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## OLD SCOTTISH VOLCANOES.

By Professor JAMES GEIKIE, LL.D., D.C.L., F.R.S.

DURING many successive periods volcanoes have played a prominent part in the geological history of Scotland, and it is to them we owe some of the most picturesque features of our country. True, we cannot show groups of well-preserved cones, such as those of the Eifel and Auvergne. So long a time has elapsed since even the latest manifestation of volcanic action in Scotland that the forces of denudation have succeeded in obliterating all the more obvious traces of that action. The lavas and fragmental materials erupted at the surface have, in short, experienced so much erosion that the present configuration of the ground bears little or no resemblance to that of any volcanic region in which igneous action has only recently become extinct. And if this be true of our latest eruptions, it is more strikingly true of those of earlier ages. We can still in many cases point to the centres from which our more ancient lavas and ashes were ejected, but not infrequently this is impossible—the products of volcanic action remain, but the sources from which they came can only be conjectured. Sometimes, indeed, lavas and ashes have alike vanished—their former existence being suggested partly by the presence of old volcanic vents plugged up with igneous rock of one kind or another, and partly by the appearance of more or less numerous sheets, dykes, and veins of formerly molten matter which has obviously cooled and consolidated below ground. In such cases it is clear that considerable denudation must have taken place before such deeply-seated portions of the ancient foci of eruption could have been laid bare, and in the general lowering of the surface all superficial volcanic accumulations have necessarily disappeared. Not infrequently direct evidence of eruptions is entirely wanting, and a

kind of indirect evidence may be all that is forthcoming. Not only may superficial volcanic accumulations have entirely vanished, but the plugged-up vents or funnels, with their associated sheets, dykes, and veins, may nowhere be seen, and yet the geologist may be convinced that before the deposition of certain strata volcanic action must have taken place at no great distance from the district over which those strata were laid down. For example, the basal portions of some great series of strata may be abundantly charged with water-worn fragments of volcanic rocks, which must obviously have been derived from the breaking up of pre-existing masses of igneous origin. Sometimes it is possible to trace the stones in question to their source, but just as often this cannot be done. The rocks underlying the conglomerates with their tell-tale fragments may not yield any evidence whatsoever of volcanic action, yet we may be justified in surmising that after their formation, and before the deposition of the overlying conglomerates, volcanic eruptions must have taken place somewhere in the neighbourhood.

When we reflect that the sedimentary formations of the globe are all of derivative origin—that is, built up out of the ruins of pre-existing rocks—it is obvious that the geological record must be very imperfect, and that of many episodes in the history of the past either no evidence has been preserved, or is not now recognisable. It is not less obvious that the oldest formations of a country, having, as a rule, been most frequently exposed to erosion and changes of all kinds, will usually show a more imperfect record, and be harder to decipher than the formations of later ages. Again, when we remember that movements of the earth's crust of one kind or another have taken place at all periods, and that in many cases, as in Scotland, such movements have resulted in the folding, crumpling, and fracturing of the crust, we cannot be surprised to find that the oldest formations are generally the most disturbed, and their structure the most difficult to unravel. Not only are the ancient rocks of Scotland very much disturbed, but they have undergone numerous complex changes both in texture and structure, whereby their original character has been greatly obscured and often obliterated. It might have been expected, therefore, that the earliest chapters of the geological history of our country are neither so full nor so readily interpreted as those that follow—the history becoming more detailed and more easily comprehended as we proceed from the oldest to the youngest systems.

The oldest rocks of Scotland belong to that primeval stage known as the Archæan, and are confined to the north-west Highlands and the Outer Hebrides. That period is incalculably remote, and its records are so fragmentary and confused that their meaning can be but dimly apprehended. So many æons separate the present from the Archæan—so profoundly has the whole structure of the earth's crust been modified since then, so many geographical revolutions has the Scottish area experienced, so frequently has its configuration been remodelled—that we know practically nothing of the conditions that obtained at the surface in those far-past ages. All that can be affirmed is that many of the Archæan

rocks are of igneous origin, and that their character is such as to lead to the belief that they were not extruded at the surface as lavas, the molten matter having obviously cooled and consolidated below ground. It is not improbable, however, that some at least of the granitoid rocks of Archæan times may represent the deep-seated products of volcanic action—that while they were intruded below, lavas and ashes may have been ejected at the surface. No recognisable traces of such ancient volcanoes, however, have been preserved—the sea-floors or land-surfaces of the Scottish area of Archæan times have apparently wholly vanished, or at least are no longer manifest. Nevertheless, it is not impossible that geologists may yet discover relics of the kind, seeing that elsewhere, as in Sweden, remains of what seem to have been Archæan volcanic eruptions have been detected.

