot the portrait of Sir Roderick Murchison, of course well be-starred and be-ribboned, paired with that of Alexander Von Humboldt, and both placed as supporters to the picture of an Austrian Archduke, whose name was given to a well-known mineral species. So great is the interest excited by the remarkable rocks of this district, and especially by those of Monzoni and Predazzo, and so various at the same time are the conclusions at which different students of them have arrived, that we may well call this region "the battle-ground of Petrologists."

There are a number of different centres of eruption which can be traced by an attentive study of the Triassic rocks of the Southern Tyrol. From most of these great quantities of agglomerates, tuffs and ashes were ejected, which have formed immense deposits in the midst of the Triassic series, and from most of them lava either of the type of augite-porphyry or melaphyre also flowed. Two of these centres of eruption, however, those of Predazzo and Monzoni, are of especial interest, from the numerous and interesting varieties of igneous rocks which they poured forth. The name of "crater," which has been applied to some of the centres of eruption by Richthofen, is an unfortunate and misleading one, for nothing can be more certain than that the different cones and craters have had their original forms entirely destroyed by denudation, and that the remarkable cup-shaped arrangement presented by the strata around each of these points of volcanic action is due, as we shall hereafter see, to a totally different cause from the explosive action that forms true volcanic craters.

The period of the formation of these several volcanic vents is that of the Upper Trias. This was conclusively shown by Richthofen, whose well-known work on the district, published in 1858, was the result of many years of patient study, and will hold its place (however much some of its minor conclusions may be modified by later investigations) as one of the most remarkable and valuable of geological monographs. A more recent and very able investigator of the district, Dr. Doelter of Vienna, finds evidence which leads him to refer all the eruptions of the area to that portion of the Upper Trias known as the "Wengener Schichten."

Among the several varieties of volcanic rocks produced at the two interesting vents of Predazzo and Monzoni, a definite order of appearance has been recognized by all geologists who have investigated the subject. This succession is as follows :—

1. Monzonite, including under this name the Hypersthene and Diallage rocks, the Diabase or Pyroxene Monzonite, the Monzoni- or Augite-syenite, and the Amphibole Monzonite.
2. Tourmaline-granite.
3. Melaphyre, with Augite-porphyry, Uralite porphyry, and the tuffs associated with these several rocks.
4. Orthoclase porphyry (porphyrites and syenite-porphyry of Richthofen).

It will be interesting to notice, in the first place, the nature and composition, both chemical and mineralogical, of these several volcanic products; then to point out the relations to one another and to the sedimentary rocks of the masses which they constitute; and lastly to seek to determine the exact conditions under which they were formed.

The Monzonite, which was known to the older writers on geology as "the granite of Predazzo," is a rock of unmistakably granitic structure, although its volcanic origin is also equally clear and indisputable. Under the general term have been included the two rocks distinguished by Richthofen as Monzoni-syenite and Hypersthene-rock, by Tschermak as Monzoni-syenite and Diabase, by vom Rath as Augite-syenite and Diabase, and by Doelter as Pyroxene-Monzonite and Amphibole-Monzonite.

The Monzonite would appear never to contain free quartz, but it seems to me, from the examination which I made of the celebrated mountain of Monzoni, to present every gradation between a rock of decidedly acid character on the one hand to one of the most eminently basic description on the other. Sometimes it is found to consist almost entirely of an aggregate of orthoclase crystals, with a small quantity of a plagioclase felspar, of biotite and of a pyroxenic constituent. It is a singular circumstance that the last-mentioned ingredient presents some very remarkable peculiarities of character, that render it very difficult to determine its exact nature. Tschermak regards it as a *hornblende*, while vom Rath considers it to be an *augite*, and in consequence calls the rock "augite-syenite."

In other varieties of the rock, however, we find the orthoclase occupying a gradually less conspicuous place, and finally disappearing altogether; while the plagioclase felspar (usually labradorite), the biotite and the pyroxenic constituent (which in the more basic varieties of the rock, though regarded at first by both De Lapparent and Des Cloiseaux as a hornblende, is now pretty generally accepted as augite), constitute the whole mass. Sometimes the augite is replaced by diallage or hypersthene, and occasionally the felspathic ingredient almost wholly disappears, and we have an augite-, diallage-, or hypersthene-rock.

In illustration of the ultimate composition of the varieties of the celebrated Monzonite-rock, we may cite the following analyses:—

	(1)	(2)	(3)
Silica	58·05	50·80	38·18
Alumina	17·71	16·20	10·06
Peroxide of Iron	—	—	17·50
Protoxide of Iron	8·29	14·37	9·47
Lime	5·81	10·00	11·84
Magnesia	2·07	3·53	9·72
Potash	3·24	3·90 (Potash and Soda)	1·38
Soda	2·98		0·52
Water	1·34	1·20	1·26
Totals	99·49	100·00	99·93

(1) is the analysis of a typical Monzoni-syenite (Augite-syenite of vom Rath) by Kjerulf. The specimen was obtained from the Margola near Predazzo.

(2) and (3) are analyses of more basic rocks (diabase or pyroxene-Monzonite) of the Canzacoli near Predazzo. (2) is an analysis by Delesse; (3) by Konya, as given by Tschermak.

The "Tourmaline-granite" is, like the Monzonite, a rock of truly granitic structure, although now universally regarded as of volcanic origin. It is a well-marked granite of a red colour made up of orthoclase of a more or less deep pink tint, white or greenish plagioclase, grey quartz and biotite. But in addition to these minerals we find, and generally in association with the quartz, considerable quantities of tourmaline, forming masses of radiating crystals sometimes of large size. The drusy cavities, which sometimes occur in the rock, frequently contain various beautifully crystallized minerals.

The following analysis of the Tourmaline-granite of the Mulatto near Predazzo, which was made by Kjerulf, will serve to illustrate its ultimate composition:—

Silica	70·73
Alumina	14·16
Peroxide of Iron	3·59
Lime	1·03
Magnesia	0·66
Potash	5·37
Soda	2·54
Loss	1·10
Total	99·24

Tschermak regards this rock as essentially composed of 30 per cent. of Quartz, 32 of Orthoclase, 27 of Oligoclase, and 10 of Tourmaline.

