Chapter 13 Tertiary major intrusions, Centre 1, Ardnamurchan (Continued)

The major intrusions referred to Centre 1 which remain to be described are as follows:

1. Composite Intrusion of Beinn an Leathaid.
2. Quartz-dolerite Intrusion of Ben Hiant.

The above intrusions are of large size and are in part sheet-like in form. Their outcrops follow the same directions as cone-sheets referred to Centre 1 (*see* (Plate 2)). In chemical and mineralogical composition they are also in part closely similar to these cone-sheets. There are consequently good reasons for assigning them and the early cone-sheets to the same intrusive period. But, since they are so much more massive, and since they possess individual peculiarities of form, structure and composition, they are described separately in the present chapter.

(1) Composite intrusion of Beinn An Leathaid

This important composite intrusion (lettered GD on the Memoir-map) forms the upper part of Beinn an Leathaid, a prominent ridge that rises west of the Braehouse–Achateny road. It is probable, though not absolutely certain, that the intrusion is a sheet inclined gently towards the west-south-west. On this understanding its vertical thickness on Beinn an Leathaid must be rather more than 400 ft., of which the lower half consists of coarse, moderately basic rock, and the upper half of granophyre or felsite.

The more basic rock outcrops as an almost continuous cliff for two miles on the east face of Cathair Mhic Dhiarmaid and Beinn an Leathaid. The cliff looks like an escarpment of a sheet, and has rude columnar jointing inclined steeply towards the east-northeast. It is, however, impossible to establish with certainty the existence of a base to the supposed sheet. A pass called Bealach nan Each crosses the cliff north-west of Braehouse, but unfortunately at this point there is a local interruption in the outcrop of the basic material. Its margin, traced against basalt lavas on the north side of the pass, is irregular in shape and unchilled.

The granophyre or felsite forms the summit of the ridge and can be identified, for instance, at the cairn of Beinn an Leathaid, where it contains numerous xenoliths of schist and quartzite. Some way down the cliff-face east of the cairn, the granophyre merges through a narrow transition zone into underlying quartz-dolerite. The narrowness of this zone makes it improbable that differentiation has occurred *in situ.* It appears rather that the basic and acid material were differentiated in depth, and then injected more or less simultaneously.

The acid part of the intrusion extends as a narrow tongue across Bealach nan Each, where the basic part locally fails. Here, too, basalt lavas can be recognized west of the acid outcrop, but generally the western termination of the composite intrusion is obscured by later cone-sheets, grouped with the outer set of Centre 2. Good exposures of cone-sheets cutting the basic portion of the intrusion are furnished in Allt Rath a' Bheulain, south-west of Beinn an Leathaid.

The composite intrusion and the later cone-sheets are alike cut off by the Faskadale Quartz-gabbro, the outermost member of the Ring-dyke Complex of Centre 3. Exposures at Lochan Tom Mhic Iain, at the south end of the outcrop, show the basic portion clearly contact altered (S26106) [NM 5117 6672]. E. B. B.

Petrology

This intrusion presents many points of petrological interest, for, in spite of its great thickness, it would appear that no portion of it is a strictly normal rock. As stated above, the sheet shows variation both in texture and colour from a grey moderately coarse-textured basic rock to a more acid paler and finer-grained upper portion. The change is gradual but pronounced and takes place through a relatively narrow transitional zone.

Even the lower basic portion, judged by the specimen collected (S23463) [NM 5203 6772], is much more siliceous than most of the quartz-dolerites with which we are acquainted, and it also presents characters that are foreign to other rocks of this nature which are represented in Ardnamurchan.

Texturally the rock appears fairly uniform and moderately fine-grained. Felspars measuring a few millimetres in length and dark specks that represent ferromagnesian minerals are the obvious constituents. Under the microscope the rock is seen to consist mainly of well-shaped rectangular crystals of zoned labradorite-andesine felspar, edged with orthoclase and embedded in a beautiful micrographic base of alkali-felspar and quartz. The granophyric matter probably constitutes 20 per cent. of the rock and indicates a fairly high alkali-content. Augite is the dominant ferromagnesian mineral and is of two kinds, a non-aluminous almost uniaxial variety (enstatite-augite) and a normal aluminous augite with the characteristically wide axial angle. Both these minerals are pale-coloured and both have a tendency towards idiomorphism, but the enstatite-augite is more prone to decompose, to furnish ochreous pseudomorphs, and to give rise to indefinite brown patches within the body of the rock.