Of much later age than the Archæan, but still of vast antiquity, are the rocks that constitute the major portion of the Scottish Highlands. The relative position of the crystalline schists that lie east and south-east of the Archæan tracts is at present undetermined. We only know that they are much younger than the Archæan, and that they may possibly include rocks of pre-Cambrian, Cambrian, and even perhaps Silurian age. They are as a rule so highly metamorphosed and confused that their precise origin is often obscure, and the absence of fossils prevents their geological position being definitely determined. East of the Great Glen, however, the structure and origin of the rocks in question are more readily deciphered. In that region they appear to consist to a considerable extent of what were originally aqueous accumulations—conglomerates, grits, sandy and argillaceous strata, and occasional limestones. These ancient marine deposits are now much altered, and over wide areas have been changed into crystalline schists. Associated with them are numerous sheets and masses of igneous rock—most of which would seem to be of an intrusive character, that is to say, formerly molten matter which has cooled and consolidated at less or greater depths from the surface. Here and there, however, the rocks in question are suggestive rather of lavas, while certain green schistose rocks occurring in the same series are supposed to represent fine-grained fragmental volcanic ejecta. If the rocks of the east Highlands, therefore, be assigned to pre-Cambrian times, we may be justified in believing that the period of their formation was marked by considerable volcanic activity—numerous flows of lava and much dust and ash having accumulated on the floor of the sea. The precise geological position of the rocks in question, however, is, as already mentioned, quite uncertain. But if submarine volcanoes really existed in the Scottish area in pre-Cambrian times, that would be quite in keeping with the evidence supplied by the presumably pre-Cambrian rocks of Anglesey, the Wrekin, Caer Cardoc, and other hills of the Welsh borders, the Malvern Hills, and Charnwood Forest—in all of which traces of volcanic action have been detected.

Of the succeeding Cambrian period the records in Scotland are somewhat scanty, and such as they are they have hitherto yielded no evidence of volcanic action. We know, however, that considerable

volcanoes existed elsewhere in the British area at that time, more particularly in Wales, and on a smaller scale in the region of the Malvern Hills and in Warwickshire. It must be remembered that it is only in the areas just mentioned that Cambrian rocks crop out at the surface, and that over extensive regions in England they must lie buried under a great thickness of later formations. The same is doubtless true of the Cambrian in Scotland. Could these concealed rocks be exposed we should probably find that volcanoes were more widely distributed during Cambrian times than the available evidence would lead us to infer.

If recognisable Cambrian rocks are only sparingly developed in Scotland, it is quite otherwise with those belonging to the succeeding Silurian period. Strata of that age constitute the larger portion of our Southern Uplands—both Lower and Upper Silurian being represented. The sedimentary rocks referred to consist of marine accumulations, and would appear to have been deposited over the floor of a somewhat shallow sea. Amongst the Lower Silurian strata of the Scottish area we find abundant evidence of volcanic action. Not only do lava-flows and beds of fine fragmental ejecta (tuffs) occur over extensive areas, but now and again we encounter thick masses of coarse "breccia" or "agglomerate"—aggregates of angular and subangular blocks and stones—which have obviously accumulated in the immediate vicinity of volcanic vents. Probably all these eruptions were submarine, but it is not unlikely that many of the volcanoes eventually grew to be subaerial, and that in time numerous volcanic islets may have dotted the Lower Silurian sea of southern Scotland. How much of the Scottish area was occupied by that sea we cannot tell. Probably Lower Silurian rocks lie concealed throughout the whole of the central Lowlands, because they reappear in a narrow belt along the southern borders of the Highlands. It is not improbable, indeed, that some of the crystalline schists of the central Highlands may really be the metamorphosed representatives of the sedimentary and volcanic rocks of the Southern Uplands. Be that as it may, we can hardly doubt that the Lower Silurian sea extended over all southern and central Scotland and a considerable portion of the Highlands. And the evidence supplied by the Silurian rocks occurring along the Highland border shows that submarine volcanoes flourished there just as they did further south.

But copious as are the records of volcanic action in the Lower Silurian of Scotland, they cannot compare with those which are met with amongst the corresponding strata of England, Wales, and Ireland. Numerous volcanoes appeared in the relatively shallow sea by which those tracts were largely covered. In Wales the earliest eruptions of Silurian times were upon a grand scale. It is out of the volcanic materials of that stage that the mountain-masses of Cader Idris, Aran Mawddwy, Arenig, and Moel Wyn have been carved and sculptured. Eventually volcanic action in the Welsh area became less vigorous—only a few volcanoes of no great size appearing here and there. But before the close of the period the subterranean forces again displayed astonishing activity, more especially in what is now north Wales. The lavas

and tuffs then ejected are conspicuously displayed in Snowdon and other heights in the same region.

