Chapter 11 Tertiary volcanic vents, Centres 1 and 2, Ardnamurchan

Extensive volcanic vents, mainly filled with agglomerate, are met with in the eastern part of the Ardnamurchan igneous complex. They pierce Tertiary basalt lavas, Mesozoic sediments and Highland schists, but are traversed by cone-sheets belonging to Centres 1 and 2, and are therefore of comparatively early date. Though they are demonstrably later than only an inconsiderable thickness of basalt lavas with which they are actually in contact, there is little room for doubt that they belong to a later period than the widespread Plateau Group of the adjoining parts of Mull and Morven. In the first place, the vent-materials of volcanic origin differ markedly in composition from these basic lavas. The agglomerates are largely composed of fragments of trachyte and more acid rocks, together with blocks of big-felspar basalt, while pitchstone lavas are associated with the vents of the Ben Hiant district. Further, no intercalation of such materials is known from the lava-succession of Morven and Northern Mull. It is true that in the upper part of the Plateau Group in Central Mull intercalated flows of big-felspar basalt have been noted. But the long duration of the pre-cone-sheet vent period in Ardnamurchan, during which no typical plateau basalt is known to have been erupted, seems to indicate its distinctness from the period of the plateau lavas. On Ben Hiant, for example, two successive vents have been mapped in which agglomerates are interleaved with recurring beds of tuff, and also, in the case of the more southerly vent, with a few flows of pitchstone lava. The infilling of these two enormous cavities must therefore have extended over a considerable time.

The vents earlier than cone-sheets may be subdivided into two groups, the Ben Hiant Vents and the Northern Vents (*see* (Plate 2), p. 71). The Northern Vents terminate westwards against later plutonic intrusions — the Ring-dykes of Centre 3 — but originally they probably extended over much of the area now occupied by these ring-dykes, for agglomerates of like composition to those of the Northern Vents are preserved as screens and cappings within the plutonic complex, and are found even as far west as Aodann within the Ring-dyke Complex of Centre 2. In addition to these early vents there is a small linear vent at Glas Eilean south of Kilchoan, which is later than the Outer Cone-sheets of Centre 2, and is referred to this intrusion-centre.

The explosive character of acid magma has been well exemplified in the repeated volcanic outbreaks of Central Mull,<ref>E. B. Bailey in Tertiary Mull Memoir, 1924, pp. 202, 203.</ref> and is also manifested in all the Ardnamurchan vents. It may be noted that at a later period certain of the basic ring-dykes of Ardnamurchan were completely or partially brecciated and then granulitized or recemented by granophyre, and that the brecciation is to be attributed to explosive gases derived from the granophyre magma.

Vent-walls are clearly exposed in the case of the Ben Hiant Vents. On the other hand, country rocks bounding the agglomerates of the Northern Vents are often much brecciated, and the exact position of the vent-walls is in such places difficult to determine. Marginal brecciation is most in evidence at interior contacts of the vent-agglomerate with basalt lavas, and it is clear that the shattered basalt lavas are earlier than the agglomerates. It is likely that these interior masses of basalt lava have slipped down into the vents. Brecciated country rocks of all kinds also form a large proportion of the materials of the agglomerates. In the Ben Hiant agglomerates, on the other hand, fragments of country rocks are little in evidence, and basalt lava only has been noted.

It will be seen on (Plate 2), p. 71, that the outcrops of agglomerate infilling the Northern Vents are elongate and often arc-shaped. The outer, eastern, vent-wall curves in a clock-wise direction from the northern coast till terminated to the south by the Ring-dyke Complex of Centre 3. This wall extends over one third of the circumference of a circle, the centre of which lies about a mile within the eastern edge of the ring-dyke complex just mentioned. The circle, if completed, would include within it the isolated patches of agglomerate involved in the ring-dyke complexes to the west, and also the outcrops along the northern coast north of the ring-dykes. Cone-sheets and early major intrusions associated with, though later than, the Northern Vents also curve around in parallelism with the outer wall of these vents. There is, therefore, little doubt that an early centre (Centre 1), about which vents and intrusions are grouped, was situated in the eastern part of the Ardnamurchan Complex.

The Ben Hiant Vents lie to the south-east of the outer bounding wall of the Northern Vents, but there is reason for connecting both vent-complexes with the same igneous centre. Both belong to the same period in the igneous cycle, and in both the contained volcanic materials are similar. Further, the two Ben Hiant Vents lie along a north-east line as if referable to Centre 1.

Ben Hiant vents (earlier than cone-sheets)

Ben Hiant, the highest peak in western Ardnamurchan, has long been known to geologists from the writings of Prof. J. W. Judd and Sir Archibald Geikie. Judd's publications date from 1874 to 1890,<ref>J. W. Judd, The Secondary Rocks of Scotland. Second Paper. On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata, *Quart. Journ. Geol. Soc., vol. xxx.,* 1874, pp. 261–264; and The Propylites of the Western Isles of Scotland, *Quart. Journ. Geol. Soc., vol. xlvi.,* 1890, pp. 373–380.</ref> Geikie's results are given most fully in his 'Ancient Volcanoes of Great Britain'.<ref>Sir A. Geikie, The Ancient Volcanoes of Great Britain, vol. ii., 1897, pp. 278–280, and pp. 318–322.</ref> Striking features of this hill are its magnificent cliff-sections of agglomerate and a great central mass of dolerite (the Ben Hiant Intrusion). With regard to these two rock-bodies, Judd and Geikie arrived at divergent conclusions. Judd interpreted the central dolerite mass, in part at least, as a pile of lava-flows, and the agglomerates as underlying them and resting transgressively across the denuded edges of the plateau basalts and older stratified rocks. Geikie rightly contended that the dolerite was intrusive, and pointed out that the outcrops of agglomerate were in some cases clearly seen to lie within vent-walls. His conclusions are in the main confirmed by the recent detailed survey. No more than two large vents can, however, be determined, whereas Geikie has indicated in his illustrations a number of small vents. The outcrops of agglomerate which he investigated are separated from one another by the later, intrusive dolerite, and they probably all form part of one large vent, here termed the Southwest Vent. The second vent indicated by the recent mapping lies north-east of, and in contact with, the South-west Vent, and is called the North-east Vent.

With regard to the dolerite, although its scarp-featuring suggests that it is built up of sheets, as both Geikie and Judd concluded, a close examination fails to locate any sheet-junctions where these are to be expected. The featuring is here considered to be due to weathering along various planes of weakness (*see* pp. 160–1). Judd's misinterpretation of the dolerite as a pile of lavas appears to be mainly due to his having overstressed certain petrographical evidence. He had knowledge of a glassy rock (pitchstone) on Ben Hiant, which he has included with the dolerite on his map.<ref>J.W. Judd op. cit.1890, fig. 1, p. 374.</ref> As we now know, the pitchstone is associated with the agglomerates, not with the dolerite. It occurs in sheets, which are interpreted as lava-flows within the South-west Vent. Judd also considered the pitchstone to be lava, comparing it with the pitchstone lava of the Sgùrr of Eigg,<ref>J.W. Judd op. cit. p.376</ref> but thought that he recognized a significant petrographical resemblance between it and the dolerite, because the latter usually has a sub-vitreous (variolitic) ground-mass. Nevertheless, though the essentially intrusive nature of the Ben Hiant Dolerite must be maintained, there is evidence that the mass may have consolidated under little cover (*see* p. 168).

As already mentioned, the agglomerates of Ben Hiant are inter-stratified with beds of ash and the pitchstone lavas. In the Southwest Vent they are contained within high vent-walls. Further, fragments of country rock are, with the exception of one mass, only found in the agglomerates in the immediate vicinity of a vent-wall. It is therefore concluded that this vent possessed an open crater, the walls of which cannot have been less than 1100 ft. high, the greatest height above sea-level at which the bedded vent-materials are now on view.

Walls of North-east Vent

The north-eastern agglomerates, which for reasons stated below are concluded to lie within an older vent, have well-exposed contacts with vent-walls of basalt lava. The contacts are seen alongside two streams on the steep eastern face of Ben Hiant, overlooking the Kilchoan-Glenborrodale road, and are inclined downwards towards the interior of the vent at angles of 35 and 50 degrees respectively. In the more southerly stream it is of interest that a composite dyke cutting the lavas is truncated by the vent-margin (Figure 11), demonstrating that an intrusive episode intervened between the basalt lavas and the volcanic agglomerates concerned. The agglomerates form a cliff rising from the inclined crater-wall, and in them a parting of tuff similarly inclined is seen at one point. A parallel arrangement of the blocks in the agglomerates is also noticeable in places, which may be due to the slipping of such fragments down the interior slope of the volcano.

To the north, the agglomerates are bounded by basalt lavas that are exposed in a prominent cliff overlooking lower ground floored by the Moine Schists ((Figure 19), p. 160). The lavas are much brecciated, and it is a matter of opinion where to draw a boundary between this broken material and vent breccias and agglomerates. No extraneous volcanic material is found among the broken basalt of the cliff, and the actual edge of the vent is therefore concluded to lie to the south of the cliff, as shown on the Memoir-map. Such intense brecciation is an unusual feature of the walls of the Ben Hiant Vents.

Walls of South-west Vent

It will be seen in (Figure 10) that this vent is bounded to the south-east by older rocks, the junction with which extends from sea-level on the east side of Maclean's Nose for a mile to the north-east. In the vicinity of this headland it can be demonstrated that the junction is steep or vertical. On the shore immediately east of the headland agglomerates are in contact with Moine Schists, while a quarter of a mile to the northeast, at a height of about 500 ft., they abut against a vertical wall of horizontally bedded basalt lavas. In the intervening ground the agglomerates form high cliffs, which may be pictured as the east of the crater, of which the wall has been eroded away (Plate 3). North-eastwards from the vertical contact just mentioned the exposed edge of the vent keeps to one level without change in direction for a quarter of a mile. The various junctions seen are described in detail below.