Besides the pyroxene, there is represented a deep olive-green hornblende that occurs as isolated somewhat irregularly bounded crystals, but more frequently either fringes or is intergrown with augite.

In addition to the quartz that enters into the constitution of the graphic intergrowths, this mineral occurs as rounded patches and also presents crystal faces towards an ochreous chloritic base that suggests for the rock an ultimate glassy residuum.

Iron-ore is represented by well-shaped octahedra, patches and plates of magnetite, and the rock as a whole is rich in apatite, more particularly in the micrographic regions which are crowded with slender prisms of this mineral.

When we examine the rock microscopically we find that the texture and composition is not nearly so uniform as might have been expected from the hand-specimen. It is noticed that there are distinct basic and acid areas, that pyroxene tends to segregate in one region and excessive micrographic matter in another, while much of the green hornblende appears to occupy an intermediate position, that is to say, where acid and basic areas encroach upon each other.

This type of hornblende, which is clearly pyrogenetic in origin, is known as a common result of hybridization between acid and basic igneous rocks. Dr. Harker, when describing the basified granophyres and hybrid rocks of Marsco in Skye, stated that this hornblende, which may be either idiomorphic or replacing augite, is constantly the dominant mineral of the hybrid rocks.

From the general abnormality of the rock-mass in question, and from a comparison with the rocks of Skye, I would suggest that this sheet is allied in origin to marscoite. It may be, therefore, that the mass is hybrid in nature, was intruded as a unit, and was followed immediately by acid magma that has further modified the earlier intrusion and formed a relatively narrow transitional zone.

The rocks of this passage-zone (S23460) [NM 5196 6769], (S23461) [NM 5196 6769], (S23462) [NM 5196 6769] show but little change in their actual mineral components, the chief variation being an increase in the amount of micrographic matter at the expense of the ferromagnesian and purely felspathic constituents. At the same time, however, there appears to be a tendency for the idiomorphic felspars to diminish in size and to become more acid in composition. In the uppermost part of the passage-zone the felspars are reduced to small rectangular individuals that have the composition of oligoclase. In this portion of the mass, also, the interstitial micrographic matter becomes exceedingly fine-grained and appears to be replaced locally by devitrified glass. The acid, upper and presumably latest portion of the intrusion (S23459) [NM 5190 6767], has what may almost be described as a pitchstone base. The rock is extremely patchy, the pitchstone-like material involving microporphyritic areas that exhibit a structure similar to that of the upper portion of the transition zone.

This acid part of the intrusion contains a number of accidental xenoliths of a siliceous nature. One of quartzite (S23459) [NM 5190 6767] shows that the quartz grains have been fritted with the development of fringes of tridymite, which mineral has as usual reverted to quartz with a retention of its crystal form. Where in contact with the igneous rock, such xenoliths have determined the growth of augite around them. Long blade-like crystals have been developed, some of which are fresh and others pseudomorphed by secondary products after the manner of enstatite-augite. H.H.T.

(2) Quartz-dolerite intrusion of Ben Hiant

This intrusion forms the greater part of Ben Hiant, including the summit and its surrounding cliffs and crags ((Plate 1), A). It has been the subject of some controversy between two previous observers, Prof. J. W. Judd and Sir Archibald Geikie.<ref>Sir A. Geikie, Ancient Volcanoes of Great Britain, vol. ii., 1897, pp. 318–322</ref> To this, reference has been already made (p. 121). While Geikie has rightly pointed out the intrusive origin of the dolerite, his conclusions are not confirmed in all respects by recent survey work. He regarded the mass as built up of a great series of sheets, which he included with his group of basic sills (the cone-sheets). The evidence bearing on this point will be fully discussed below.