The next rocks, taken in the order of their appearance, are those which von Buch and the earlier writers spoke of as black-porphyries and basalts; they are now classed as Melaphyres, Augite-porphyries and Uralite-porphyries. The so-called Melaphyres consist principally of plagioclase felspar with occasionally a little orthoclase, augite, olivine (usually in a much altered condition) and magnetite. Except on the ground of their age, there appears to be no reason whatever for removing them from the basalts. Sometimes the rock becomes porphyritic in structure, from the diffusion through it of large plagioclase crystals; at other times the whole mass becomes coarsely granular, and has been classed as a diabase, though it should probably be more properly called a dolerite. When the rock contains large crystals of augite scattered through it, it becomes an augite-porphyry, and where (through alteration, as Tschermak shows) these augite crystals present the Uralite modification, the rock passes into uralite-porphyry. All these basic rocks graduate into one another, they frequently assume an amygdaloidal structure, and are associated with enormous masses of agglomerates, tuffs and ashes of similar composition. The chemical constitution of these rocks is illustrated by the following mean analyses as calculated by Tschermak from the closely approximating results arrived at by a number of different chemists.

	Melaphyres.	*Augite-porphyries.*
Silica	53·01	49·78
Alumina	17·05	18·83
Protoxide of Iron	11·95	11·47
Lime	8·27	10·44
Magnesia	3·77	4·87
Potash	3·42	2·65
Soda	2·56	2·05
	100·00	100·00

Of still younger date than the basaltic rocks just described are others of restricted distribution, which Richthofen called Syenite-porphyry and Porphyrite, but which are by Dr. Doelter classed as Orthoclase-porphyry. They are coarse-grained rocks of porphyritic, occasionally approaching to granitic structure, consisting of a granular or felsitic base in which twinned crystals of red orthoclase, with hornblende and magnetite, are scattered. This rock, like portions of the Quartz-porphyry of Botzen, often contains considerable quantities of the mineral of the pinite group known as Liebnerite. We subjoin the following analysis by Kjerulf in illustration of the ultimate composition of the Orthoclase porphyries:

Silica	59·17
Alumina	19·75
Protoxide of Iron	1·71
Lime	3·92
Magnesia	0·40
Potash	4·03
Soda	3·54
Water, Carbonic Acid, etc.	6·94
	98·43

We have dwelt at considerable length on the petrological characters of these old volcanic masses of the Southern Tyrol, because of the great amount of attention which they have attracted among geologists ever since the days of Von Buch, and the lively discussions of which they have been the subject. They are interesting also, as presenting us with rock-masses of the most perfectly granitic structure, of which the volcanic origin is certainly not open to doubt; this will at once appear when we come to notice their relations to the sedimentary rocks; I am not indeed aware that the fact has been ever disputed by any competent observer. We will now proceed to notice some of the more salient features of the structure and relations of these igneous rocks, which serve to throw light on the questions of their age and mode of formation.

As already mentioned, the whole of the smaller and scattered volcanic outbursts in the Southern Tyrol took place during the period of the Upper Trias. This is proved in the most conclusive manner, by the way in which the igneous rocks are only found intrusive among the lower members of the formation, while their tuffs are interstratified with the beds of its higher members. According to Dr. Doelter's most recent researches, as we have before pointed out, all the eruptions must have taken place during the period of the formation of the "Wengener Schichten." In the district which denudation has exposed to our study, we find, as already remarked, a number of different centres of eruption, most of which however have only produced rocks of basaltic character, Melaphyres with Augite- and Uralite-porphyries. But two of these centres of eruption are of larger size and more complex structure, that of Predazzo having emitted the whole of the interesting varieties of rocks we have noticed in the preceding pages, and that of Monzoni all except the tourmaline-granite.

The Monzonite rises in great intrusive masses through the midst of the limestones and other rocks of the district, which assume, for a considerable distance around, a highly crystalline character. Sometimes, as at Monzoni, vast masses of the metamorphosed limestone are seen to be actually entangled and inclosed in the midst of the igneous rock. Concerning the relations of the two varieties of Monzonite to one another, very various opinions have been expressed by different observers. Richthofen regarded the more basic portions of the rock, to which he gave the name of "hypersthene-rock," as traversing the Monzoni-syenite, which constitutes the larger part of the mass, in veins. But although such veins of the basic variety of the rock do occur traversing the more acid kind, as is well seen in the Margola near Predazzo, yet the observations of Dr. Doelter upon Monzoni would appear to lead to the conclusion that the great masses of rock with plagioclase felspar are not sharply divided from those in which orthoclase is the predominant constituent. Indeed, as I have before observed, it is possible to find at Monzoni every possible gradation, from the most acid to the most basic variety of the rock.

The Tourmaline-granite, which is seen only near Predazzo, also rises in great intrusive masses, which traverse the Monzonite, and send off veins into it; so that there can be no doubt as to the more recent date of its eruption.

The Augite-porphyry, Uralite-porphyry, and Melaphyre constitute intrusive masses rising through the Monzonite and the Tourmaline-granite and giving off veins which traverse both of these rocks. These basaltic rocks are, as already stated, by far the most widely distributed products of the volcanic ejections of the Trias period in the Southern Tyrol, and are found at all the centres of eruption.

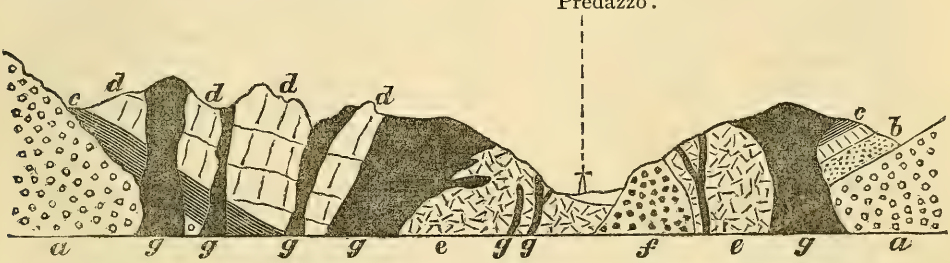
The last-formed of these Triassic volcanic rocks are the porphyrite and syenite-porphyry of Richthofen (the orthoclase-porphyry of Dr. Doelter), which, however, only occurs in the form of veins traversing all the other rocks, but does not constitute any considerable proportion of the intrusive masses.