East of Maclean's Nose, close to high-water mark, the agglomerates are in contact with reddish felspathic Moine Schists. Land-slipping has occurred in this vicinity, but there is evidence that the rock-mass showing this contact is undisturbed. It is traversed by a north-west dyke and by a north and south line of crush, both of which are in line with a corresponding dyke and line of crush in the adjoining cliffs of agglomerate. It seems unlikely that land-slipping could have taken place without altering the orientation of the dyke and crush-line. The vertical junction of agglomerate with the basalt lavas is seen at the top of grassy scree-covered slopes, in an angle of the cliffs where a projecting buttress of flatly bedded basalt lavas ends against still higher cliffs of agglomerate. The junction is sharp and clean-cut, and the reddish-brown spheroidally-weathering lavas bordering it are easily distinguished from the agglomerate in contact, which is fine-textured and greyish in colour. Farther north-east the edge of the vent is again exposed in two stream-sections. In the sides of a steep gully formed by the first stream, agglomerate and flatly bedded tuff abut against a steep wall of basalt lava. The actual junction, however, is disturbed, as though the vent-materials had slipped down at their contact with the vent-wall. In the second stream, beyond a fault against which the lavas terminate, a small mass of intrusive dolerite of Ben Hiant type is interposed between agglomerate and Moine Schists.

North-east of the last-mentioned stream the vent-margin bends somewhat abruptly, runs uphill to the north-west, and forms a north-eastern boundary to the South-west Vent. Along this margin a vertical junction of fine-grained agglomerate with basalt lava is exposed just south-west of where another stream has cut a channel in the lava-escarpment. It will be seen from (Figure 10) that this line, continued farther to the north-west, exactly separates two sheets of pitchstone lava belonging to the South-west Vent from agglomerates that occur to the north-east, and which are included with the North-east Vent. The agglomerates are evidently bedded, as shown by an interbedded tuff seen in the stream, and by their scarp-features that run at right angles to the line of junction with the pitchstone lavas. The conclusions are drawn that the agglomerates to the north-east are bedded in an older vent, that a later vent was formed to the south-west, and that the pitchstone lavas extruded within it terminated abruptly against a wall composed of the earlier bedded agglomerates. The stream above mentioned bends near its source across the junction of the earlier agglomerates and the upper of the two pitchstone lavas. Exposures of these rocks occur within a foot or two of one another, but their actual contact is not seen. The pitchstone is, however, unbrecciated, and is with little doubt later than the adjacent agglomerates. There is further evidence that the north-west line above described is not a line of fault. For, the inclined edge of the Ben Hiant Intrusion, that is later than all vent-materials but is traversed by many north-west crush-lines, crosses the line concerned at a right angle a short way uphill from the pitchstone lavas, and is neither shifted nor crushed at this particular point.

Since the Ben Hiant Intrusion separates the outcrops of vent-agglomerate on the north side of the hill, both from each other, and from the large outcrop to the south-west the walls of which have just been described, it cannot be definitely decided whether all these agglomerates lie within one vent or in several. The disposition of the outcrops would seem to suggest that they all belong to one vent (*see* Memoir-map).

No actual contact is seen between agglomerate and wall on the north side. In the steep banks of a stream south-east of Beinn na h'Urchrach, agglomerate outcrops a few yards from a bounding wall of Lower Lias limestone, and marmorization of the limestone was noted by Sir A. Geikie.<ref>Sir A. Geikie, The Ancient Volcanoes of Great Britain, vol. ii., 1897. p. 280, footnote.</ref>

Materials infilling the Ben Hiant Vents

Agglomerates

The agglomerates consist of angular fragments varying from a foot or more in length down to small particles, together with bombs of large size. These constituents seldom show any signs of bedding, though their stratified nature is evident since the agglomerates are interleaved with beds of tuff. Angular blocks of trachyte are perhaps most plentiful, but others of rhyolite and dacite are also usually present. All these rock-types may be found at any level in the 1000 ft. of agglomerate exposed in the South-west Vent, though it is often noticeable that at any particular place one type greatly preponderates over the others.

Vesicular structure is especially well developed in the darker, trachytic types. The vesicles do not show any concentric arrangement, and whether the fragments are shattered portions of bombs, or of lava-flows within the crater, is not certain. The vesicles are unfilled by amygdale-minerals, and the fragments would appear to have been broken off from their parent masses soon after solidification and before such minerals of late formation had time to crystallize. In contrast to the relatively small fragments of the more acid rocks, there are large sub-rounded blocks of big-felspar basalt (Figure 12). These are especially numerous in the South-west Vent, but have also been found in the uppermost layer of the earlier North-east Vent. The blocks are usually 6 ft. and upwards in length, and are interspersed amongst the more acid materials in the agglomerates. They do not bear vesicles, but have all the appearance of being true bombs. Two blocks of exceptionally large size, 50 to 80 yds. long, occur near the top of the western, seaward slope of Ben Hiant (*see* (Figure 10) and (Plate 1), B). At their edges they are brecciated and veined by tuff, an observation made by Mr. Bailey. Perhaps these two immense masses are portions of a lava-flow within the vent, which became separated by subsequent explosions, though it is possible that they may be bombs.

Fragments of country rocks are absent or at any rate very rare in the Ben Hiant vents, except in the immediate vicinity of a vent-wall. For example, fragments of amygdaloidal basalt lava are abundant in the North-east Vent on its eastern side next to the inclined wall formed of these lavas. Again, at Maclean's Nose, amygdaloidal basalt fragments are restricted to the proximity of the vent-wall, here composed of Moine Schists. Since the basalt lavas occur in place at a height of some hundreds of feet above the latter locality, these fragments must have fallen down thus far at least into the vent. Blocks of schist have nowhere been noted, though angular quartz, which is plentiful in some of the tuff-beds, may have been derived from the comminution of schists by explosion (p. 136).

An exception to the above rule is an elongate mass of brecciated olivine-basalt (S2107) [NM 522 336], which lies far within the South-west Vent (Figure 10). Possibly it may be a remnant of a wall isolated by the subsequent enlargement of the vent, as in the case of the Kilchrist Vent of Skye.<ref>A. Harker, The Tertiary Igneous Rocks of Skye, Mem. Geol. Surv., 1904, p. 17.</ref> The Ben Hiant Vents, however, differ from the Kilchrist Vent in the interbedding of tuff and pitchstone lavas with their agglomerates. Their orifices must consequently have been cleared of broken country rock by explosion, and open craters formed in which the vent-materials were laid down. Our information, however, is incomplete, in so far as no crater-floor is seen at the present level of denudation.

Bedded tuff

The various larger fragments in the agglomerates are, as a rule, bound together by others of smaller dimensions. Sometimes they are set in a matrix of fine ash or tuff. The deposition of the tuff often continued after the showers of larger fragments had ceased, so forming a distinct bed of tuff. Sometimes the upper surface of such a bed is well defined, with agglomerate abruptly overlying it (Plate 3), B. In other cases, the tuff grades upwards to form the matrix of the succeeding agglomerate.

Tuff-beds are well seen along the cliffs south-east of Maclean's Nose, where certain of them are indicated on (Figure 10) by bedding-signs. They are either horizontal or else very gently inclined towards the interior of the vent. They are usually only a foot or two in thickness, but range up to 5 ft. or more in some cases. Along the lower part of the cliffs above the talus slopes they were judged to recur at intervals of about 20 feet in the agglomerates. Owing to the steepness of the cliffs individual beds could not be traced very far, but one bed was observed to continue for about 100 yds.

The tuffs are often excessively fine grained. Microscopic examination shows that finely divided angular quartz is an ingredient (S22293) [NM 5400 6230] and (S22446) [NM 5368 6194], in all likelihood derived from the comminution of schists (*see* p. 136).

Pitchstone lavas

Three separate outcrops of pitchstone occur within the South-west Vent, south-east of the Ben Hiant Intrusion (*see* (Figure 10)). Each consists of one or two sheets that are gently inclined inwards towards the interior of the vent. As already stated, the sheets are concluded to be lava-flows within the crater. The lowest outcrop consists of a single flow that is seen at one point to be interbedded with the tuffs and agglomerates of the vents. In the next outcrop only the lower portion of one flow is now on view, and there is evidence that it is earlier than an intrusion of Porphyritic Dolerite in the vent. The third outcrop may be later than the Porphyritic Dolerite, and includes two flows, of which the upper is at one place succeeded uphill by agglomerate. This agglomerate is the highest vent-material now seen in the South-west Vent, the centre of which is occupied by the great Ben Hiant Intrusion (*see* (Figure 19), p. 160).

On account of their internal structure the pitchstone sheets have been concluded to be lava-flows. The evidence is best seen in the lowest outcrop east of Stallachan Dubha, which is crossed by a stream-gully affording a practically complete cross-section. The sheet consists structurally of lower, middle, and upper portions, of which the lower and middle portions display perfect columnar jointing. In the lower portion the hexagonal columns are arranged at right angles to the lower surface of the sheet, which rests upon slightly hardened tuff. In the middle portion the columns change abruptly in their direction and are arranged more or less parallel to the base of the sheet. These are of much smaller diameter than the upright columns below. Towards the top of the middle portion, small, oval-shaped amygdales are found which are lined with bluish chalcedony and centred with drusy quartz. In one place there are giant amygdales a foot in length, in which calcite is developed within the drusy quartz and chalcedony. At a higher level still, the pitchstone is unjointed and amygdales occur in increasing numbers till finally, towards the top of the sheet, they become very small and irregular in form, so that the rock may be termed a pitchstone-slag. The actual top is unfortunately not seen, for a gap of a foot or so separates exposures of the pitchstone-slag, above the left bank of the stream, from overlying agglomerate and spheroidally-weathering tuff. The three-fold structural sub-division of the sheet, however, seems sufficient evidence that we are dealing with a lava-flow and not an intrusion. The asymmetry negatives an intrusive origin, while the three-tier structural arrangement recalls that of the columnar basalt lava of Staffa.<ref>G. A. Burnett *in* The Geology of Staffa, Iona, and Western Mull, *Mem. Geol. Surv.,* 1925, p. 65.</ref>This structural arrangement cannot be in the nature of an accident, for it is seen to be repeated in the upper of the two pitchstone sheets of the uppermost outcrop. In this case, lower and middle tiers of columnar pitchstone, exactly similar to those just described, are capped by amygdaloidal unjointed pitchstone, as is well seen at one point on the south-west side of the outcrop just east of a stream (Figure 10). Inadequate exposure prevents us from determining whether the sheets develop the three-tier structural arrangement elsewhere. Other outcrops show either the lower tier with upright columns or else the unjointed amygdaloidal portion.