In mineralogical composition the Ben Hiant quartz-dolerite differs from the type characteristic of the cone-sheets, though their chemical analyses are practically identical (p. 82). Olivine is generally present in the Ben Hiant type, and also a variolitic ground-mass more or less segregated in patches. This variolite is unlike the more acid mesostasis of the majority of cone-sheets. It has been noted in the case of one cone-sheet, which occurs north of the Ben Hiant Intrusion and approximately along the same line of strike.

The most important variation in rock-type throughout the mass is comprised in a local sheet-like development of variolite, to be described in detail below (p. 166). Also, considerable changes in texture occur from place to place. Along the shore on the western side of the hill, where the intrusion rises from sea-level as a dyke-like mass, coarser varieties approaching gabbro are met with. The outer parts of this dyke-like portion of the intrusion are composed of the coarse-textured dolerite, while the centre consists of the normal, finer-grained variety. The two varieties appear to grade into one another, though they may perhaps represent separate injections. At higher levels on the hill there is considerable variation in texture, though the rock is nowhere truly gabbroic. No sharp contacts between portions differing in texture could be made out, such as would suggest that the mass is made up of multiple injections.

The mass is everywhere traversed by close-set joint-planes which are vertical or steeply inclined (*see* (Plate 1), B). To these dominant planes of weakness the steep faces and precipitous cliffs characteristic of Ben Hiant are due. The joints extend upwards through the mass without any ascertainable interruption, as may be seen for a vertical distance of some 500 ft. on the precipitous north side of the hill. On the steep, though less abrupt, southern side, the closely-jointed dolerite has been weathered back in three or four great tiers, one above the other, which give this part of the hill a bedded appearance. A close examination failed, however, to locate any intrusive contacts where the bedded aspect would lead one to expect them.

The intrusion is traversed by a few north-west lines of crush, the positions of which are marked by straight-running hollows. These extend approximately parallel to the face of the hill on its western side. When viewed from a distance, from the neighbourhood of Kilchoan, the hill thus presents a false appearance of flat bedding ((Plate 1), A.). Other denudation-hollows extend steeply up this hillside, and seem to indicate sheet-margins inclined at about 35 degrees to west-north-west, corresponding to the inclination of the cone-sheets of the district. No evidence of intrusive contacts, however, could be found where rock is continuously exposed across such apparent sheet-contacts. Further, the jointing in the dolerite at such places does not run at right angles to the apparent sheet-margins, but remains vertical. The lines of weakness along which weathering has acted are believed to be cone-sheet fractures, which were not intruded by magma. Only one instance of a cone-sheet cutting the Ben Hiant dolerite is known (p. 166). It is noteworthy that the cone-sheet concerned extends continuously up through 1000 ft. of agglomerate but only penetrates a sheet-like outlier of the dolerite for a few feet.

A perfectly developed set of prismatic joints, enclosing six-sided columns a yard or more in diameter, is developed at one point in a basal portion of the mass. The locality is on the north side of Ben Hiant, alongside the most easterly stream traversing the dolerite, 300 yds. south of a cross-country track shown on the Memoir-map. The rock is much weathered, but the margins of the columns have proved more resistant than the softer interiors. They form slightly raised, six-sided rims, each separated by a joint-plane from the rims of adjoining columns. The hardening of these margins must be connected with the joint-planes, and is presumably due to the action of vapours escaping from later-consolidated interior portions of the mass. Similar hardened rims to hexagonal columns of basalt lava, hitherto unrecorded, were observed in the Island of Mull, near the summit of Coire Bheinn to the west of Ben More. In this case the rims were grey in colour, as though pneumatolized, while the interiors were of normal brown-weathering basalt.

Form of intrusion

The Ben Hiant Intrusion rises abruptly from sea-level on the west side of the hill as a dyke-like mass (*see* (Figure 19)). At an altitude of 400 ft., on its north side, this mass spreads outwards to flatly override agglomerates of the Ben Hiant vent and the older bedded rocks. On its south side a similar extension at a height of over I000 ft. is indicated by an outlying cake of dolerite on Stallachan Dubha. When followed uphill along the centre of the dyke-like portion the dolerite grades into variolite, which is interpreted as a quickly chilled upper surface of the intrusion (p. 168). This western portion of the Ben Hiant dolerite is, therefore, of mushroom shape.