From the peculiar arrangement affected by the stratified rocks around the different centres of eruption, Richthofen, as we have already seen, applied to them the name of "craters." It must, however, be clear to every one who carefully examines the question that the actual volcanic cones, and therefore the craters themselves, must have been destroyed by denudation before the deposition of the highest beds of the Trias. It seems to be certain, from an examination of the tuffs produced by them, that the eruptions of this period must have taken place under the waters of a comparatively shallow sea, and that the cones, as they were built up, gradually rose to the surface, when (as in the well known case of Graham's Isle) they would be gradually destroyed, and their materials distributed by the waves. Near the centres of eruption we find the coarsest agglomerates containing bombs and ejected masses of the surrounding sedimentary rocks; but as we recede from these centres the ejected materials become of gradually finer character, and more mingled with aqueous sediments. In the latter condition they are often seen to be crowded with the beautiful fossils of the St. Cassian series, and alternate with other beds of the "Wengener Schichten."

Although it cannot be proved that the Monzonite-rock and the Tourmaline granite actually reached the surface, yet it is in the highest degree probable that they did so. They certainly could not have formed extensive lava-streams, nor have given rise to any great quantity of tuffs by explosive action; indeed we are unable to determine exactly the form which these particular granitic rocks would assume on reaching the surface. Their composition is, however, identical with that of certain sanidine-trachyte and andesitic lavas. Probably, after the manner of many lavas of this class (such as the Domites of the Auvergne), they constituted very imperfectly liquid masses, which quietly welled forth, forming dome-shaped hills, the extrusion of which was accompanied by but little explosive action.

Very different, however, must have been the phenomena attending the eruption of the more basic rocks,—the so-called melaphyres, augite-porphyries, and uralite-porphyries. Not only do these appear to have flowed from the igneous centres in lava-streams of considerable length and thickness, but the explosions which accompanied them certainly gave rise to the formation of the most prodigious quantities of scoriæ and ashes. From the study of these vast deposits we obtain the clearest insight into the conditions under which the volcanic outbursts to which they owed their origin must have taken place.

An interesting circumstance with regard to the relations between these great intrusive masses, which formed the centres of old Triassic volcanos, and the sedimentary rocks by which they are surrounded, was first pointed out by Leopold von Buch, and regarded by him as being altogether inexplicable, as indeed, if his theory of "elevation-craters" were true, it certainly would be. This is the constant dipping of the stratified rocks around the different igneous centres, not *away* from them, as we might at first be led to imagine would be the case, but *towards* them. This fact is very clearly exemplified at Predazzo, as the accompanying section, which has been derived from one of those published by Richthofen, will show; and it was also very clearly represented in the earliest sections of the district given by von Buch himself.



Section across the so-called "Crater" of Predazzo, illustrating the dip of the stratified rocks towards the centre of eruption.

a Botzen porphyry (Permian).
b Lower Trias. }
c Middle Trias. } Sedimentary rocks.
d Upper Trias. }
e Monzoni-syenite with "diabase" veins.
f Tourmaline granite.
g Melaphyre.

That these singular cup-shaped depressions of the strata around each of the volcanic centres in the Southern Tyrol can have no claim whatever to be called "craters," in the ordinary sense in which geologists use that term, we have already remarked. The true explanation of the phenomena presented by them is to be found in a fact, first pointed out by Darwin, but of which illustrations have since been found in many widely separated volcanic districts—namely, that the ejection of volcanic materials at any point is liable to be followed by subsidence of the rocks around it. I have elsewhere shown how very frequently this kind of action takes place, and what beautiful illustrations we have of it even in our own islands. From my study of the rocks of the Southern Tyrol it appears to me to be perfectly clear that, after the cessation of volcanic activity at the numerous small centres of eruption, the central mass must, in almost every instance, have subsided before the denuded ruins of these old volcanos were buried under the later deposits.

Perhaps, however, the most interesting circumstance of all connected with these old volcanic outbursts is the insight which they afford as to the mode of origin of those beautifully crystallized minerals which are so frequently ejected from the craters of active volcanos, like Vesuvius, or are found among the agglomerates and tuffs of extinct ones like the Laacher See. There is probably no locality in the whole world which has yielded so large a number of mineral species as the flanks of Vesuvius and the cliffs of Somma; and as second only to it we may probably rank the mountain of Monzoni. Strange to say, the species and varieties of minerals found at these two localities have very much in common. This will be clear to any one who is acquainted with the ordinary Vesuvian minerals, and will compare the following list of those which have been obtained at Monzoni.

Minerals of Monzoni.

*Augite.
*Fassaite (pseudomorphs after Monticellite.)
Sahlite (Pyrgom).
Epidote (Pistacite).
†Garnet (Grossular).
*†Spinel.
Pleonaste.
Ceylandite.
†Vesuvian.
†Gehlenite.
Mica.
*†Biotite.
*Wollastonite.
Orthoclase (Adularia).
Anorthite.
Labradorite.
*Brandisite.
Scapolite.
*Monticellite (Batrachite).
*Serpentine.
*Vorhauserite.
†Gymnite.
Axinite.
Zircon.
*Titanite.
Prehnite.
Chabasite.
Laumonite.
Thomsonite (Comptonite).
Apatite.
†Brucite.
Quartz.
Calcite.
*Magnetite.
Specular Iron.
Iron Pyrites.
Copper Pyrites.

The species marked * are most usually found in connection with the more basic varieties of the Monzonite, those with the † more commonly occur near the acid varieties of the rock.

At first sight, no localities would appear to offer greater points of dissimilarity than the lava slopes of Vesuvius and the dark rugged granitic mass which rises in the very heart of the brilliant white pinnacles of the far-famed Dolomite Mountains; and yet, as we shall proceed to show, there is much in common between them, and only a slight examination of the question will be necessary to convince the observer that the beautifully crystallized minerals have in both cases been formed under identical conditions.

The interesting minerals of Vesuvius are found, as every mineralogist is aware, by breaking up the blocks of limestone (which have been blown from the crater, especially during certain eruptions, or which are found in the agglomerates of Somma, the products of older outbursts), and the crystallized minerals are seen lining their cavities.

The volcano of Vesuvius has been opened through the midst of masses of Subapennine-limestone, and it is in the metamorphosed fragments of the rock, evidently torn from the sides of the vent, that the minerals in question are found. The formation of these minerals is clearly due to the contact of masses of igneous rock, charged with imprisoned water and various gases, with the masses of limestone they have penetrated, and to the play of those chemical and crystallizing forces, which under these remarkable conditions are called into being.