In the Lake District of north-west England the relics of Silurian volcanoes are not less conspicuous. Eruptions appear to have commenced in that region almost at the dawn of the period, and to have continued without interruption nearly to the close of Lower Silurian times. While it is doubtful whether any of the Welsh volcanoes ever became sub-aerial, there are some grounds for believing that the eruptions of the Lake District were not wholly submarine. Roughly contemporaneous with the Welsh and Cumbrian volcanic rocks are those so well exposed along the eastern borders of Ireland, where there would appear to have existed numerous and often closely contiguous volcanic vents.

The volcanic activity which thus characterised the Lower Silurian period throughout the British area eventually became exhausted. With the extinction of the numerous volcanoes of southern Scotland, the Lake District, Wales, and east Ireland, the effusion of lava and ash on the floor of the Silurian sea practically ceased. Only in the far west of Ireland and in Gloucestershire is there any evidence to show that volcanic action was continued into Upper Silurian times.

In the Scottish area the succeeding Old Red Sandstone period was marked by strenuous and long-continued volcanic action. Some of the more conspicuous hill-ranges of the Scottish Lowlands consist largely of the lavas and tuffs ejected from our Old Red Sandstone volcanoes. Among the ranges referred to are the Sidlaw and Ochil Hills, the Pentlands, and not a few of the hills in south Ayrshire. The Old Red Sandstone strata of Scotland consist of a Lower and an Upper series—in the former of which volcanic rocks attain a great development. The physical conditions under which the strata in question appear to have been accumulated may be very shortly outlined. After Upper Silurian times the Scottish area was converted into dry land. This change was brought about by a great movement of the earth's crust, whereby the floor of the Silurian sea was gradually uplifted and squeezed in a direction from south-east to north-west. In consequence of this upheaval by lateral thrust, the new-born land showed an irregularly wrinkled surface, being traversed from south-west to north-east by parallel ridges and intervening depressions of varying width and extent. The depressions thus formed inland seas or great fresh-water lakes—the margins of which can still be traced more or less satisfactorily, although in many places they have been obscured by subsequent modifications of the surface. It was in these lakes that the Old Red Sandstone strata gradually accumulated. To the several basins in question Sir Archibald Geikie has given distinctive names. The largest lake—"Lake Caledonia"—stretched from what is now our east coast south-westward across Arran and the south end of Cantire into Ireland as far as Lough Erne. It extended, in short, over the whole breadth of the central Lowlands, between the Highlands and the Southern Uplands. The deposits of another basin—"Lake Orcadie"—occupy wide areas in the region of the Moray Firth and the Orkney and Shetland Islands. "Lake of Lorne" is the name given to the basin which includes the Old Red Sandstones of western Argyllshire;

while the area occupied by the Old Red rocks of the Cheviot Hills and Berwickshire is designated "Lake Cheviot." It is needless to say that Lake Orcadie, Lake Caledonia, and Lake Cheviot must have extended east and north-east into regions which are now submerged.

Each of those ancient lakes became the scene of vigorous and prolonged volcanic activity. Eruptions appear to have commenced at a very early stage, and to have persisted in some cases down almost to the close of the Lower Old Red Sandstone epoch. To understand the nature of the conditions under which the volcanic eruptions took place, we must remember that the sedimentary strata with which the igneous rocks are associated give evidence of having been accumulated in relatively shallow water, and yet they attain a great thickness. The thickness of the red sandstones occupying the basin of Lake Caledonia, for example, can hardly be less than 18,000 feet. Obviously this great depth of material of shallow-water origin could only have been accumulated upon a gradually subsiding floor. The bottoms of the basins slowly sank down, but the lakes never attained a profound depth, because sedimentation kept pace with depression—the amount of sand and mud transported from the adjacent high grounds and spread upon the lake-floors effectually prevented over-deepening. It is probable, therefore, that the great crustal movement which brought the topographical features of Old Red Sandstone times into existence was continued during that period—that wrinkling of the crust did not cease when the great lakes appeared, but that the upward folds of the crust continued slowly to rise and the downward flows as slowly to sink. To supply all the material carried down from the contiguous high grounds into the lake-basins implies enormous denudation of the land—the gradual lowering of the latter being compensated by the process of upheaval, just as the filling-up of the troughs was prevented by the continuous sinking of their floors.

The lavas and fragmental ejecta attain in some basins a great thickness. In that of Lake Caledonia they reach not less than 6000 feet. Probably the bulk of these materials was erupted on the floors of the lakes, but here and there the volcanoes would seem to have grown so rapidly as to become subaerial. In Lake Caledonia there appear to have been two chains of volcanoes, both extending in the same general direction—from south-west to north-east. The relics of the northern chain are seen in the Sidlaw and Ochil Hills, in Cantire and Arran, while the southern chain is represented by the Pentland Hills and by numerous heights that extend in the same general direction towards the south-west along the flanks of the Southern Uplands into Ayrshire.