The intrusion of the dolerite through the materials infilling the south-west Ben Hiant Vent, its mushroom shape, and its probable termination upwards near to the present denudation-surface, render it likely that the mass is a vent-infilling. On the other hand the eastern portion of the intrusion follows a different plan. On the lower ground north-east of the summit, tongues from the Ben Hiant dolerite extend out into the country rocks. These tongues follow the direction and inclination of the adjoining cone-sheets, from which they cannot indeed always be distinguished in the field.

Towards the central mass of Ben Hiant they come together to form one continuous dolerite outcrop, but their sheet-like form is in certain cases still apparent. The absence of chilled margins, or sharp junctions, in exposures where such sheet-like masses are seen to join, is unlike the behaviour of cone-sheets, which are invariably chilled when in contact with one another. The tongues from the Ben Hiant dolerite also differ from neighbouring cone-sheets in having a lower inclination, usually not more than 10 degrees. Two possibilities as to their origin may be considered. They may be either cone-sheet feeders of the main mass of the Ben Hiant Intrusion, or they may be offshoots from the latter along cone-sheet fracture lines. Taking into consideration the mushroom form of the great mass of dolerite comprising the west part of the intrusion and the absence of intrusive margins to the sheet-like masses where seen in contact, the latter explanation is here adopted. It would seem probable that the cone-sheet fractures were formed simultaneously with the intrusion of the main mass of the dolerite.

Sir A. Geikie, in his account of Ben Hiant, has referred to the sheet-like apophyses described above, and has mentioned that one of them extended for more than a mile from the main mass. They no doubt greatly influenced him in his conclusion that the Ben Hiant Intrusion was built up of a series of sheets. In the absence of ascertainable sheet-margins at any point within the Ben Hiant mass, his conception can, however, scarcely be maintained, especially since the rock type concerned is of hypabyssal character and therefore prone to chilling.

The field evidence on which the above general account is based is given below.

North-west margin

The north-west margin of the Ben Hiant Intrusion outcrops on the western shore of Ben Hiant which may be reached from the direction of Kilchoan by a track that skirts the coast from Mingary. Above high-water mark, in the angle of a bay north-west of the margin, Kilchoan Schists, with felspar pebbles in certain layers, are exposed and dip south-east. Near by, on the shore, a porphyritic basic sill is intruded along the bedding of the schists, while farther inshore a cone-sheet may be seen with contrary inclination to north-west. About 30 yds. south of the cone-sheet the Ben Hiant dolerite is first exposed, but its contact with the schists is not on view. Outcrops on the adjoining steep hillside are, however, sufficiently numerous to show that this margin of the dolerite is practically vertical. At a height of about 400 ft. the margin abruptly turns north-west along the face of the hill, and the dolerite forms a well-marked scarp above steep slopes composed of schist overlain by Trias breccia and Lower Lias limestone. The actual margin of this flatly-disposed portion of the dolerite is obscured by fallen blocks. From this point, the scarp continues round to the north-west side of Beinn na h'Urchrach, where it extends for a mile as a very strong feature. The base of this escarpment coincides almost exactly with the margin of the intrusion against brecciated basalt and agglomerate, except where a broad tongue of the dolerite is shown on the map projecting northwards for a quarter of a mile. The northern margin of this tongue is ill-defined, largely because of discontinuity in rock-exposure, which increases the difficulty of separating the Ben Hiant dolerite from outcrops of cone-sheets.

Sir A. Geikie has given an account, accompanied by illustrations, of what he terms the massive sill of Beinn na h'Urchrach.<ref>Sir A. Geikie, The Ancient Volcanoes of Great Britain, vol. ii., 1897, pp. 321, 322, and Figs. 326, 327.</ref> There is, however, no similarity between his description and the Beinn na h'Urchrach escarpment, which undoubtedly forms an integral part of the Ben Hiant Intrusion. On the other hand, Geikie's description and figures are evidently based on close observation in the field, and the intrusions with which he was concerned seem obviously to be the cone-sheets of this Memoir. An explanation of the difference between his conclusions and our own concerning Beinn na h'Urchrach seems to be that Geikie has applied this name to a prominent ridge farther north, called Beinn nan Losgann, to which his observations are closely applicable. But since Geikie's illustrations are not accompanied by a scale of distances one cannot be altogether certain as to this.