The columnar portions of the pitchstone sheets are often intruded by thin sills of stony pitchstone (S21459) [NM 5431 6255]. The sills are evidently due to the intrusion into fissures in consolidated pitch-stone of portions still liquid. According to Bailey such auto-intrusion is developed in still more striking fashion in the case of the pitchstone lava of the Sgùrr of Eigg.<ref>For a statement of the evidence for considering the Sgùrr of Eigg pitchstone to be a lava-flow, *see* E. B. Bailey, The Sgùrr of Eigg, *Geol. Mag.,* N.S., Dec. vi., vol. 1., 1914, pp. 296–305.</ref>

Unlike the intrusive sheets of sheath-and-core pitchstone in Mull,<ref>E. M. Anderson and E. G. Radley, The Pitchstones of Mull and their Genesis, *Quart. Journ. Geol. Soc., vol. lxxi.,* 1915, pp. 205–217.</ref> stoniness has not been developed along the joint-planes of the pitchstone lavas of Ben Hiant. This seems all the more remarkable, since the two rocks are practically identical in chemical composition (*see* p. 84). The reason for this difference we do not know. Stoniness, however, is developed as a secondary character in the Ben Hiant pitchstones where they come into contact with intrusive masses. For example the uppermost pitchstone becomes stony next to the great Ben Hiant Intrusion, a quarter of a mile south of the summit (S21466) [NM 5382 6296]. Stoniness in the lowest pitchstone, alongside the stream and near to the overlying intrusive mass of Stallachan Dubha, may also be ascribed to contact-action. It is again met with in the middle outcrop of pitchstone (S21462) [NM 5382 6242], north of Stallachan Dubha, immediately next to the intrusion of Porphyritic Dolerite, and elsewhere this pitchstone is a normal black vitreous rock. The actual contact of the two rocks is not seen, but the development of the stoniness suggests that the Porphyritic Dolerite is later than the pitchstone. Conversely, in the case of an amygdaloidal extension of the upper outcrop of pitchstone above the Porphyritic Dolerite, the retention of its vitreous character in close proximity to the Porphyritic Dolerite may perhaps be regarded as evidence that the pitchstone is here the later of the two rocks. J.E.R.

Northern vents (earlier than cone-sheets)

An irregular outcrop of vent-agglomerate and tuff occupies about half the countryside between Ben Hiant and the north coast at Faskadale.<ref>The Faskadale exposures and their abundant content of acid fragments have been described: Sir A. Geikie, Ancient Volcanoes of Great Britain, vol. ii., 1897, p. 278.</ref> As already mentioned, it has a roughly arcuate form, as if grouped about Centre 1 of (Plate 2). Along its outer convex boundary the agglomerate comes against pre-Tertiary rocks, and its margin, so far as one can judge from imperfect exposures, is tolerably abrupt. Its inner concave border, on the other hand, lies against Tertiary basalt lavas and is extremely indefinite. The lavas have been greatly shattered by the vent-explosions, and there is no exact line of separation between them and the adjacent agglomerate. Moreover, as already stated, it is quite possible that the lavas have bodily slipped down into their present situation. Perhaps the amount of their descent into the vent was considerable, for in the Camphouse district only a narrow belt of agglomerate separates porphyritic basalt lavas from schists, without any intervening Mesozoic sediments. In their porphyritic character these lavas, indeed, recall the upper lavas of Mull rather than those of the lower or plateau group.

The agglomerate of this northern series of vents, besides containing abundant debris of basalt lavas, is rich in fragments of Mesozoic sediments and of gneiss or schist. It also includes numerous small blocks of acid rocks that are often porphyritic. These acid fragments cannot be attributed to the breaking up of any exposed country rock, and their presence suggests that the vent-explosions were connected with acid magma. E.B.B., J.E.R.

The following localities may be given for masses of Mesozoic sediments of unusual dimensions:

1. At a point 400 yds. north-east of the mouth of the Achateny Water there is a block of false-bedded calcareous sandstone with obscure fossils, which measures 100 ft. in both directions. The bedding is nearly vertical. Similar sandstone is not known in the part of the Mesozoic sequence that remains intact east of the vent, but it is fairly abundantly represented by smaller blocks (up to 15 by 20 ft.) in the neighbouring agglomerate. The sandstone may be of Inferior Oolite age.
2. A strip of brecciated black shale occupies the foreshore 500 yds. south-east of Ardtoe Island, north of Kilmory. Again, rock of this type is unknown to the east outside the vent. (There is some uncertainty as to whether the fossils listed on pp. 40–41 came from this mass or from another farther east).
3. There is a good exposure of sandstone in a stream close to Kilmory school, and several others of sandstone and black shale within 500 yds. of this locality, especially towards the north-west and south-east. Individually these exposures give an impression of Mesozoic outcrops *in situ,* but thorough examination of the evidence leaves no doubt that the sediments occur as masses involved in vent-agglomerate.
4. The Loch Mudle Fault, 1000 yds. east-north-east of Braehouse, runs along a little stream, and is drawn on the map as separating basalt lava on the east from vent-agglomerate on the west. An exposure shows 30 ft. of Lower Lias limestone dipping steeply away from a substantial outcrop of gneiss and towards the lavas. Both the limestone and

the gneiss are probably enveloped in agglomerate, which, close at hand, contains small blocks of like materials.

There are only three exposed contacts of the northern vent-agglomerate with its outer wall. Where the edge of the vent reaches the coast, half a mile north-east of Kilmory, agglomerate is in contact with Lower Lias limestone (Broadford Beds) and the limestone is brecciated. A quarter of a mile inland a little roadside quarry shows agglomerate in contact with Lower Lias shales (Pabba Beds). The agglomerate overlies the shales, transgresses their bedding at a low angle, and is largely composed of their debris. Seven hundred yards farther south-east, Lower Lias limestone is seen with a vertical junction against agglomerate, and the agglomerate contains fragments of the limestone. The absence of extensive brecciation of the outer wall is very marked in all three localities. E.B.B.

As evidence of recurrent explosions within the complicated Northern Vent or Vent-complex, one may cite certain tuff-filled fissures traversing tuff and agglomerate. A good example occurs in the left bank of the Allt na Mi-Chomhdhail, 550 yds. upstream from the main road, and 1300 yds. due north of Camphouse. Another tuff vein, traversing basalt lava, is exposed in the floor of a roadside quarry 960 yds. south of Braehouse, and can be traced for 25 yds.

The vent-agglomerates, though later than the basalt lavas, seem to be earlier than all the intrusions with which they are visibly associated. They are cut by early major intrusions, cone-sheets, ring-dykes, and dykes. Exposures west of Faskadale Bay afford admirable illustrations of this relationship (*see* (Figure 16)). In the most westerly outcrops, south of Rudha Groulin and Rudha Carrach, which are chiefly of tuffs, contact alteration due to the adjoining ring-dykes is very pronounced.

On the other hand, the agglomerates are later than some quartz-dolerite and leidleite intrusions (*see* p. 137). For example, they contain blocks of quartz-dolerite with acid veinings on the west shore of Faskadale Bay. Such inclusions afford an interesting demonstration of the occurrence of intrusions earlier than any seen *in situ* at the present level of denudation.

Glas Eilean Vent (later than Outer Cone-Sheets of Centre 2)

A narrow strip of volcanic breccias has been mapped for two thirds of a mile north-eastwards from the south-east extremity of Kilchoan Bay. The breccias are best exposed on the promontory of Glas Eilean, which is separated from the mainland as an island at high tide, and along the shore to the north-east (Figure 13). They mark the course of a linear vent that extends parallel to the trend of adjacent cone-sheets belonging to the Outer Set of Centre 2. Along the shore-section the vent is bounded by Tertiary basalt lavas to the north-west, and by Moine Schists to the south-east, both of which formations are cut by numerous cone-sheets. On the east side of Glas Eilean the cone-sheets cutting the Moine Schists constitute a veritable plexus of intrusions and are represented diagrammatically on (Figure 13).

A post-vent fault forms the north-west boundary of the vent on Glas Eilean, and is presumably responsible for the down-thrown lavas on this side. The fault-plane between vent-agglomerate and brecciated basalt lava belonging to the vent-wall is here vertical. The lavas are seen to dip steeply away from the fault, as indicated on (Figure 13). The fault then crosses the vent obliquely, interrupting the outcrop of agglomerate and breccia for a space, and then extends along the seaward side of the vent. There, the fault-plane, hading west, is again well seen, where a cone-sheet cutting the Moine Schists on the shore has been traced up to the dislocation. The sheet is deflected from its normal course close to the fault, and a fractured portion of it is seen as though extending along the fault-plane. Since it does not present a chilled margin against the fault-plane, as it does against the Moine Schists, the fault is concluded to be of later date.

In contrast to the well-defined junctions between country rocks and vent-materials where in faulted contact, no exact line of division exists elsewhere. It is a matter of opinion where to draw a line between brecciated country rocks belonging to the vent-wall and similar materials that form the greater part of the contents of the vent. There can, however, be no doubt that the brecciated country rocks mapped as lying within the vent have suffered vertical displacements from their original positions, for the vent-materials are heterogeneous, and fragments of different rocks are found side by side. For example, on Glas Eilean they consist partly of Jurassic limestone and sandstone not seen *in situ* in the vicinity, partly of the basalt lavas and schists that form the vent-walls. In addition, fragments of cone-sheets are abundant, and others of porphyritic basalt and of an acid compact rock are occasionally to be found. An interesting feature on Glas Eilean is the occurrence of large brecciated masses of Jurassic limestone traversed by cone-sheets. So little relative movement of the brecciated fragments composing each mass has taken place that the original relationship of the plexus of cone-sheets cutting the limestone can be easily made out. Coherent masses would seem to have been separated from the vent-wall in the first instance, and to have been brecciated by subsequent explosions while lying within the vent itself.

The explosions responsible for the brecciation are to be ascribed to an acid magma, of which the included acid fragments are a sign. Also, at one point, on the east side of Glas Eilean, a light yellow compact material, found under the microscope to be an acid tuff (p. 140), infills all the cracks and crevices of the breccias. To the unaided eye the veinings appear exactly similar to the net-veining characteristic of the margins of many ring-dykes in Ardnamurchan (see (Figure 34)). An intrusion of the acid magma that formed the tuff is probably represented by an irregularly running dyke of fluxion felsite or rhyolite that cuts the breccias and fine agglomerates of the vent near the head of the little bay north-east of Glas Eilean.

From what has been said above, coupled with the fact that not a single cone-sheet cuts the breccias, it is certain that the vent is later than the Outer Cone-sheets of Centre 2, or, at any rate, that portion of the belt of cone-sheets where the vent is situated. The parallelism between vent and adjacent cone-sheets seems to mark the vent as connected with Centre 2. It needs no great assumption to conclude that such a linear vent may be the superficial expression of a linear intrusion, below ground, guided by a ring-fissure, as already remarked in an introductory chapter (p. 77). J.E.R.