Now the exquisite products which Nature has, at Vesuvius, exported from below and duly delivered at the surface, by the transporting power of steam, may be examined by us at Monzoni, still lying in the workshop in which they were elaborated. In the case of Vesuvius, volcanic explosions have brought the minerals to us, but in that of Monzoni denudation has enabled us to penetrate to their birthplace; and in the very heart of this old volcano, now cold and dead, the geologist may study the products of operations similar to those which are doubtless taking place, far below the surface, in the case of vents which we still see in activity around us.

The various localities for the beautifully crystallized minerals of Monzoni all appear to be situated at the junction of the igneous rocks with the limestone masses, through which they have burst or which are in some cases entangled in them. It has also been shown, as indeed we might have anticipated, that the species of minerals produced at the planes of contact of the limestone with the more basic igneous rocks (hypersthene and diallage rock, diabase or pyroxene monzonite) are different from those which have originated at the junction surfaces of the more acid rocks (the Monzoni- or augite-syenite). We have indicated in our list of minerals those which are usually found near the masses of basic rock, and such as occur in proximity to the more acid ones respectively.

In not a few cases, as might be expected from the great age of the deposits in which they lie, and the vast series of changes to which they have been subjected, some of the minerals have been converted into pseudomorphs. And on the same ground we may easily account for the absence of all those more unstable mineral products which are found at Vesuvius and other active volcanic vents. We have the clearest proof that the volcano of Monzoni, and the other contemporaneous ones of the Southern Tyrol, have gone through a precisely similar series of changes to that which has befallen our own old volcano of Arthur's Seat, and many similar ones in Central Scotland,—namely, that they have first been buried under many thousands of feet of younger strata, and that subsequently, by the upheaval and denudation of these, they have been once more exposed to view at the surface. To a recently published memoir of vom Rath we are indebted for much new and most valuable information concerning the nature and mode of origin of the minerals of Monzoni. I need not in this place do more than refer to the similarities of the varieties and manner of occurrence of these beautiful minerals of the Tyrol with those which I have described as occurring among the ancient volcanos of the Highlands.

We have now shown how, through the accidental removal by denudation of the overlying rocks of the Southern Tyrol, the fact has been revealed to us that during the Permian period enormous masses of volcanic rock (identical in character with the modern Liparites and Dacites) were erupted along a line nearly coincident with that of the subsequently formed Alpine Chain; and that these grand outbursts—which led to the formation of volcanic mountains at least 8000 to 9000 feet in height—were followed after an interval by the opening of a number of sporadic vents in the same district. We have also pointed out that both to the eastward and westward of the region which we have been more particularly describing, and evidently constituting part of the same linear series of contemporaneous eruption, we find, wherever the superincumbent rocks have been removed by denudation, similar evidences of volcanic action taking place prior to the formation of the Alpine system.

In concluding this chapter we shall enumerate and very briefly describe the principal exposures of the products of this old line of volcanic action.

On the shores of the Lake of Lugano there occurs a tract occupied by igneous rocks, which are shown, by their relations to the sedimentary masses of the district, to have been erupted after a portion of the Permian strata were deposited, and before the great mass of the Triassic rocks were formed. These igneous rocks appear to consist of great masses of quartz-porphyry, very similar to that of Botzen, with smaller and subordinate outbursts of porphyrite and melaphyre. Some masses of truly granitic rock appear in the same district, which may also perhaps belong to the same age. The general resemblance of these rocks of Lugano and Ticino with those of the Southern Tyrol is very striking; and, were we able to remove the masses of younger strata which cover almost the entire country between these two districts, we should probably find the two areas of igneous rocks to be parts of the same continuous series. Indeed, at more than a dozen intermediate points, the widely-spread Permian quartz-porphyries have been detected in the bottoms of deep valleys, and wherever the newer rocks have been cut through by denudation.

Passing *eastward* from the grand exposures of the pre-Alpine volcanic rocks, we find them again making their appearance in the country about Raibl in Carinthia. The beautiful red quartz-porphyry of this locality (containing 76 per cent. of silica) is associated with volcanic tuffs, and rocks of more basic character; there is the clearest evidence that these rocks were erupted at the same period as those of the Southern Tyrol and Lugano. Isolated exposures of the same rocks have also been detected at a number of other points in Carinthia.

Still farther in the same direction, and where the Alpine chain sends off its two great eastern branches, namely, the Carpathians stretching to the north-east, and the Julian Alps extending towards the south-east, we find masses of eruptive rock of the same age as those we have been noticing. Such are the various igneous masses of the Island of Lissa and other points in Dalmatia, and the melaphyres of Waag, which are of Permian age, with others at several points in the Carpathians and Transylvania, which were erupted at intervals during the Trias and part of the Lias period. The occurrence of all these igneous masses would seem to indicate that, not only was there made manifest at the close of the Permian epoch the existence of a line of weakness in the earth's crust, nearly coincident with the great central Alpine mass, but that the principal fractures radiating from it must have been already even at this early period determined.

In several future chapters we shall endeavour to trace the successive manifestations of the volcanic forces in the same area, and to show their relations to the tremendous exhibitions of force resulting in those grand movements by which the Alpine rocks have acquired their present positions and relations.

P.S.—I am indebted to my friend, Prof. vom Rath of Bonn, for calling my attention to an error into which I have fallen in the last chapter of this series. On page 54, I have classed the gaseous exhalations of the Büdos Hegy in Transylvania with those of the Solfatara, as having an elevated temperature. This is not the case, however, the gas evolved at the former locality having the same temperature as the surrounding atmosphere.

(*To be continued.*)

IV.—Some Considerations on the Probable Conditions under which the Palæozoic Rocks were Deposited over the Northern Hemisphere.

By Henry Hicks, F.G.S.

(*Continued from page* 160.)