South-east margin

In form, the south-east portion of the Ben Hiant Intrusion bears a close resemblance to that just described. It is everywhere bounded by the older rocks that fill the Ben Hiant vents. A junction with these materials is seen on the western coast, below high-water mark, where the dolerite is in irregular contact with a highly baked basaltic rock, and is quite unchilled. For a short distance along the shore within this margin, the dolerite is traversed by acid veins, a frequent marginal feature of the ring-dykes, but not seen elsewhere within the Ben Hiant mass. It is noteworthy that these veins are only developed at this, the lowest exposed part of the intrusion. Further, as already stated (p. 160), this portion of the dolerite is more gabbroid in texture than at higher levels, which is in keeping with the foregoing evidence of its crystallization under relatively deep-seated conditions.

The margin extends from the western shore up steep slopes to a height of 1200 ft., and is highly inclined to the north-west (Plate 1), B. From this point, it continues along a more level course at the base of high crags in which the characteristic close-set vertical jointing of the dolerite is well seen. It then changes direction to curve around the eastern side of the intrusion, and across a spur north-east of the summit. It there enters the north-east sector of the intrusion, a description of which, from Beinn na h'Urchrach to the spur just mentioned, will be given below.

There remain to describe two isolated masses of quartz-dolerite of Ben Hiant type which occur on the south side of the hill. The larger mass forms the peaks of Stallachan Dubha ((Figure 10), p. 122), and is separated from the Ben Hiant Intrusion proper by a wide shallow hollow floored by the vent-rocks. It forms a cake-like mass, with close-set almost vertical joints, resting upon agglomerate and pitchstone lava of the South-west Vent. Its flat base is clearly displayed along two hollows that cross the mass, and indeed nearly divide it into three separate parts. There can be little doubt that it is the denuded remnant of a sheet-like extension southwards of the main Ben Hiant Intrusion, an extension that has its parallel on the north side of Ben Hiant in the over-riding escarpment of Beinn na h'Urchrach (p. 162). The beautifully displayed jointing of the Stallachan Dubha crags is a feature in common with the main portion of the intrusion.

A contact of the Stallachan Dubha dolerite with baked tuff is exposed at the base of a crag on the north side of the mass, north of the centre peak and close to a stream. The dolerite is fine-grained at the actual junction, but does not develop a chilled edge. When traced up the crag above, this marginal type is seen to grade into dolerite of normal grain within a few yards.

The second isolated outcrop of quartz-dolerite of Ben Hiant type is met with due east of Stallachan Dubha at a margin of the South-west Vent ((Figure 10), p. 122). It is seen in a stream-section between the vent-agglomerate and the vent-wall that is there composed of schist. The form of this little mass is quite obscure.

North-east margin

The irregularities in the behaviour of the north-east portion of the Ben Hiant Intrusion have been already briefly stated (pp. 161–2). These complications begin beyond the north-east end of Beinn na h'Urchrach. A continuous outcrop of older rocks extends uphill and southwards across this end of the great Beinn na h'Urchrach escarpment, so that there appears at this point to be a northerly inclined base to the intrusion. The older rocks consist of agglomerate and Lower Lias limestone and shales, and are exposed mainly in a stream-section. Farther east, in a hollow north of the central mass of Ben Hiant, the form of dolerite becomes very complex in detail. Scarp and dip-slope featuring is developed which is to be ascribed to the intrusion of dolerite into inclined fissures, but such apparent apophyses appear to be interconnected by a complicated series of less massive injections. For example, in a stream half a mile north of Ben Hiant summit, in which Lower Lias limestone and sandstone intervening between apophyses are exposed, these sediments do not form a continuous outcrop, but are irregularly traversed by dolerite at intervals.