Petrology

Agglomerates, Ben Hiant Vents

One of the most striking features of the agglomerates that occur around Ben Hiant is the generally acid nature of the component fragments. Although a variety of tock-types enter into the composition of the agglomerates, it is patent that trachytes, rhyolites, and dacites constitute the bulk of the material, and point to the former existence of acid extrusive and intrusive rocks of which practically all other records are wanting.

The most prevalent rock-type met with is a bostonitic trachyte (S22822) [NM 5421 6320], (S22824) [NM 5421 6320], (S22291) [NM 5424 6323]. Generally it is a microporphyritic rock of which the phenocrysts are alkali-felspar and aluminous augite, while the matrix is most usually a fine-textured mass of small prisms of alkali-felspar, with scattered magnetite, minute scales of biotite and occasional large apatites.

The felspar phenocrysts in the microporphyritic types reach a quarter of an inch in length (S22822) [NM 5421 6320], usually show a mottled structure, and are referable to perthite or anorthoclase. Their outline is somewhat irregular and they may occasionally show a nucleus of soda-plagioclase. Albite may also occur as individuals (S22824) [NM 5421 6320].

The augite is subordinate to felspar both as regards the number and size of the phenocrysts. It builds small idiomorphic or rounded crystals of a greenish colour, and although prone to serpentinous decomposition is apparently an aluminous variety with a moderately large axial angle. We must not, however, dismiss the possibility of the former presence, in some instances, of a uniaxial augite of enstatite composition (S22291) [NM 5424 6323], similar to that encountered in the Inninmore pitchstones of Mull and in the Ben Hiant pitchstones hereafter described.

The ground-mass consists commonly of a plexus of narrow short microliths of alkali-felspar, most frequently arranged in a fluxional manner, abundant grains of finely divided magnetite, and small limonitic and chloritic patches that appear to represent original biotite. In some instances seemingly original biotite in a fresh condition can be detected in the ground-mass (S22822) [NM 5421 6320], but it is not always easy to distinguish between primary biotite and that developed as a result of a low grade thermal alteration which has affected much of the material in the Ben Hiant vents. A little quartz is usually present. It may occur as isolated patches within the porphyritic felspars, where it is probably of secondary origin, or scattered throughout the matrix in a manner that suggests an original constituent (S22443) [NM 5605 6241].

That some of these trachytic rocks were in part glassy and possibly intrusive types, is suggested in some examples (S22825) [NM 5421 6320] by areas that exhibit a pronouncedly acicular type of crystallization. In such cases the felspars of the matrix are slender and skeletal and have glass interiors. Augite exists as minute needles and magnetite in the form of rods. Structurally, rocks of this nature approach more nearly to pitchstones than to trachytes, but the phenocrysts are of alkali-felspar and augite, and are identical with those which occur in the more truly trachytic rocks described above. Thus, their affinity to the trachytes is established.

A porphyritic structure in the trachytes is not by any means universal, and several instances can be cited of rocks of trachytic aspect which are devoid of porphyritic constituents. In such cases the rock consists of a felted or fluxionally arranged mass of alkali-felspar prisms, with uniformly distributed minute crystals of magnetite, and small ragged flakes of biotite (S22292) [NM 5424 6323].

Certain non-porphyritic microlithic rocks of a somewhat more basic composition are also represented (S22445) [NM 5280 6207]. These appear to have responded more readily than others to thermal conditions that existed in the vents, and which affected in varying measure most of the vent-material. They have a finely trachytic structure, produced by the disposition of microliths of alkali-felspar, but they are certainly richer in ferromagnesian constituents and poorer in silica than are the trachytes described above. In their altered condition, recrystallization of the base has frequently produced a definite minutely granular structure; and, under high magnifications, they show abundant scattered granules of recrystallized augite and magnetite, with some secondary biotite (S22448) [NM 5415 6324], (S22449) [NM 5224 6412].

From the agglomerate of Maclean's Nose comes a most beautiful fluxion rhyolite (S21446) [NM 5328 6183] (Figure 14), A. It contains abundant sharply crystallized phenocrysts of orthoclase, one to two millimetres in length, in a devitrified felsitic base that shows remarkable flow-banding, and an approach here and there to a sub-spherulitic structure. That the rock is a portion of a lava-flow associated with agglomeratic material is indicated by the fact that it has in its eruptive course gathered to itself a number of fragments of a variety of rocks. Amongst these xenolithic fragments plateau basalts preponderate, but there are also broken crystals of a greenish augite similar to the porphyritic augite of the trachytes.

In addition, a rock of dacitic composition (S22823) [NM 5421 6320] is met with.

It contains small isolated and grouped phenocrysts of andesine, numerous small decomposed crystals of augite, and grains of magnetite, in a quartzo-felspathic matrix of variable texture.

The above account is descriptive of those rocks which occur in the agglomerates of Ben Hiant, and which cannot be matched in solid form in the accessible portions of the vent-walls. In petrological types they are most closely paralleled by the trachytic and rhyolitic rocks associated with agglomerates, and described by Dr. Harker, from Fionn Choire in Skye.<ref>A. Harker, The Tertiary Igneous Rocks of Skye, Mem. Geol. Surv., 1904, pp. 58, 59.</ref> Plateau basalts, some with porphyritic olivine (S21447) [NM 5318 6232], and others non-porphyritic(S22444), are prevalent constituents of the vent-agglomerates near the walls, and numerous large blocks of a big-felspar basalt (S22447) [NM 5370 6202], some much shattered, are also encountered. This big-felspar rock is similar to certain porphyritic basalts that occur as north-west dykes (p. 347). It is dark grey and fine textured, and is closely packed with white or honey-yellow crystals of fresh felspar which range up to an inch or more in greatest dimension. Although the rock in the hand-specimen looks perfectly normal and unaltered, microscopic examination (S26138) [NM 5343 6157], (S22295) [NM 5368 6233] shows that in every instance it has been intensely shattered, but that the fractures and comminution have, in a large measure, been effaced by the healing process of metamorphism. The porphyritic felspars are of a medium labradorite, much twinned, occasionally albitized, and usually fringed with oligoclase. Augite is represented by moderately large pale-brownish crystals, and was evidently an original porphyritic constituent. Olivine was not an abundant mineral, but its presence is proved by the occurrence of small dark-green serpentinous pseudomorphs. Magnetite is plentiful, but is more or less restricted to the matrix. The matrix in which these larger porphyritic elements are embedded is an obviously disrupted mass of felspar, augite, and iron-ore, which has to a great extent suffered recrystallization as the result of thermal alteration. In it, small fragments of felspar have recrystallized, larger fragments have grown less basic fringes, augite has formed as small granules and prisms, magnetite has recrystallized, and a certain amount of biotite has been developed. These re-formed and regrown minerals are embedded in an ultimate residuum of oligoclase that acts as a base and is rich in apatite.

Although all the basalt masses show equally the effects of shattering, some evince more intense thermal alteration than others. In the case of certain xenolithic masses in the Ben Hiant Intrusion (S22452) [NM 5255 6236] the albitization of the felspars is more pronounced, and a greater amount of biotite has developed in the broken-down matrix at the expense of original iron-ore.

It is probable that the shattering was accomplished in the vent soon after the rock had consolidated, and that the metamorphism of the blocks was produced by the inherent heat of the crater, prior to their incorporation in the agglomerates. It is impossible to attribute the metamorphism of these masses to the thermal influence of any known intrusions, and further, they show a higher grade of metamorphism than that of the tuffs and other rocks with which they are now associated.

Bedded Tuff, Ben Hiant Vents

The tuffs (S22293) [NM 5400 6230], (S22446) [NM 5368 6194] are often excessively fine-grained. Microscopic examinations show that they are typically clastic rocks, although igneous material bulks largely in their composition. They contain abundant small grains of quartz and minute flakes of white mica which are probably derived from the adjacent schists, but the greater part of their fine material,' as is shown by broken crystals of plagioclase and augite, has had its origin in plateau basalts. Such large fragments as are encountered are also mainly of basaltic composition.

Agglomerates, Northern Vents

The great mass of agglomerates which stretches southwards from the coast near Achateny towards Camphouse has been made the subject of close study. It is more than usually rich in fragments of the various country rocks that bound the vents, but a representative collection of other types shows a general assemblage similar to that met with in the Ben Hiant Vents to the south. As at Ben Hiant, porphyritic bostonitic trachytes are extremely abundant (S23598) [NM 520 706], (S23601) [NM 520 706], (S23605) [NM 520 706]. They carry the usual phenocrysts of anorthoclase and albite, and aluminous augite which in some instances may be described as being abundant (S23603) [NM 520 706]. Soda- and potash-felspars frequently occur together, but occasionally either orthoclase (S23605) [NM 520 706] or anorthoclase (S23602) [NM 520 706] form the only felspar phenocrysts. The ground-mass, though usually microlithic, shows some variation in texture, and biotite is certainly not a noteworthy constituent. The petrographical characters of all these trachytes, however, and of those of the Ben Hiant Vents are so similar that there can be no doubt of their close relationship and probable contemporaneity.

Spherulitic quartz-rhyolites are also represented amongst the more acid fragments (S23599) [NM 520 706], (S23600) [NM 520 706] ((Figure 14), B). These are probably related to the fluxion rhyolite described from the South-west Vent of Ben Hiant (S21446) [NM 5328 6183], but on the whole are more quartzose. One specimen (S23599) [NM 520 706], collected from the east of the Achateny Water, contains abundant rounded phenocrysts of quartz surrounded by beautiful spherulitic growths, while similar growths without quartz-nuclei occur in the matrix. Another rock (S23600) [NM 520 706] from the same district is similar as to the matrix, but does not carry the porphyritic quartz.

Amongst other fragments collected on the shore near Achateny farm, it is interesting to note definitely intrusive types such as quartz-dolerites, leidleites, and pitchstones. The quartz-dolerites are represented by rocks of moderately coarse type that resemble either the coarser varieties of basic cone-sheets (Talaidh type (S23609) [NM 520 706], or the more vitreous quartz-dolerite of the main Ben Hiant intrusion (S23608) [NM 520 706]. Of rocks of augite-andesite composition, one (S23606) [NM 520 706] may be described as a somewhat basic leidleite with the characteristic acicular type of crystallization.<ref>H. H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924, pp. 281, 282.</ref> It consists of irregularly grouped and distributed laths and skeletal growths of acid labradorite, elongated crystals of a brownish augite, and abundant finely divided magnetite, in a chloritic base that represents an original glassy residuum.