Upper Silurian.—At the close of the Lower Silurian, as already stated, changes of considerable importance took place in some of the areas which had undergone depression. The sea-bottom was now raised in parts of Western Europe, and in North America, and islands of some extent formed. In Europe the most important were those in North Wales, Shropshire, Cumberland, the South of Scotland, and in Nassau. It is probable also that one or more extended along Southern Europe, from Portugal into Spain, etc., but the evidence concerning this is as yet imperfect. In America, according to Logan, Dana, etc., the principal parts raised at this time were the Green Mountain regions, and the ridge extending from Lake Erie over Cincinnati into Tennessee. These American ridges appear to have been raised to a great height, and to have remained afterwards in part dry land, even to the close of the Palæozoic. The islands in Europe were raised only to a small height above water-level, and were probably all again submerged by the close of the Upper Silurian. The uplifting did not take place in Britain until after the close of the Bala period, or after the Upper Bala Limestone had been formed over the British area. The changes may be said, therefore, to have taken place when the Lower Llandovery rocks were being deposited over the parts still submerged. The uplifting in Europe occurred chiefly in regions where volcanic action had previously taken place, and the changes seem to have been produced on the whole rapidly. For instance, in Wales the upheaval, and a subsequent depression of most of the upheaved parts, must have taken place during the time that the Lower Llandovery rocks were being deposited in the surrounding sea, for in many places the Upper Llandovery rocks may be now seen resting on the upturned edges of the Lower Silurian beds. Again, as the Lower Llandovery rocks appear to have been made up for the most part from the denudation of these islands, where an abundance

THE

GEOLOGICAL MAGAZINE.

NEW SERIES. DECADE II. VOL. III.

No. XII.—DECEMBER, 1876.

ORIGINAL ARTICLES.

I.—Contributions to the Study of Volcanos.—Second Series.

By John W. Judd, F.G.S.,
Professor of Geology in the Royal School of Mines.

On the Volcanic Outbursts which accompanied and followed the Formation of the Alpine System.

Of the amount of vertical movement which took place in the great mountain axis of the Eastern continent, subsequently to the deposition of the Eocene strata, the following facts afford sufficient proof. The marine Nummulitic rocks, besides constituting very large portions of the flanks of this vast mountain axis, and of its connected chains, such as the Pyrenees, the Carpathians, and the Caucasus, form the actual summits of such grand Alpine peaks as the Diablerets, and the Dent du Midi, rising to the heights of 10,670 and 10,531 respectively above the sea-level; while in Western Thibet the same Eocene strata are seen raised to an elevation of no less than 16,500 feet above the sea.

But even these measures, vast as they are, supply us with a very inadequate conception of the amount of disturbance to which the district in question has been subjected during the post-Eocene epoch. In order fairly to realize the all-powerful action of the subterranean forces at work in the later Tertiary periods, we must examine the enormous beds of sand and pebbles constituting the Lower, Middle, and Upper Miocene of the Western Alps, and presenting an aggregate thickness in places of between 7000 and 8000 feet—telling, as they do most unmistakably, of local subsidences of not less than that amount with subsequent re-elevations to an equal extent.

It is only, however, when we come to examine the constantly highly inclined, the frequently vertical, and sometimes greatly contorted and even inverted positions of these Miocene rocks, that we are fairly impressed with the magnitude of those earth-movements, of which these districts were the scene during the second half of the Tertiary epoch. These facts, of which we find such striking evidence in Switzerland and the Western Alps, are equally patent to the geological student in Eastern Europe. In the Tsil Thal on the flanks of the Transylvanian Alps, for example, a portion of a vast deposit of Oligocene strata, consisting of clays, sandstones and coals, with a thickness of between 2000 and 3000 feet, has been bent into a sharp synclinal fold, and this fragment has alone survived the denuding action which has effected the complete removal of every trace of the strata of the same age from the whole of the country around.

But even in respect to geological times comparatively much more recent, we find abundant evidence of the occurrence of movements of considerable extent, if of less violence, in this portion of the earth's crust. On the southern side of the great mountain axis, where disturbances seem to have been prolonged to a later period than on its northern margin, there have been subsidences sufficient to permit of the accumulation of more than 3000 feet of Pliocene or Subapennine strata; and these subsidences have been followed by upheavals, which at some points, as in Sicily, have raised the marine beds to heights of more than 3000 feet above the sea-level. And here again we find the evidence in Eastern Europe quite in accord with that found in the West. For example, the Congerian and Paludina strata of Sclavonia, the equivalents of the Pliocene of Western Europe, have a thickness of more than 2000 feet; and they have been clearly subjected to very considerable local disturbances during those movements of upheaval, through the agency of which they are now exposed at the surface.

That even in post-Pliocene times movements of no insignificant amount took place, we have also abundant evidence. In our own country, marine shells at an elevation of 1400 feet in Moel Tryfaen and 1200 feet at Macclesfield tell of subsidence and re-elevation during the so-called Glacial period, of which these measures are the *minimum* limit. The evidence derived from these marine shells at such great elevations can only indeed be got rid of by such violent hypotheses as those of the Universal Deluge sweeping everything before it in its passage, or of Messrs. Belt and Croll's "ice-caps," which scrape up ocean-bottoms and push them on to mountain-tops. For our own part, if compelled to choose between these two hypotheses, we should decidedly confess to a preference for the older, which has also the advantage of being an orthodox one.

Nor were the movements which took place in our own country in post-Pliocene times by any means exceptional, for there are many facts which point to more extensive and violent ones having occurred during that period in the Western Alps.

The great changes which were brought about during the same period in the physical geography of Eastern Europe (though there, probably from local causes, unattended with those extreme glacial conditions which characterized Western Europe and Eastern America) bear witness to the continued activity of the subterranean forces. Nor have we any reason for doubting that these forces still retain some of their activity—difficult as it may be to demonstrate their effects by means of the monuments belonging to the insignificant periods of human history.

Now all the facts derived from a study of the positions assumed by Tertiary strata of different ages, both in Western and Eastern Europe, point to the same conclusion—namely, that within and around the great mountain axis of the Eastern continent subterranean disturbance, commencing in the Oligocene period, and thence gradually augmenting in violence, attained its climax towards the close of the Miocene, and then as gradually died away during the Pliocene post-Pliocene, and recent periods; the movements on the southern flanks of the axis being more prolonged than on its northern side.