East of the stream last mentioned, a ridge is formed of a well-exposed sheet-like apophysis, having a dip-slope inclined at about io degrees to the west, and a high scarp to the east. This scarp borders a stream that winds northwards for a mile to enter a deep hollow south of Loch Mudle, eroded along the course of the Loch Mudle Fault. The scarp-feature is composed of cross-jointed dolerite, and is underlain by the much weathered columnar dolerite that has been already described (p. 161). Exposures are continuous between the base of the scarp and the much weathered dolerite, but a careful search failed to locate any sign of intrusive contact between the two types of rock. The two varieties of dolerite would appear to have been injected almost simultaneously.

The well-marked scarp extends southwards to ascend the eastern spur of Ben Hiant already referred to (p. 163), where it has a westerly inclination of 20 degrees (*see* (Figure 20)). On this ridge, also, it is underlain by an easily weathered variety, which is largely covered by grass. Northwards from the exposure by the stream where the two varieties are seen together, the dolerite continues out into the schists for more than a mile as an isolated tongue, which has been mapped by Mr. E. B. Bailey. This extensive apophysis is composed of both hard and soft varieties, the former frequently containing abundant xenoliths of schist, which are also found in its more southerly outcrops. In the hollow at the south end of Loch Mudle, it terminates against the Loch Mudle Fault, by which its outcrop is shifted to the south-east, where it is seen again on a ridge east of the fault-hollow (*see* (Plate 2)). There, the characteristic xenoliths of schist are often abundant. The direction of this elongate tongue is exactly parallel to the trend of adjacent cone-sheets referred to Centre 1. The amount of its inclination, however, seemed to the writer to be distinctly less than that of the cone-sheets.

Age relations

Much of the evidence bearing on the date of intrusion of the Ben Hiant dolerite has been given in foregoing pages. This, together with additional facts, will now be briefly stated, and their significance discussed.

Along its south-east margin the dolerite is in steep contact, from sea-level through a vertical distance of 1200 ft., with the materials infilling the South-west Vent. This western dyke-like portion of the mass may therefore be said to be intruded with marked discordance through the vent-materials, since the latter are found in well-exposed sections to consist mainly of flatly interbedded tuffs, agglomerates, and pitchstone lavas. The later date of the dolerite is demonstrated by actual contacts (pp. 163, 164). Further evidence of this is supplied by the contact alteration which, as Dr. Thomas finds under the microscope, all vent-materials show in proximity to the dolerite. In the field the contact alteration is also obvious. South-east of Ben Hiant summit, the margin of the intrusion is bordered by a scarp of baked older rocks comprising agglomerates, belonging to the two Ben Hiant vents, and the Porphyritic Dolerite plug (p. 150). Close-set vertical jointing has been developed in the rocks forming the scarp, so that the latter, at a distance, strikingly resembles a cross-jointed sill. Such jointing, arising in baked rocks at right angles to the margin of the intrusion concerned, has also been observed in the ring-dyke complexes (pp. 272 and 286).

Though the Ben Hiant Intrusion is later than all vent-materials, it nevertheless appears as if it were connected with the Ben Hiant vents. Its lateral expansion upwards in mushroom form, and the evidence supplied by its capping of variolite (p. 168), suggest that the magma filled the throat and crater of the volcano, and that its upper surface solidified under little if any cover. On the other hand, when we examine the evidence bearing on its age relations with the cone-sheets referred to Centre 1, there arises a strong probability that the intrusion of the dolerite took place during this cone-sheet period. This evidence has been already stated, but is briefly summarized below.

1. In chemical composition the Ben Hiant dolerite is identical with quartz-dolerite forming cone-sheets (p. 82). In mineralogical composition it differs from the majority of cone-sheets. It is, however, similar to at least one cone-sheet

(S24468) [NM 5609 6299] which is situated, like the Ben Hiant dolerite mass, towards the exterior of the cone-sheet belt referred to Centre 1.