Another type (S23607) [NM 520 706] is much more glassy. It shows numerous small phenocrysts of aluminous augite with moderate axial angle, and a few small albitized felspars, in a ground-mass composed of slender felted microliths of oligoclase, and a deep-brown residual glass. The rock is vesicular, the cavities being filled mainly with a deep-yellow iron epidote.

The origin of these intrusive types is obscure, but although of earlier date, they are certainly related petrographically to the Ben Hiant intrusions.

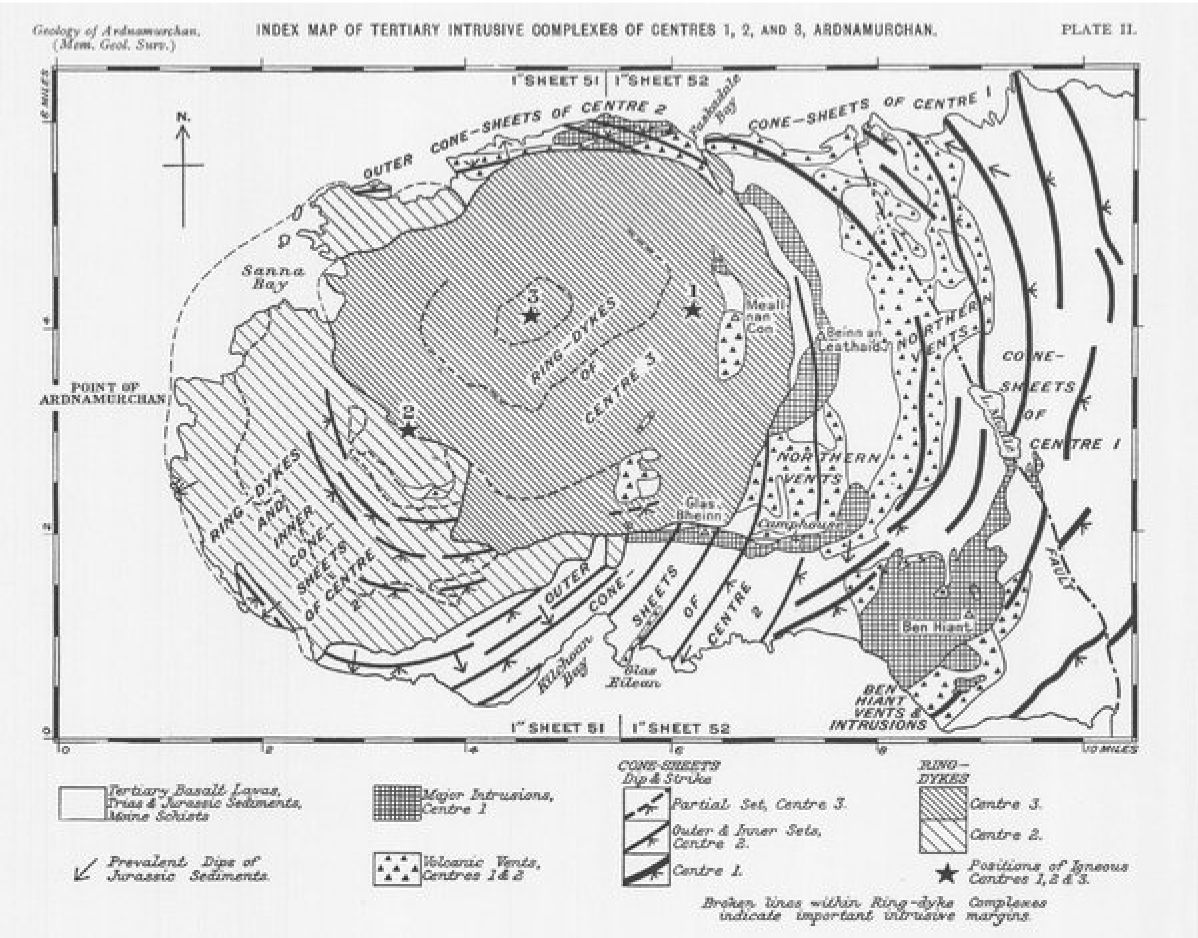
Pitchstones of Ben Hiant

(Anal. I and II, (Table 3), p. 84). — The pitchstones of Ben Hiant, as represented by the analysed and other specimens (S21255) [NM 540 622], (S21458) [NM 5426 6272], (21462), are dark-brown to black vitreous microporphyritic rocks through which small felspar phenocrysts are abundantly distributed. Their variation in colour is largely due, not to any inherent difference in composition, but to the extent to which devitrification of the glassy base has proceeded. Microscopically, the rocks are seen to contain phenocrysts of plagioclase and pyroxene in a pale-brown glass that is replete with microliths of felspar and augite, and contains in addition a little magnetite and apatite. The felspar of the phenocrysts occurs as well-crystallized individuals about one to two millimetres in greatest dimension. The crystals are usually twinned according to the Carlsbad law, but albite and pericline lamellation are frequently observed. Their boundaries are quite sharp against the glassy base, but the crystals are sometimes spongy and enclose patches and strings of glass. Most of the crystals show zoning that produces a gradual progressive extinction from the centre towards the margin. Their optical sign is uniformly negative and they appear to range from an exterior of basic labradorite to an interior that approximates to anorthite in composition. The only other microporphyritic mineral is a pyroxene, most commonly a pale-green augite, that occurs in moderate abundance as well-shaped prisms, usually of smaller dimensions than those of felspar. The crystals are elongated parallel to the *c* axis and show the usual simple terminations of augite. They are slightly pleochroic in shades of greenish-yellow. Optically, this mineral has a fairly wide extinction, but its almost uniaxial character proclaims it a member of the enstatite-augite group, that is to say, a non-aluminous variety having the composition of enstatite and accompanied by a special set of optical properties. As found by Mr. Hallimond for the uniaxial augite of certain Mull pitchstones, it has an optically positive sign in common with the generality of augites. It is somewhat prone to alteration and passes into green serpentine (S21461) [NM 5422 6254]. A rhombic pyroxene that builds crystals of similar dimensions to those of the augite is sometimes present and is indistinguishable from the latter except by its straight extinction, biaxial character, and somewhat different pleochroism (S21458) [NM 5426 6272].

The microliths of the ground-mass, scattered indiscriminately throughout the brown glass, are oligoclase and a greenish, presumably aluminous, augite. There is generally no arrangement of the crystallites indicative of flow, but perlitic cracks are a noticeable feature of the glassy base (S22294) [NM 5402 6225]. On devitrification the glass breaks up into small areas of acid plagioclase with some quartz, and it appears that this devitrification frequently commences around the porphyritic crystals (S21460) [NM 5391 6280] or along perlitic cracks where such happen to be well developed (S22294) [NM 5402 6225]. Devitrification of the glassy base is exceptionally well marked when these rocks have come within the influence of some later intrusion, such as the Ben Hiant Porphyritic Dolerite (S21462) [NM 5382 6242] or the great Ben Hiant Intrusion (S21466) [NM 5382 6296]. In the latter case there has been a more pronounced metamorphism with recrystallization and the production of finely divided biotite. The mineralogical characters and chemical composition of these rocks are practically identical with the inninmorite-pitchstones of Mull,<ref>H. H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924, pp. 282–284.</ref> which showed an augite-andesite composition (Anal. A, (Table 3), p. 84) and were characterized by the presence of phenocrysts of basic plagioclase and enstatite-augite. Although the Mull occurrences were in the form of sills and the Ben Hiant pitchstones are undoubtedly lavas, there is no reason for not classing the latter with the inninmorites. Structurally these rocks are very similar to the well-known pitchstone of the Sgùrr of Eigg,<ref>A. Harker, The Geology of the Small Isles of Inverness-shire, *Mem. Geol. Surv.*, 1908, pp. 170–176.</ref>but chemically they belong to a less siliceous and more definitely andesitic type. This difference reveals itself mineralogically in the more basic character of the felspar phenocrysts, and chemically in an increase of the percentage of lime and soda at the expense of potash.

Glas Eilean Vent

In the vent-breccia of Glas Eilean the fragments collected are chiefly of plateau basalts (S24018) [NM 6277 6277] with others of more acid nature. One of the latter is an intrusive type that may be referred to as an albite-granophyre (S24017) [NM 4840 6277]. It consists of moderately large microporphyritic crystals of albite or albiteoligoclase, with pseudomorphs after augite, in a matrix composed of small crystals of albite and potash-felspar set in a granophyric base. The matrix of the agglomerate (S24016) [NM 4843 6279], (S24019) [NM 4843 6279] is especially interesting on account of its showing unmistakable signs of the explosive action of an acid magma. It is composed almost entirely of siliceous scoriaceous fragments and whisps of acid glass which show plainly the characteristic lunar and curvilinear form of glass fragments due to explosion. In the hand-specimen the dark basalt fragments strongly contrast with the lighter-coloured siliceous tuff that acts as their matrix. Strings of tuff (S22237) [NM 483 635] occur, some few yards away from the true agglomerate, in the shattered plateau-basalt walls of the vent. As in the case of the matrix of the agglomerate the tuff is of a highly comminuted scoriaceous nature. It consists of a roughly laminated mass of minute chips of devitrified glass, some of the fragments showing well-defined fluxion structure, others being of the nature of disrupted pumice. The basalt lava against the tuff is of the ophimottled plateau type, and enters largely into the composition of the immediately adjoining fragmental material. H.H.T.



(Plate 2) Index map of Teriary intrusive complexes of Centre 1, 2, and 3 Ardnamurchan.