And it is a most interesting circumstance that a very striking relation can be shown to exist between these movements in the great mountain axis itself and the activity of the volcanic belt which stretches on either side of it. The volcanic outbursts which, as we have seen, commenced in the Oligocene period, acquired continually new strength and vigour, till at the close of the Miocene they had built up a series of volcanic cones, rivalling Etna in their proportions and forming almost continuous chains stretching on both sides of and parallel to the great mountain axis; but, from that period down to the present, the volcanic activity has been in a state of continual but gradual decline, the vast cones falling into ruin, and the dying subterranean energies sufficing to produce only long lines of spluttering "puys;" till finally geysers and mud-volcanos, hot-springs and gaseous exhalations, testify to their having reached the stages of exhaustion, senility and utter decay. Yet this decline certainly took place faster on the northern side of the axis—where not a single active vent at present remains—than on its southern side—where Etna and Santorin, Vesuvius, Stromboli, and Volcano retain something of the fires of their youth; and where not a few outbursts during the historical period in the same Mediterranean area have served to remind us that forces as yet unspent still have their habitation beneath it.

We have already spoken of the evidences of the gradual appearance and growth in energy of the volcanic forces on both sides of the Alpine system during the Oligocene period. We will now briefly sketch, so far as the materials at our disposal enable us to do so, the actual condition of the volcanic centres which surrounded the Alpine system at the period of their maximum violence, towards the close of the Miocene period.

Among the most interesting of the facts established during the voyage of the "Challenger" is that of the existence of a great submerged ridge stretching from north to south through the Atlantic. The few peaks of this ridge, which rise from depths of 25,000 feet, and now reach the sea-level, there forming groups of islands, are almost all volcanic, though usually either extinct or exhibiting evidences of various stages of decadence. It is hardly possible to doubt that the subsidence and submergence of this vast ridge is connected with the gradual decline of volcanic energy beneath it. The evidence obtained in Greenland, the Hebrides, Madeira, and the Azores, all points to the inference that the period of maximum activity in this volcanic band was the Upper Miocene; and certain facts in our own islands suggest the conclusion that the commencement of volcanic action in it must be referred to a somewhat earlier portion of the Tertiary period. Hence it is not difficult to picture to ourselves the existence in later Tertiary times of a great band of volcanic peaks, comparable in magnitude and parallel in position with the range which now forms the western boundary of the great American continent. Of this great volcanic chain we trace the structure of portions still unsubmerged in Franz Josef Land, Spitzbergen, Greenland, Jan Mayen Island,[1] Iceland, the Faroe Islands, the Hebrides, the North-East of Ireland, the Azores, Canaries, and Cape de Verde Islands, Fernando Neronha, Ascension, St. Helena, and Tristan d'Acunha, in some of which eruptive action is wholly extinct, while in others it still retains a considerable degree of vigour.

From this great Atlantic volcanic band there extended in Miocene times one great branch to the westwards running through the Arctic Archipelago, and two great branches stretching eastwards; one of these latter being situated on the northern side of that great zone of subterranean movement which now forms the mountain axis of the Eastern Continent, and the other lying on the southern margin of the same disturbed district.

The northern volcanic chain was constituted as follows. In what is now the Auvergne rose the vast trachytic and phonolitic cones of the Mount Dore, the Cantal and Mount Mezen, so well described by the late Mr. Poulett Scrope; each a lofty mountain comparable to Etna in its proportions. Following a line parallel to a great curve of the Alpine main axis we are conducted by the smaller outbursts of the Black Forest and Odenwald to the district of the Lower Rhine. Here the greatly denuded masses of the Siebengebirge, the Westerwald, the Habichtswald, and the Rhon-gebirge, with the less ruinous mass of the Vogels-gebirge, indicate the existence of vast volcanic cones in the Miocene period, not inferior in dimensions to the three great volcanos of the Auvergne. The series, interrupted for a short distance by the great lateral axis now forming the ranges of the Thuringer Wald, the Franken Wald, and the Fichtel Gebirge, is continued by those two giant volcanos of Bohemia, now in their ruined state constituting the Duppaner Gebirge and the Leitmeritzer Gebirge, the latter of which is cut through by the Elbe. Again following an inflexion of the great Alpine axis, and crossing the lateral range of the Carpathians, we reach the Hungarian series of volcanos, and recognize the evidence of gigantic Miocene cones or groups of cones in the mountains of Gran and Visegrad, the district around Schemnitz, the Matra, the Tokay-Eperies Mountains, the Vihorlat Mountains, the Hargitta Mountains, the Transylvanian Erzgebirge, and the volcanic districts of the Banat of Hungary and Northern Turkey. In the southern extremity of the Crimea, in the Caucasus, and in the volcanic rocks forming the southern extremity of the Oural, we trace the extension of the same line of Miocene volcanos till it is finally lost in the mists that still enshroud the geology of Central Asia.

[1] Mr. Major has shown that there is ground for believing that a series of old rocks mentioned in some old sailing directions as existing midway between Iceland and Greenland, and called Grumbjorns Skerries, were blown up by a volcanic eruption in 1456, and long after that date formed a reef which has since diminished greatly in height. Here then we probably have another relic of this submerged chain of volcanic peaks.

The greater oscillations, attended with the more sweeping action of marine denudation, which have affected the southern range of Miocene volcanos,—those north of the Alps having for the most part suffered only from subaerial waste,—has resulted in reducing the former to a much more ruinous condition than the latter. In the numerous intrusive masses of gabbro, serpentine, diorite, etc., which abound in the Iberian and Italian peninsulas, and which are, in many cases at least, of post-Eocene age, as well as in some skeleton volcanos, like those of the Euganean Hills and Styria, with vents like those of Sardinia, Central and Southern Italy, Sicily, and the Ægean Sea, which have continued in action to more recent periods, we find the different centres of volcanic action on the southern side of the Alps, exhibiting every stage of dissection by denudation. This southern chain is continued eastwards by the volcanos of Asia Minor, Persia, and Afghanistan into Northern India.

The extinction of the great volcanic cones, both on the north and south sides of the central mountain axis, was followed, as we have already remarked, by the appearance of scattered "puys" which can be reckoned by thousands, and were evidently thrown up along lines of fissure opened in the plains surrounding the extinct cones.

It is impossible to regard as accidental the close agreement which we have thus shown to exist between the critical periods in the history of the last great movements in the Alpine axis, and those of the volcanic outbursts in the surrounding areas; more especially as we have seen that the igneous activity was developed along lines having the most unmistakable parallelism to the principal Alpine chains.