The foci of eruption are in many places recognisable. Sometimes these are occupied by larger or smaller bosses of some crystalline igneous rock; at other times the pipes or funnels are filled with agglomerates or breccias. Now and again also we encounter thick sheets of igneous rock which have obviously cooled and consolidated below ground—denudation having gradually removed the rock-masses underneath which they formerly lay entirely concealed.

Another interesting area of Old Red Sandstone volcanic rocks is that of the Cheviot Hills. These hills consist of a great series of lavas

accompanied by very little tuff. The chief focus of eruption is marked by a boss of granite, which occupies an area of 20 square miles, and rises into the summit of the range. From this granite numerous dykes and veins proceed outwards into the surrounding lavas. Brief mention may also be made of the rocks of St. Abb's Head, which consist of a series of lavas and tuffs, near which we can see the focus of eruption, filled up with angular and subangular fragments and intrusions of crystalline igneous rock.

Volcanic activity, in short, characterised all the great basins in which the Lower Old Red Sandstones of Scotland were deposited—the "Lake of Lorne" and "Lake Orcadie," like the others, had their volcanoes; and it is interesting to note that this was the case also in the south of Ireland, where in the Killarney district lavas and tuffs are associated with strata of Lower Old Red Sandstone age, accumulated under the same geographical conditions as obtained in Scotland.

Volcanic action seems to have died out during Lower Old Red Sandstone times in all the ancient Scottish lakes, with the exception of the Orkney basin, where lavas and tuffs and pipes of eruption indicate the existence of subaqueous volcanoes during the deposition of the Upper Old Red Sandstone. It may be added that there is evidence of at least one considerable volcano having been active in the south-west of Ireland, near Limerick, at approximately the same time.

The Devonian rocks of the south-west of England occupy the same stratigraphical position as the Old Red Sandstones of Scotland, and are probably therefore roughly contemporaneous. But while the Scottish series are of lacustrine origin the Devonian strata have been accumulated in the sea. Associated with these marine deposits occur lavas and ashes, showing that volcanic action supervened in southern England at some stage during the vast period of time which separated the close of the Silurian from the beginning of the Carboniferous period. The Devonian submarine volcanoes may therefore have been active at about the same time as the lake volcanoes of Old Red Sandstone times.

The succeeding Carboniferous period was marked especially in Scotland by extensive volcanic action. Eruptions seem to have commenced with the very dawn of the period and to have continued down to the time when the "Coal-measures" began to be accumulated—the "Coal-measures" forming the uppermost division of the great Carboniferous system.

Strata younger than the Carboniferous cover relatively small areas in Scotland, hence it is possible to acquire a fuller knowledge of Carboniferous volcanoes than of the eruptions of earlier periods. Rocks of Carboniferous age may be said to occupy nearly all the low grounds of central Scotland. True, they are often concealed under superficial accumulations of various kinds, but the abundant sections laid bare by streams, rivers, and the sea, together with numerous artificial openings of every kind, have enabled geologists to obtain a clear view of the structure and general character of the great coal-bearing system of strata. The geographical conditions that marked the formation of the Lower Old Red Sandstone were continued, but with many modifications, while the

Upper Old Red Sandstones were being deposited. The great lakes, it is true, had been more or less silted up, and their areas had been also restricted by considerable earth movements, but broad lake basins persisted up to the close of the period.

No hard and fast line separates the deposits of Upper Old Red Sandstone times from the basement beds of the Carboniferous system—the general character of the latter suggesting, however, a gradual passage from lacustrine to lagoon and estuarine conditions. There are few parts of central Scotland in which volcanic action did not manifest itself from time to time during the protracted Carboniferous period. In some regions the eruptions were of relatively short duration, while in other areas they persisted through many long ages. The earlier volcanoes were of a character akin to those of Old Red Sandstone times. Amongst the oldest were those from which the lavas and tuffs in the neighbourhood of Kelso were ejected. The rocks referred to are well displayed in the hills about Stitchell and Smailholm. They occupy a considerable area, extending from Greenlaw in the north to Roxburgh in the south. East of Kelso they are overlaid by younger sedimentary strata, and we cannot tell, therefore, what their range may be in that direction. It is obvious, however, that they must formerly have covered a wide area to the south and west of their present boundary, for dotted over the region in question many old vents are still conspicuous, such as the Dunian, Ruberslaw, Minto Crags, and the Eildons.

But the most continuous stretch of Carboniferous volcanic rocks is that which circles round the north-west borders of the coal-fields of Stirlingshire and Lanarkshire, and forms the Campsie Hills, the Kilpatrick and Kilbarchan Hills, and the broad belt of high ground that extends from Castle Semple Loch to the valley of the Avon, near Strathaven. Belonging, apparently, to the same stage of volcanic activity are the lavas and tuffs of Arthur Seat, and the similar but more abundantly developed volcanic rocks of North Berwick and the Garlton Hills. The plugged-up vents of that region are well represented by the Bass Rock, North Berwick Law, and Traprain.