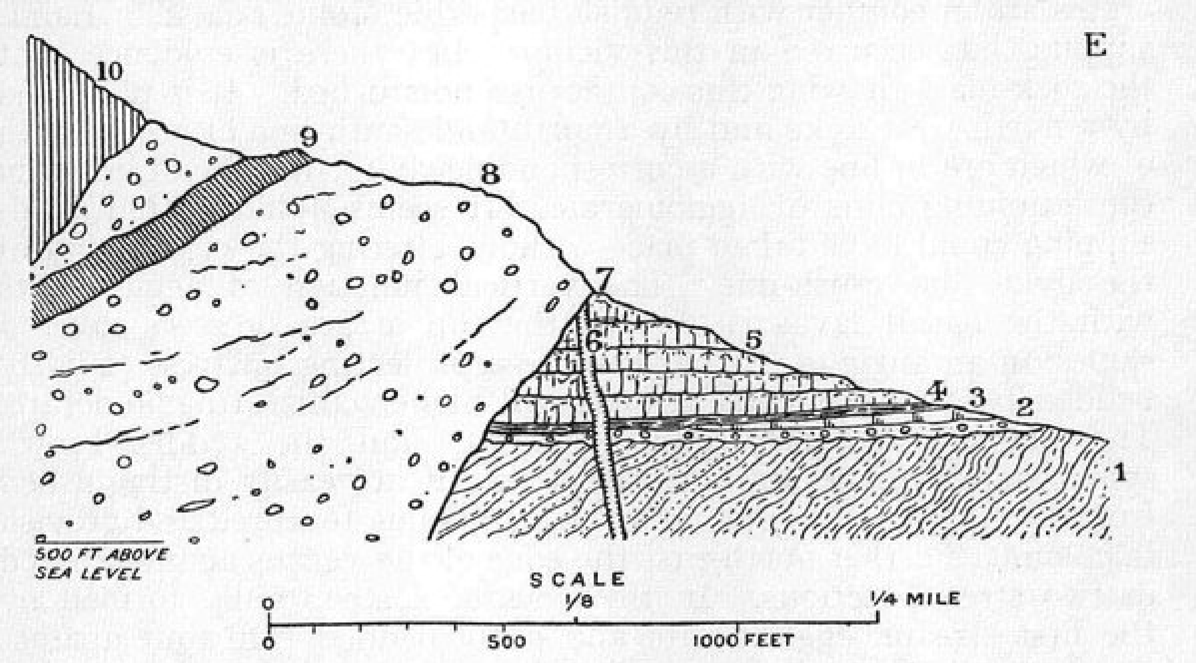


FIG. 11.—*Section of North-east Vent of Ben Hiant.*

1, *Moine Schists.* 2, *Trias.* 3, *Lower Lias limestone.* 4, *Basal Tertiary mudstone.* 5, *Tertiary basalt lavas.* 6, *Pre-vent composite dyke.* 7, *Edge of vent.* 8, *Vent-agglomerate.* 9, *Quartz-dolerite cone-sheet.* 10, *Ben Hiant Intrusion of quartz-dolerite.*

(Figure 11) Section of North-east Vent of Ben Hiant.1, Moine Schists. 2, Trims. 3, Lower Lias limestone. 4, Basal Tertiary mudstone. 5, Tertiary basalt lavas. 6, Pre-vent composite dyke. 7, Edge of vent. 8, Vent-agglomerate. 9, Quartz-dolerite cone-sheet. 10, Ben Hiant Intrusion of quartz-dolerite.

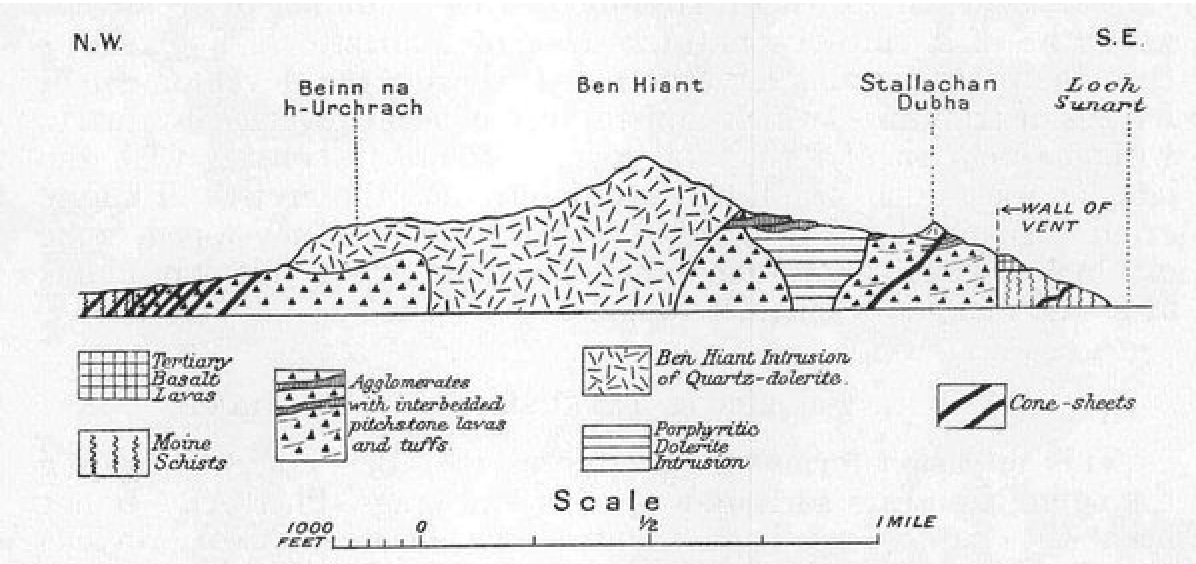


FIG. 19.—*Section across Ben Hiant.*

(Figure 19) Section across Ben Hiant.

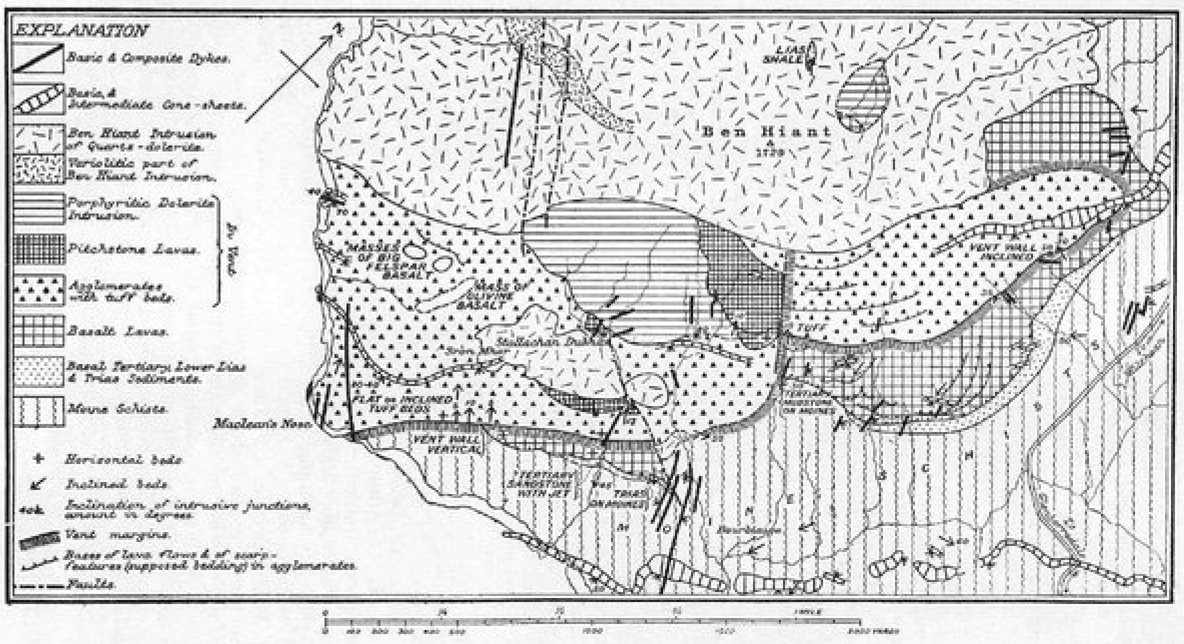
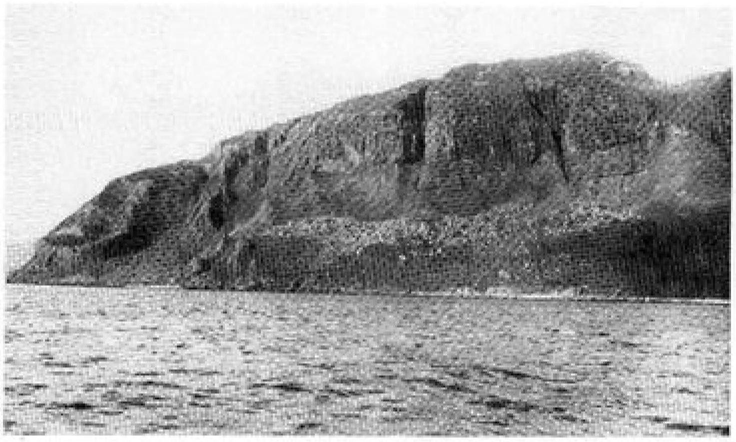


FIG. 10.—*Map of Vent-Complex, eastern side of Ben Hiant.*

(Figure 10) Map of Vent-Complex, eastern side of Ben Hiant. Geology of Ardnamurchan.



A.—*View of Maclean's Nose, Ardnamurchan, from east.*
(For Explanation, *see* p. viii.)

B.—*Agglomerate cliffs of Maclean's Nose.*
(For Explanation, *see* p. viii.)

(Plate 3) A. View of Maclean's Nose, Ardnamurchan, from east. Cliffs extend up to 800 ft. above sea-level, and are formed of vent-agglomerate with flatly interbedded tuffs. On extreme right of scree, buttress of basalt lava marks a vertical wall of the vent. Exposure of vent-wall (Moine Schist) again occurs on shore near point of Nose (see p. 124). Geological Survey Photograph, No. C2859. B. Agglomerate Cliff of Maclean's Nose. In foreground, flat bed of tuff (below hammer) with agglomerate above and below. The view is taken from near extreme right of Plate 3, A, looking towards the Nose. Geological Survey Photograph, No. C2848.