Now it is of the very highest importance that we should fully recognize the vastness of the changes which have taken place in the physical geography of the continent during a comparatively recent geological epoch: for in the action of the great subterranean movements during the later Tertiary periods we can scarcely fail to recognize—if the amount and effects of the disturbances be fully realized—a competent cause for some of the more important of the physical phenomena that mark the history of this epoch in Western Europe; and among these we may especially mention that extension of the Alpine glaciers, which seems to have characterized several of the most recent of the geological periods.

In seeking for the causes of the extension of glaciers during former geological periods, we cannot but regard it as a most unfortunate circumstance that geologists have often appealed for explanations of the phenomena they witness to the little-known and less-understood action of the ice-fields that are supposed to cover Greenland and the Antarctic continent. Hence has grown up the hypotheses of vast movements of "continental ice," of "ice-sheets," and "polar ice-caps," the very existence of which rests on the smallest and slenderest basis of evidence. For the supposition that the icebergs of Arctic regions are not derived from large and confluent glaciers, but from detached portions of ice-sheets which have the power of over-riding hill and valley alike, I must confess myself to have failed to find a particle of proof in any of the works describing the results of polar explorations.

If, instead of speculating on what is going on beneath these imaginary "polar ice-caps," we turn our attention to a country which affords the grandest illustrations of glacial action in the world—I refer to New Zealand—and which has had the advantage of having been thoroughly explored by such competent observers as Hector and Hochstetter, Haast and Hutton, not to mention many others, we shall, I think, be led to frame opinions on the subject which have the advantage of being more in harmony with all the facts observed, both physical and palæontological.

New Zealand is situated some five degrees nearer to the equator than are the Alpine regions of Europe; yet, during very recent periods in the world's history, the former district was subjected to glacial action on the grandest conceivable scale, the remaining monuments of which are of the most striking and unmistakable character. Even the shrunken relics of those glaciers which still remain are of a magnitude which make the existing Alpine glaciers appear puny by comparison; one of them extending to within 500 feet of the sea-level, in the midst of a country covered with tree-ferns and palms.

When these remarkable glaciers and the proofs of their former greater extension were first described, the facts were of course adduced by many geologists as a proof that the whole globe had, during certain periods, been subjected to secular refrigeration; and New Zealand was supposed to afford the strongest possible demonstration of the existence of "the Glacial Period." But the careful study of all the evidence, especially the palæontological, has compelled the whole of the distinguished geologists we have named above to entirely renounce their former views upon the subject, this reform in opinion having been led by Dr. Hector in 1863. The fossil shells belonging to the whole series of Tertiary and post-Tertiary deposits prove conclusively that no such changes of climate as are argued for by advocates of universal Glacial periods ever took place in the Southern hemisphere; and these conclusions of the New Zealand geologists are fully supported by those arrived at by Professor M'Coy in Australia.

Nor are the palæontological facts pointing to the same conclusion in the case of the Northern hemisphere less convincing. It has been argued from the existence of large blocks, and the poverty of the fauna in certain sub-Alpine deposits, that "glacial epochs," or a general refrigeration of climate in the Northern hemisphere, occurred both in the Eocene and Miocene periods. We shall not stay to point out how cautiously the presence of merely transported blocks—not exhibiting any glacial striation—should be accepted as evidence of glacial action, in the face of the facts which have been published by Mr. Drew concerning the composition of the "fans" of the Himalaya. But, assuming that an extension of glacial action did take place in the Alps during the Eocene and Miocene periods respectively, that these "glacial periods" were of purely local and not of universal character, we have the most complete proofs which it is possible to conceive.

As was so well pointed out by Mr. Searles Wood, we find in the Hampshire and Paris basins the most beautiful and perfect illustrations of the whole series of Eocene and Oligocene deposits at a number of points, *situated more than ten degrees nearer the pole* than the Alpine regions; and yet in these, not only are we met by the fact of the absence of even the smallest trace of the physical action of glaciers, but, as every student of the British, French, and Belgian Tertiaries is well aware, there is not a particle of evidence in favour of such dwarfing of certain species, accompanied by the migration and extinction of others, which could not fail to accompany the extension of the supposed polar ice-caps during parts of those periods.

Again, in the case of the Miocene, we have in the Vienna basin a complete series of deposits formed in the same latitude with the Alps, which exhibit in the characters of their faunas clear evidence of a gradual passage from tropical, through sub-tropical, to the temperate conditions of the adjoining seas, but no trace whatever of any such interruption as could not fail to have been produced by a period of excessive cold.

I need scarcely refer to the supposed existence of a "Glacial period" during Jurassic times, for the evidence of which my own observations in Sutherland have been again and again quoted, in spite of the numerous facts which, as I have myself pointed out, militate in the strongest manner against any such hypothesis.

To the readers of this Magazine, too, it will be unnecessary to recall the important verdict pronounced by Professor Nordenskiöld, after his long and careful examination of the geological deposits of the Arctic regions, where surely, if anywhere, evidence in support of the alternation of glacial and mild periods ought to be observed. He declares that "from Palæontological science no support can be obtained for the assumption of a periodical alternation of warm and cold climates on the surface of the earth."

Nor is the evidence against the universality of glacial periods wholly derived from Palæontology. The general absence of recent marks of glacial action in Eastern Europe is well known; and the series of changes which have been so well traced and described by Professor Szabó as occurring in those districts seems to leave no room for those periodical extensions of "ice-caps" with which some authors in this country have amused themselves and their readers.

Mr. Campbell, whose ability to recognize the physical evidences of glaciers will scarcely be questioned, finds quite the same absence of the proof of extensive ice-action in North America, westward of the meridian of Chicago.

In the face of all these facts, it is impossible to avoid the conclusion that the so-called "Glacial Epoch" was a *purely local* phenomenon, confined to Western Europe and Eastern America, and that earlier extensions of glacial action were equally due to local causes.

Hence we are altogether spared the necessity of discussing such hypothetical explanations for secular changes of climate as have been advanced by Croll, Belt, Drayson, and others; seeing that not only are there no facts calling for the aid of any such hypotheses, but that the conclusions of both the palæontologist and field-geologist point in quite a different direction. We are far from regretting the publication of those charming works which have lately treated geological questions on the hypothesis of the occurrence of a rhythmical succession of hot and cold periods during the earth's past history. Yet we cannot help thinking that, had their authors paid a little more regard to the established results of palæontological investigation, each of the works in question might have been presented to the public in the form of three thin volumes rather than as a single bulky one.