All the eruptions referred to are assigned to an early stage of the Carboniferous period, and appear to have taken place on the floors of lagoons and estuaries, but in certain cases the eruptions were submarine, as is shown by the occasional occurrence of sea-shells in fine-grained tuffs. Not a few of the old foci of eruption have been located, as we have seen. Some of these are met with in the very heart of the great lava-fields, others appear near their margins, while yet others lie beyond—separated, it may be, by several miles from the nearest lava-flow. The vents in question frequently form conspicuous hills, which is invariably the case when the material that plugs them is of harder consistency than the surrounding rocks. Sometimes the plug consists wholly of a massive crystalline igneous rock, at other times it is an aggregate of angular and subangular blocks, or the vent may be occupied both by crystalline rock and fragmental materials. From the distribution of these old vents and the trend of the associated lavas and tuffs we gather that ejections took place sometimes from chains or lines of contiguous volcanoes, and

in other cases from irregular groups of cones. Eruptions occurring now here, now there, broad subaqueous plateaux were eventually built up, which it is needless to say must have been much more extensive than the hilly tracts that now represent them.

The later stages of the Carboniferous period in Scotland were marked by a somewhat different type of eruptions—namely, by numerous more or less isolated volcanoes, many of which were of insignificant dimensions. They seem to have resembled the *puys* of Auvergne. Many were mere cinder-cones from which no lavas were ejected. Others, again, were of more considerable size, and from these not only loose fragmental materials, but more or less numerous flows of lava proceeded. When several such puys were closely associated, their united efforts succeeded in building up broad plateau-like banks, on a smaller scale, however, than the volcanic plateaux of early Carboniferous times. Most of the eruptions now referred to seem to have taken place in lagoons and estuaries or in shallow bays of the sea. Now and again, however, the puys were probably subaerial.

The dominant movement of the crust during the growth and decay of these later Carboniferous volcanoes was one of subsidence, so that the puys which erupted in lagoons or upon the floor of the sea were eventually buried under slowly accumulating sheets of sedimentary materials, and in this manner many of them have been preserved. That the eruptions frequently took place under water is shown by the intercalation amongst the tuffs of fossiliferous shales, etc., and now and again of limestones, containing sea-shells and corals. It is improbable, however, that all the eruptions were subaqueous. Doubtless some of the larger puys which commenced upon the floor of sea or lagoon eventually succeeded in becoming subaerial. Nor is evidence wanting to suggest that not a few volcanoes erupted on dry land, and after their extinction became clothed with coniferous trees, the remains of which often occur abundantly in the tuffs associated with the old vents.

Although in many cases portions of the lavas and fragmental materials ejected from the puys can still be seen surrounding the foci of eruption, yet more usually all traces of the cones have vanished, and all that remains to mark the sites of the volcanoes are the plugs of igneous rock that occupy the "necks" or pipes of eruption.

The relics of these Carboniferous puys often form conspicuous features in the landscape. Fife is especially rich in this respect. The Binn of Burntisland, the Hill of Beath, and the Saline Hills are excellent examples. The Castle Rock of Edinburgh, Binns Hill and Tor Hill in Linlithgowshire, Great Moor, Tinnis Hill, and other similar isolated hills in Liddesdale may also be mentioned.

The earlier and more extensive eruptions of the Carboniferous period had not ceased before the puy type of volcano made its appearance, but the latter continued long after the great plateau-eruptions had come to a close. The puys in the east and south-east of Scotland were the first to die out. In Ayrshire and Renfrewshire, however, they remained active down to the beginning of that stage which is represented by the uppermost division of the Carboniferous system, known as the "Coal-

measures," when they finally became extinct. There is nowhere any trace of volcanic action having marked the accumulation of that great series of coal-bearing strata.

During the crustal movements which affected Scotland in post-Carboniferous times, the Carboniferous strata, with their abundant igneous rocks, were folded and fractured, and have subsequently experienced enormous denudation. The backs of the many upward folds have been gradually planed away, and the whole succession of the strata from the lowest to the uppermost stages has thus been exposed. Hence we see not only the lavas and tuffs which have from time to time been ejected at the surface, but the numerous "sills" or sheets and dykes of formerly molten rock which never rose to the surface, but were injected at less or greater depths. Owing to the fact that these igneous intrusions usually consist of much more durable rock than the strata amongst which they occur, they often form well-marked ridges and heights in the Lowlands. Salisbury Crags, Corstorphine Hill, the Lomond Hills, Cult and Cleish Hills are good examples, and many others might be cited. Most of these intrusions seem to belong to that later stage of volcanic activity which was marked by the puy-like eruptions described above.