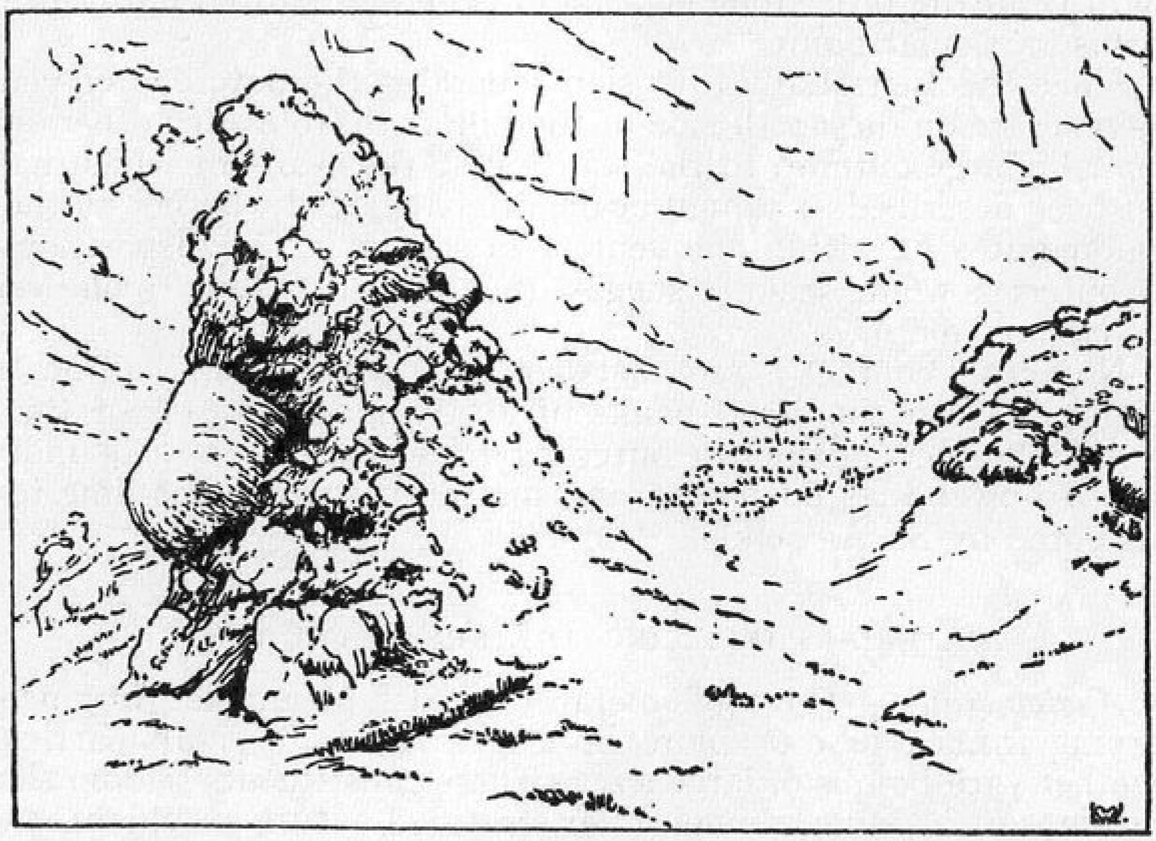
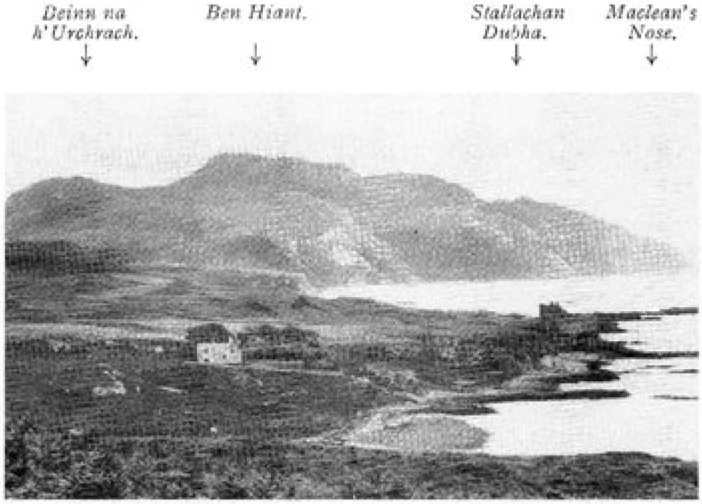


FIG. 12.—*Vent-agglomerate with large blocks of big-felspar basalt, near Maclean's Nose, Ben Hiant.*
Drawn from Geological Survey Photograph No. C. 2843.

(Figure 12) Vent-agglomerate with large blocks of big-felspar basalt, near Maclean's Nose, Ben Hiant. Drawn from Geological Survey Photograph No. C. 2843.

Geology of Ardnamurchan.
(Mem. Geol. Surv.) PLATE I.



A.—*View of Ben Hiant, Ardnamurchan, from west*
(For Explanation, *see* p. viii.)

B.—*Marginal Scarp of Ben Hiant Intrusion, seen from south-east*
(For Explanation, *see* p viii.)

(Plate 1) A. View of Ben Hiant, Ardnamurchan, from west. Main mass of this rocky hill is Ben Hiant Intrusion (see (Figure 19), p. 160). Maclean's Nose to right is agglomerate. Junction of these rocks extends from shore up well-marked hollow, seen on photograph above Mingary Castle (see also Plate 1, B). Stallachan Dubha is formed of outlying portion of Ben Hiant Intrusion. Scarp-features in middle distance are due to cone-sheets. Mingary Castle stands on a craignurite sill. Promontory beyond is Rudha a' Mhìle ((Figure 25), p. 177). Geological Survey Photograph, No. C2829. B. Marginal Scarp of Ben Want Intrusion, seen from south-east. The view is taken from west of Stallachan Dubha (see Plate 1, A and Explanation). The Ben Hiant Intrusion is closely jointed. Vent-agglomerate forming foreground contains two large masses of big-felspar basalt (p. 126), one in centre of view, the other to the left. Geological Survey Photograph, No. C2850 .

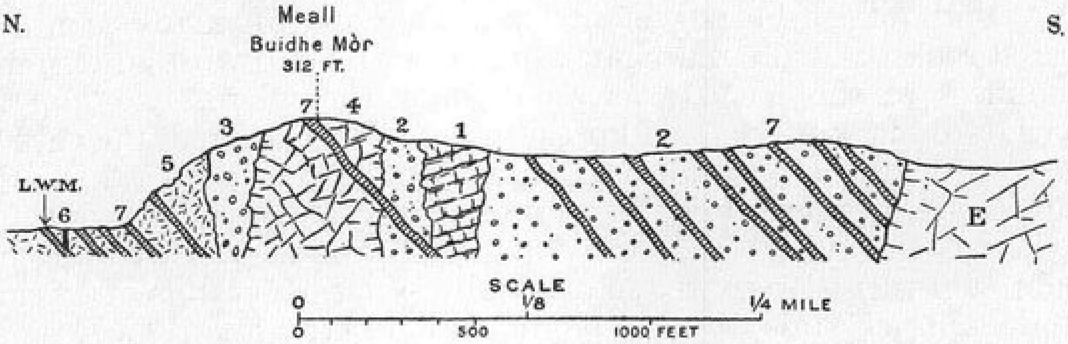


FIG. 16.—*Section, west of Faskadale Bay.*

1. *Basalt lava in vent.* 2, *Vent-agglomerate.* 3, *Screen of vent-agglomerate separating intrusions* 4 *and* 5. 4, *Gabbro of Centre* 1. 5, *Granophyre of Centre* 1. 6, *Basic E.N.E. dyke, seen to cut some cone-sheets and to be cut by others.* 7, *Cone-sheets of Centre* 2. E, *Great Eucrite Ring-dyke of Centre* 3. L.W.M., *Low-water Mark.*

(Figure 16) Section, west of Faskadale Bay. 1. Basalt lava in vent. 2. Vent-agglomerate. 3. Screen of vent-agglomerate separating intrusions 4 and 5. 4. Gabbro of Centre 1. 5. Granophyre of Centre 1. 6. Basic E.N.E. dyke, seen to cut some cone-sheets and to be cut by others. 7. Cone-sheets of Centre 2. E, Great Eucrite Ring-dyke of Centre 3. L.W.M., Low-water Mark.

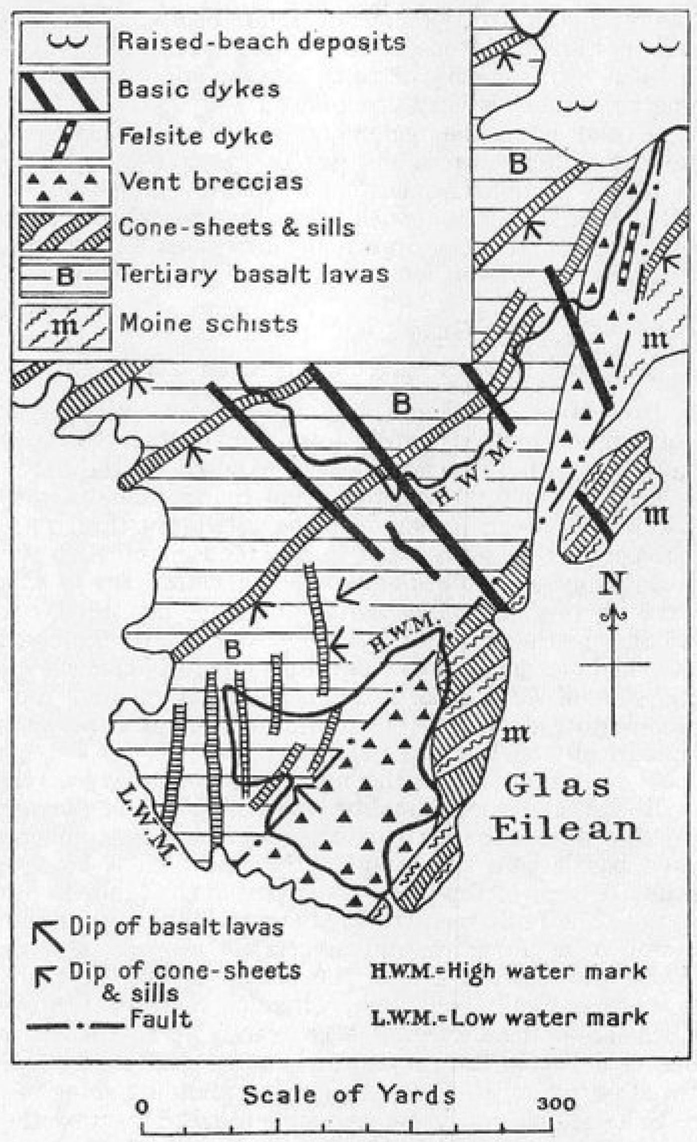


FIG. 13.—*Map of Glas Eilean Vent, south of Kilchoan.*

(Figure 13) Map of Glas Eilean Vent, south of Kilchoan.