The distinguished geologists of New Zealand, to whom we have before referred, on finding that the hypothesis of a great reduction of temperature in the Southern Hemisphere was quite untenable, began to search for other causes to which the former extension of their glaciers could be referred. Such a cause they believe themselves to have discovered in the demonstrated former existence of widely extended tracts (now reduced to narrow ridges only by denudation) above the snow-line, and the maintenance of these vast gathering grounds for glaciers during enormous periods of time, by the subterranean movements that have so greatly affected New Zealand.

Have not precisely similar causes been at work in the case of the Alpine district, and are not the phenomena of the former extension of glaciers in that area far more in accord with such a cause, as we have just referred to, than with the hypothesis of alternations of climatal condition, due to astronomical causes—even supposing that these were not so distinctly negatived by palæontological evidence? Since the incubus of the Universal Deluge was got rid of by geologists, no hypothesis more obstructive to the development of their science has appeared, than the doctrine that the existence of ice-action in a district is a proof of secular refrigeration of climate.

Of the various cosmical causes so ably discussed by Mr. Searles Wood in recent numbers of the Geological Magazine, we may readily grant that one or more may have contributed in some degree to the production of variations in climate during past geological times; but, until the effects of those local changes of level which we know to have occurred have been fully taken into account and proved to be inadequate in each special case, it is surely very rash indeed on the part of geologists to appeal to agencies, of which the origin and effects are confessedly so little understood. And while it is scarcely possible to assign a limit to the size which glaciers might attain—if supplied from feeding grounds of sufficient elevation and extent, on which a large amount of precipitation was constantly taking place—it is very difficult indeed to understand how a simple reduction of temperature should produce the effects which are so constantly assigned to it by some writers.

In the case of the Alps I know of no glacial phenomena which are not capable of being explained, like those of New Zealand, by a great extension of the area of the tracts above the snow-line, which would collect more ample supplies for the glaciers protruded into the surrounding plains. And when we survey the grand panoramas of ridges, pinnacles and peaks, produced for the most part by subaerial action, we may well be prepared to admit that before the intervening ravines and valleys were excavated, the glaciers shed from the elevated plateaux must have been of vastly greater magnitude than at present. This increase of the area above the snow-line, resulting in the extension of the glaciers, would likewise follow from the elevations of the whole mountain mass; and the same movement would also account for the transport of blocks across the wide Swiss valley, and their lodgement on what are now opposing slopes. It is an interesting confirmation of these views that the Western Alps, where the subterranean action has been most violent and prolonged, is also the district in which the glacial action has been most powerfully marked.

We need scarcely add that, if these views be correct, there is no necessary connexion, either in their period or in their cause, between the extension of glaciers in Northern Europe and the Alps respectively. The identification of the two series of events rests indeed on no sufficient palæontological or physical evidence.

I have not in this article attempted to deal with the remarkable phenomenon of the prevalence of more uniform climates over the whole globe during past geological periods, the admission of which, as Dana and Nordenskiöld have so well pointed out, it is hardly possible to avoid. This is perhaps the most difficult problem which geologists are called upon at the present day to face. Possibly the results of the Arctic Expedition, when fully worked out, may throw some new light on this important question.

If, in the series of articles which we are now bringing to a close, we have been led to dwell at greater length upon the proofs of subterranean action, than upon those more obvious results due to the operation of external forces upon the earth's crust, it is with no desire to under-estimate the importance of the latter, but rather with a view to counteract the somewhat one-sided statements that have been made concerning the relative effects of the two classes of terrestrial forces.

Prof. Geikie and Mr. Croll have done excellent service to geological science in reviewing and calling attention to the results of estimates of the amount of waste produced by subaerial denudation, and the rate at which the surfaces of our existing continents are being worn away. Fully agreeing with Prof. Hughes that, as actual measures of geological periods, such estimates are open to so many sources of error and are so difficult of application as to be worthy of but little reliance, we nevertheless regard them as having a very great value in enabling us to appreciate the reality and the important effects of operations ever going on insensibly around us.

We venture to think that still further uses may be served by these same estimates, in giving us the means of realizing the amount of work effected by those subterranean forces, the results of the operation of which are even less easily detected than those of subaerial waste.

That the ordinary processes of the earth's economy have been maintained in constant operation throughout a long succession of geological periods we have the clearest proof. And, as a necessary consequence of this, we are bound to conclude that something like the same *general balance* between the elevated and submerged areas of the earth's surface has been preserved during those periods.

Now nothing comes out more clearly from the ingenious estimates to which we have referred than the conclusion that—in a period of time of comparatively short duration, geologically speaking—the whole of the existing continents would be washed away, and their materials deposited on the bed of the ocean by the action of the agencies of waste and transport now in operation—were these destructive forces not counteracted by the constant elevation of portions of the earth's crust.

Assuming then, as we have seen there are good grounds for doing, that the general balance between land and water has been maintained during very long geological periods—the subterranean movements of the earth's crust, if all in the direction of elevation, would produce effects that would be exactly represented by the total effects of subaerial and marine waste during the same period.

But seeing that a large amount of the effects of elevation must of necessity be neutralized by those of depression, we are forced to conclude that the results produced by subterranean are *far greater* than those brought about by surface denudation. That, indeed, the results of the latter are actually compensated by the excess of the elevatory movements over those of subsidence.

To enable us therefore to establish anything like an actual relation between the work performed by subterranean and surface forces, in modifying the earth's crust, we should require to obtain a measure of the effects of movements of depression. Here Mr. Croll's calculations, based on the thickness of the sedimentary rocks, may be of some use, for, as Mr. Darwin has so well shown, the stratified rocks must almost without exception have been deposited in subsiding areas, and the thickness of the rocks thus becomes a measure of the amount of subsidence that the areas on which they were deposited have undergone. But as many areas are undoubtedly subsiding, without receiving sediment at all, even this will only give an unknown fraction of the quantity required.

From all these considerations then we are driven to conclude that the work performed by surface agencies, in modifying the forms of the earth's crust, vast as it is, bears but a very small, though indeterminable, proportion to that effected by the subterranean forces.

THE END.