Elsewhere in the British Islands volcanic action played a subordinate part during the Carboniferous period. There is evidence, however, of submarine volcanoes having existed in England, as in Derbyshire and Devonshire, and in King's County and near Limerick in Ireland.

Overlying the youngest Carboniferous strata in Scotland comes a series of red sandstones, the relation of which to the underlying Coal-measures shows that a vast period of time separates the two formations. The Scottish Carboniferous system, as we have seen, was laid down during a period when the earth's crust in our area was slowly subsiding. The movement may not have been continuous—there may have been long pauses, and these may even have been interrupted sometimes by gradual uplifting. But certainly the dominant movement was one of subsidence. It happened then that while the conditions of sedimentation in the earlier stages were for the most part estuarine, in the later stages the lagoons and estuaries, owing to increasing subsidence, were often largely replaced by more or less open sea, over the floor of which flourished the corals and other organisms whose remains constitute the limestones of the Carboniferous system. But the formation of limestone was frequently interrupted—lagoon and estuarine conditions returning again and again, until finally marine invasions ceased—the whole of the uppermost division of the Carboniferous strata (Coal-measures) having been apparently accumulated in estuaries and lagoons. While many of the coal-seams, which occur as well in the Limestone series as in the Coal-measures, represent old land surfaces—thick jungles and marshy growths—not a few would seem to have been formed in shallow water —estuarine or sea-water as the case may have been. In short, the flora of the period not only covered the broad deltas and lowlands of central Scotland, but even invaded the quiet waters—gigantic, reed-

like trees flourishing abundantly in shallow lagoons and estuaries, over the floors of which much vegetable sludge and slime gradually accumulated.

Great crustal movements supervened eventually, and the geographical conditions of the Scottish area were revolutionised. The old lagoons and estuaries vanished, and were replaced by a wide land-surface, which for a long period of time became subject to denudation. The folded and fractured Carboniferous rocks had consequently experienced much waste before the succeeding Permian strata came to be deposited. These Permian beds, chiefly red sandstones, have only a very limited distribution in Scotland. They occur chiefly in the valley of the Ayr, and in Nithsdale and Annandale. Owing to the paucity of their organic remains, there is some uncertainty as to their precise stratigraphical position, but they probably were deposited during the later stages of the Permian period, and may even pertain in part to the subsequent Triassic period. They appear to have been accumulated in inland lakes or basins, much after the manner of the Old Red Sandstone, but the basins were on a much smaller scale. Nevertheless the Permian strata must formerly have extended far beyond their present limits, for they have obviously suffered much denudation.

Volcanic action, which, as we have seen, had ceased to agitate the Scottish area before the formation of the Coal-measures, and had remained dormant during the vast lapse of time that separated the deposition of these "measures" from the accumulation of the overlying Permian sandstones, again broke out. The volcanoes of Permian times all belonged to the puy-type, and most of them were small. Many, indeed, appear to have been mere tuff- and cinder-cones—the products of one eruption. From some, however, not only fragmental materials but lavas were ejected. Sometimes these puys are disposed along lines of "faults" or fractures, at other times they do not appear to be connected with fractures, but occur scattered about in irregular groups. They are especially numerous in Ayrshire and the east of Fife. As in most cases only the plugged-up "necks" remain, it is often impossible to say whether the puys erupted in water or on dry land. In the valley of the Ayr, however, lavas and tuffs are interstratified with the red sandstones, and the same is the case in Nithsdale, so that it is quite certain that some at least of the Permian eruptions were subaqueous. Bearing in mind that the Permian sedimentary strata were formerly much more extensive, and may well have covered wide areas over which many isolated "necks" are distributed, it is not improbable that these latter may also have erupted on the floor of the ancient basins—their lavas and tuffs, and the sandstones with which they may have been interstratified, having been removed by denudation.

In the east of Fife many old vents occur which have been assigned to the Permian period—although no strata of that age are met with in that region. They closely resemble, however, the corresponding "necks" of Ayrshire and Nithsdale, and like those they are of much later date than the Carboniferous strata they traverse. They often form conspicuous isolated hills, such as Kellie Law and Largo Law, and numerous

examples can be studied upon the shore between Elie and St. Monans, where they have been bared and cut into by the sea.

The denudation which has so greatly affected the Permian rocks of Scotland has in many cases revealed the igneous masses which were injected below the surface, cooling and consolidating there. The best examples of such "sills" occur in Ayrshire, and are especially well developed in the neighbourhood of Dalmellington, not a few of the hills in that district owing their origin to the presence of intrusive masses. Kilmein Hill may be cited as a good example.

The only certain evidence of Permian volcanic action in England is met with in Devonshire, where lavas and tuffs are interstratified with the red sandstones, but hitherto none of the vents from which these may have come has been discovered.