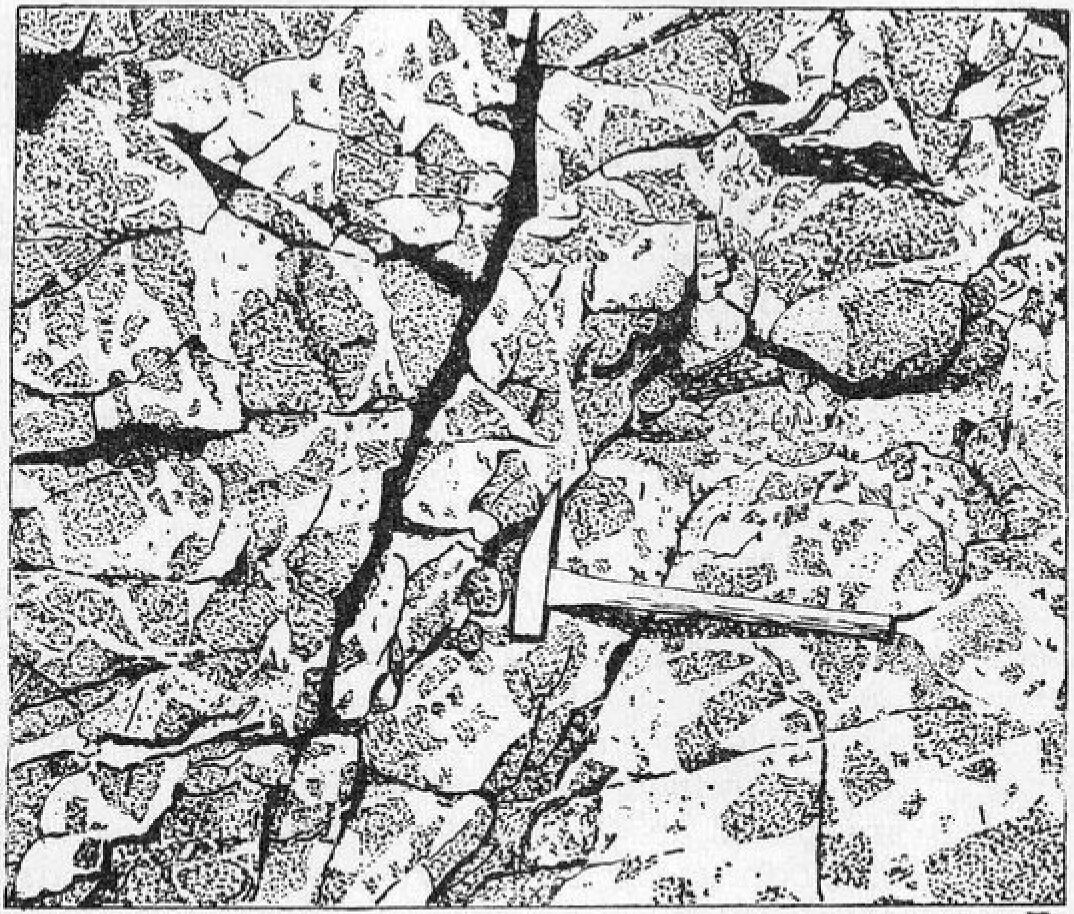


FIG. 34.—*Quartz-dolerite net-veined by granophyre, Sgùrr nam Meann Ring-dyke, on shore south-west of Sgùrr nam Meann.*
Drawn from Geological Survey Photograph, No. C. 2773.

(Figure 34) Quartz-dolerite net-veined by granophyre, Sgùrr nam Meann Ring-dyke, on shore south-west of Sgitrr nam Meann. Drawn from Geological Survey Photograph, No. C. 2773.

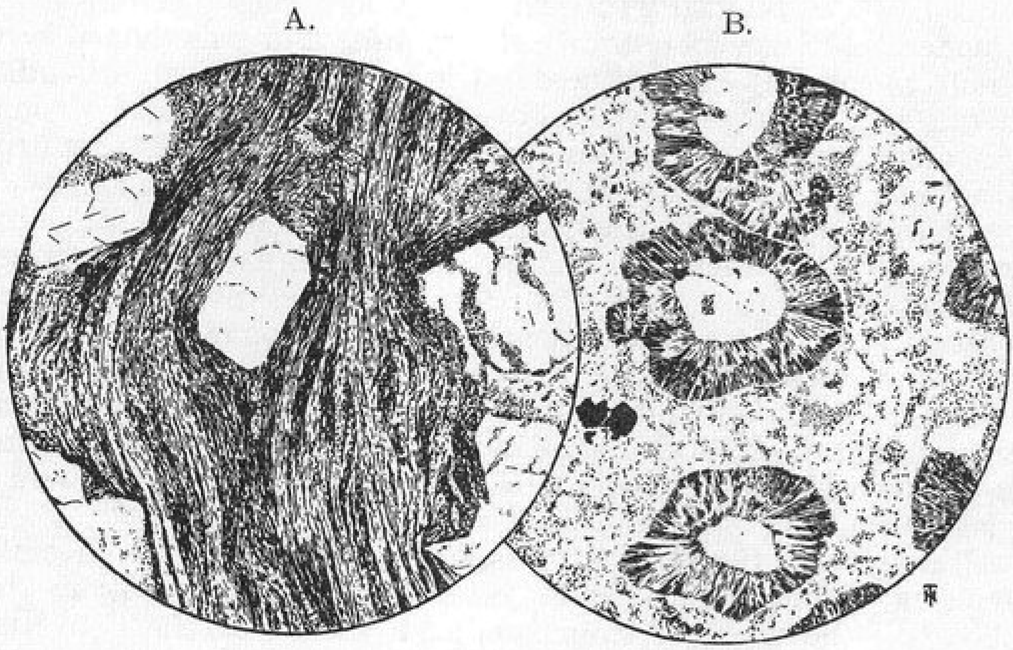


FIG. 14.—*Acid types from the Vents.*

A. (21446)×20. *Rhyolite with well-developed fluxion-structure, from the Agglomerate of Maclean's Nose, Ben Hiant.*

B. (23599)×20. *Spherulitic Quartz-rhyolite from East of Achateny Water. Showing phenocrysts of quartz surrounded by spherulitic growths of quartz and alkali-felspar, in a devitrified felsitic matrix.*

(Figure 14) Acid types from the Vents. A (S21446) [NM 5328 6183] &mu 20. Rhyolite with well-developed fluxion-structure, from the Agglomerate of Maclean's Nose, Ben Hiant. B (S23599) [NM 520 706] × 20. Spherulitic Quartz-rhyolite from East of Achateny Water. Showing phenocrysts of quartz surrounded by spherulitic growths of quartz and alkali felspar, in a devitrified felsitic matrix.

TABLE III

SUB-ACID AND ACID MAGMA-TYPES (*see* Fig. 6)

	INNINMORITE.			GRANITE AND GRANOPHYRE.			
	A.	I.	II.	III.	B.	C.	
SiO_2	64·13	64·30	66·06	68·42	71·60	74·87	SiO_2
Al_2O_3 ..	13·15	14·18	13·14	13·54	13·60	11·24	Al_2O_3
Fe_2O_3.. ..	1·08	1·09	2·27	2·53	2·40	0·34	Fe_2O_3
FeO	6·31	4·44	2·84	2·02		1·22	FeO
MgO	1·08	1·47	0·77	0·22	0·21	0·22	MgO
CaO	3·62	2·87	2·75	2·13	2·30	1·30	CaO
Na_2O ..	3·64	4·30	4·28	5·12	5·55	3·31	Na_2O
K_2O	2·32	2·83	1·54	4·08	3·53	5·68	K_2O
$H_2O > 105°$ ..	2·71	3·02	3·38	0·15	0·70	0·49	$H_2O > 105°$
$H_2O < 105°$ ..	0·36		0·74	0·25		0·29	$H_2O < 105°$
TiO_2	1·19	0·75	1·08	0·81	—	0·26	TiO_2
P_2O_5	0·31	0·17	0·09	0·38	—	0·09	P_2O_5
MnO	0·27	0·26	0·31	0·10	—	0·05	MnO
CO_2	—	0·00	0·37	0·06	—	0·49	CO_2
FeS_2	0·00	—	trace	0·05	—	0·33	FeS_2
SO_3	—	0·00	0·16	trace	—	—	SO_3
Cr_2O_3.. ..	—	0·00	trace	trace	—	0·02	Cr_2O_3
(Co, Ni)O ..	0·00	—	0·00	—	—	—	(Co, Ni)O
BaO	0·09	0·16	trace	0·03	—	0·04	BaO
Li_2O	0·00	—	trace	trace	—	0·00	Li_2O
F	—	—	—	—	—	0·00	F
C	—	traces	—	—	—	—	C
Organic matter..	—	—	0·02	—	—	—	Organic matter
	100·26	99·84	99·80	99·89	99·89	100·24	

A. (15990; Lab. No. 387.) Fairly glassy Inninmorite or Inninmorite-Pitchstone. Sheet. $\frac{3}{16}$ mile S.W. of Trigonometrical Station on Beinn an Lochain, Mull. Quoted from E. M. Anderson and E. G. Radley, *Quart. Journ. Geol. Soc.*, vol. lxxi., 1915, p. 212. *Anal.* E. G. Radley.

I. Inninmorite-Pitchstone. Lava. E. slope of Ben Hiant, Ardnamurchan. *Anal.* Harcourt Phillips.[1]

II. (21255; Lab. No. 739.) Inninmorite-Pitchstone. Lava. In stream bank $\frac{3}{8}$ mile S. 12° E. of Trigonometrical Station at 1729 ft., Ben Hiant, and $\frac{1}{4}$ mile W. 3° S. of Bourblaige, Ardnamurchan. *Anal.* B.E. Dixon.

III. (22820; Lab. No. 789.) Augite-granophyre. Major intrusion, Centre 2, Ardnamurchan. 800 yds. S. 30° E. of Grigadale. *Anal.* B. E. Dixon.

B. Augite-granophyre. 100 yds. E. of summit, Carrock Fell, Cumberland. Quoted from A. Harker, *Quart. Journ. Geol. Soc.*, vol. li., 1895, p. 129. *Anal.* G. Barrow.

C. (24380; Lab. No. 820.) Biotite-granite. Northern granite mass, Arran. Glen Rosa, $\frac{1}{4}$ mile above confluence with Garbh Allt. Quoted from G. W. Tyrrell, 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928, pp. 155–156. *Anal.* B. E. Dixon.

[1] Supplied by Dr. A. Harker.

(Table 3) Sub-acid and Acid Magma-Types (see (Figure 6)).