After the Permian period volcanic action remained for some time dormant. During the preceding period that action had been gradually becoming weaker, and finally a long pause ensued. In Permian times renewed activity was manifested, but on a much reduced scale. Prolonged as was the interval that separated the latest eruptions of the Carboniferous from those of the Permian, it was relatively short as compared with the vast succession of ages that supervened after the Permian, during which the British area remained wholly undisturbed by volcanic action. The enormous sedimentary accumulations of the Jurassic and Cretaceous periods (of which so large a part of England is built up) speak only of quiet deposition in widespread seas. Nowhere do they yield the slightest trace of contemporaneous volcanoes. These systems are very sparingly represented in Scotland, although there is every reason to believe that they must formerly have had a wider extension. It is quite possible, therefore, that considerable parts of the Scottish area may have been overflowed by the Jurassic and Cretaceous seas. But however that may have been, there is no evidence to show that less dry land existed in Scotland during Jurassic and Cretaceous times than during the preceding Triassic and Permian periods. It would seem, in short, as if the major portion of Scotland had remained above water throughout the long Mesozoic era.

The succeeding Tertiary systems are likewise very sparingly represented in the Scottish area by aqueous sedimentary rocks. But, on the other hand, igneous rocks greatly abound and bear witness to excessive volcanic activity. These Tertiary eruptions were on a far greater scale than those of earlier ages, and gave rise to vast plateaux, the shattered and much denuded relics of which are well seen in the Inner Hebrides. The islands of Skye, Canna, Rum, Eigg, Mull, and the adjacent coastlands of Ardnamurchan and Morven consist largely of the rocks in question, and were probably all at one time connected, forming together one great volcanic plateau. Many of the most striking mountains in the west of Scotland have been carved out of these Tertiary rocks. Among them may be named the Cuillen Hills in Skye, the Scuir of Eigg, and Goat Fell in Arran.

Distinct phases characterised the eruptions of Tertiary times. The first phase was marked by the wholesale fracturing and fissuring of the

crust, by the rise of molten matter in the clefts thus formed, and its frequent escape at the surface in prodigious floods. The great plateau-basalts of the Inner Hebrides, of Antrim, the Færöe Islands, Iceland, and Greenland all belong apparently to the same geological period, and all alike formerly had a much wider extension. It would seem that in early Tertiary times the whole of the area extending as a broad belt from Greenland to Scotland was underlaid by a vast sea of molten matter, struggling to gain a passage to the surface. The overlying crust, bulged up and strained by the rising fiery tide, was shattered by earthquake shocks, and a multitudinous series of cracks and fissures appeared, up through which in many places the imprisoned molten matter escaped and poured out in many successive streams. The lava appears sometimes to have welled up and overflowed from long lines of fracture, at other times it issued at various points upon such fissures. Indeed, the surface of the growing plateau appears to have been studded with rows of volcanoes, and here and there with more or less isolated or sporadic vents —the pipes of which can still be seen in many places. Lavas chiefly were erupted, but not infrequently loose ejecta of large blocks and smaller rock-fragments and cinders were shot out, and now and again fine dust and ashes. While lavas flowed out at the surface, it often happened that molten matter was injected at various depths below, forming here and there thick "sills" or sheets, with accompanying tortuous veins and dykes. Although the earlier eruptions may in some places have been submarine, yet wherever the base of the volcanic series is exposed it appears to rest upon an old land-surface. Successive floods of lava gradually filled up the valleys and depressions, and eventually covered the hills, thus completely obliterating the topographical features of a wide region, and building up a vast plateau over the buried land. Now and again there were pauses in the volcanic activity, during which, in some places at least, the rocks forming the surface of the plateau were exposed to atmospheric action, and decayed; while here and there pools, lakes, and streams appeared, and a vigorous vegetation clothed the land —the plants being indicative of warm, genial climatic conditions. Hence in time sedimentary deposits accumulated, and in these were preserved relics of that flora. These now form the thin leaf-beds and coals which appear intercalated among the plateau-basalts of Iceland, the Færöe Islands, and the Inner Hebrides.

The evidence would lead us further to believe that the great basaltic plateau, of which the Inner Hebrides are the truncated remains, formerly occupied all the area that separates those islands from the mainland and extended far westward into regions which are now submerged. From the Highlands large rivers made their way across the plateau during the period of its growth, and here and there dug out deep ravines and broader hollows which were subsequently overflowed and buried under younger floods of lava. Nay, even after the plateau-basalts ceased to be ejected the same rivers continued the work of erosion, excavating their channels in the youngest basalts that capped the plateau. Enormous denudation has since taken place, but one of these old river-courses has been singularly preserved in the island of Eigg. The Scuir of that

island is the relics of a pitchstone-lava, which occupies the bed of an old river with its gravelly accumulations. The flanks of the ancient valley have been denuded away, and the river-bed with its pitchstone now forms the dominant height of the island. The pitchstone must have come from some small vent in the neighbourhood—the last known to have erupted on the surface of the volcanic plateau—and to the lucky accident of the lava having found its way into a valley we owe the preservation of the ancient river-gravel.

Some time after the accumulation of the plateau-basalts had been completed, the region appears to have been again shaken by earthquakes and traversed by abundant fissures into which molten matter was injected, but there is no evidence to show that any of these fissures communicated with the actual surface. They are now represented by a numerous series of dykes, resembling those of the earlier stage, but being usually smaller and often more tortuous and irregular in their course.

The latest phases of volcanic activity in Tertiary times were marked by the uprise within the plateaux of enormous masses of igneous rock, none of which, however, appears to have actually reached the surface. The earliest intrusions consisted of basic rock, known to geologists as *gabbro*, that rose in great boss-like masses, from which innumerable sheets proceeded outwards, insinuating themselves between the bedded basalts of the plateau. So enormous is the amount of the intrusive matter that the surface of the plateau must have bulged up here and there above these boss-like intrusions.

Of later date than the intrusions of gabbro are large and small ones composed of more acid rocks, such as granite, felsite, and pitchstone. Some of the bosses pertaining to this stage are of great extent and now form mountain masses, such as the Red Hills of Skye and the granitic heights of Arran. Like the earlier gabbro intrusions, none of these acid rocks reached the surface—they are wholly subterranean in origin, although they may well have influenced the surface of the volcanic plateaux into which they rose, causing it to bulge upwards.

It is quite clear that the latest period of volcanic activity manifested in the British Islands far exceeded in importance any other of which we have evidence. When the formation of the great plateau was completed it is probable that it not only occupied the area between north Ireland and the west Highlands of Scotland, but extended away to the north-west by the Færöe Islands and Iceland, and perhaps even to Greenland. After the cessation of volcanic action subsidence ensued—the plateaux was fractured and rent, and vast segments slowly sank under the waters of the Atlantic. The portions that remained above the sea came in time to be still further lowered by denudation—until in many places the deep-seated bosses of gabbro and granite were exposed, and now, owing to their superior durability, these have assumed the character of dominant heights, the basalts which formerly covered and surrounded them having been largely removed. The volcanic islands of the Inner Hebrides are thus mere outliers or remnants of a plateau—the constituent rocks of which formerly attained a thickness of many thousand feet. The plateau-basalts are now restricted to these islands and the adjacent

coast-lands, but it is possible that they may formerly have covered considerable areas in what are now the lowlands of central Scotland. These lowlands are traversed by many great dykes, a few of which have been followed more or less continuously into England. It seems likely enough that some of these may have communicated with the surface, and that lava may have flowed from them. But the whole surface of the land has been so greatly lowered since they were injected, that even if they had emitted lavas these might well have been removed by subsequent denudation. Many dykes, however, did not reach the original surface, but are now exposed owing to the removal of the rocks underneath which they were formerly concealed. Indeed, in our coal-fields not a few have been encountered which die out before the existing surface is reached. The presence of these great dykes, which may occasionally be followed for miles in a nearly straight line, crossing deep valleys and running over considerable hills, implies such enormous denudation of the surface that it is hard to believe that so much rock material could have been removed since Tertiary times. Moreover, there are other geological facts that lead one to doubt whether the dykes referred to have any connection with the eruptions of Tertiary times. Some of them at least would appear to be of Carboniferous age, and the probabilities are that the same is true of many others. But even if it cannot be shown that the Tertiary basalts ever invaded central Scotland, the evidence is overwhelming as to the former existence of a vast volcanic plateau, of which the rocks of Antrim and the Inner Hebrides are the sorely wasted relics.



## THE MERGUI ARCHIPELAGO: ITS PEOPLE AND PRODUCTS.

By R. N. Rudmose Brown, B.Sc.

(*With Illustrations.*)

Lying somewhat off the great trade routes and the travel arteries of the East, the Mergui Archipelago has received scant and infrequent attention at the hands of geographers and naturalists. The few casual remarks that are to be found with regard to it in geographical works and books of reference are none too accurate, and the only existing maps (Admiralty Charts 216A, 216B, and 824) are far from reliable. One of the earliest, if not actually the first, record of a visit to the Mergui Archipelago was in 1792 when a certain Captain T. Forrest [1] made a voyage southward from Calcutta in search of suitable sugar-growing countries. He traversed the archipelago, but beyond some quaint diagrammatic panoramas of the islands his book gives little information.

Several writers since then have drawn attention to the peculiar inhabitants of the archipelago, the Selungs, but it is to Dr. John Anderson, late superintendent of the Calcutta Museum, that we are indebted

[1] A Voyage from Calcutta to the Mergui Archipelago, Th. Forrest. London, 1792.