2. On the north-eastern side of the Ben Hiant Intrusion apophyses from it are injected along inclined fractures that follow the same trend and direction of inclination as adjacent cone-sheets.
3. The Ben Hiant Intrusion is cut by one cone-sheet, and accordingly must be earlier than some part of the cone-sheet period. The cone-sheet concerned penetrates for a short distance the outlier of Ben Hiant dolerite forming Stallachan Dubha (Figure 10). Though no typical cone-sheets are intruded into the main mass of the Ben Hiant Intrusion, the presence of cone-sheet fractures, unfilled by magma, seems to be indicated by the erosion-featuring of the mass (p. 160). Possibly an intrusion of the Ben Hiant magma into such a fissure is represented by an inclined sheet with ill-defined edges which traverses the dolerite on the north-west slope of Ben Hiant. The sheet-rock is a very fine-textured dolerite of Ben Hiant type (S26108) [NM 5352 6346]. Since it is not contact altered it cannot be xenolithic, and it must therefore be intrusive in relation to the main mass.

Variolite

On the Memoir-map the variolite (lettered qD') has been separated from the doleritic portion of the Ben Hiant Intrusion. As its occurrence is of considerable interest the mass is described in detail.

In the hand-specimen the typical variolite is black and sub-vitreous. Such rocks are seen in the field to pass gradually downwards, by increase in number and size of crystals, into normal Ben Hiant dolerite. The outcrop covers a narrow area on the upper slopes of the mountain, west-south-west of the summit ((Figure 10), p. 122). For the most part the variolite forms a comparatively thin layer over the dolerite, and it nowhere extends in depth like a dyke. The elongate shape of the outcrop down the hillside appears to be partly the effect of downthrow along two north-west crush-lines that cross the outcrop; the higher portions of the outcrop, however, east of the more westerly crush-line, contribute to the effect by being inclined slightly downhill towards the west. West of this crush-line the variolite forms a flat capping at the top of steep slopes above the dyke-like portion of the Ben Hiant Intrusion. Along the top of the capping small vesicles are developed in the variolite. This capping is exposed in section along a stream, on the north side of which it forms a 20-ft. cliff (Figure 21). The variolite is there prismatically jointed, with narrow six-sided columns inclined gently to north-north-east. In the underlying dolerite the more widely spaced vertical jointing that is characteristic of the Ben Hiant Intrusion is developed. The hexagonal columns of variolite are of much smaller diameter than those already described from a basal portion of the Ben Hiant Intrusion (p. 161). There is thus similarity between the columnar structures developed in the Ben Hiant mass and those of the pitchstone lavas of the Southwest Vent (p. 128).

The gradation downwards of variolite into dolerite is well seen in the cliff-section above mentioned. Towards the base of the cliff, small scattered felspar crystals make their appearance. These increase gradually in the downward direction both in size and abundance, and form crystal-groups. At a slightly lower level the groups coalesce into a delicate crystal network with meshes of variolite. Finally, variolite becomes further reduced in amount and occurs as streaks and patches in a doleritic rock. The conclusion was reached in the field that the felspars had grown out of the variolite ground-mass, and this is confirmed by microscopic examination (p. 171).

The above evidence points to the variolite being a quickly cooled upper portion of the Ben Hiant Intrusion. The chief objections to this interpretation are, the inclined disposition of the layer of variolite on the upper slopes of Ben Hiant, and the narrowness of the outcrop. These difficulties, however, may not be of fundamental importance. It is not impossible to imagine a ventinfilling, consolidated beneath its own quickly cooled crust, having a concave upper surface: and of this crust the variolite seen may be a remnant. Similarly, if narrowness of outcrop cannot be regarded as due merely to the chances of denudation, it may be surmised that a first-formed crust of variolite was broken through during a renewed upward movement of magma, and that a portion north of the elongate outcrop now seen became displaced.

Other occurrences of variolite in connexion with the Ben Hiant Intrusion are as follows. Along the south-east margin, the baked older rocks in contact with the Ben Hiant dolerite are penetrated by thin veins of variolite, evidently derived from the margin of the intrusion, though their actual continuityhas not been proved. Again, thin sheets of variolite occur here and there in the dolerite, and are probably auto-intrusions of the dolerite magma. Good examples traverse a scarp of dolerite that overlooks Camas na Cloiche Moire bay, some 450 ft. above sea-level. These variolite sheets have thin selvages of glass (S21452) [NM 5203 6321], and they seem to lend support to the conclusion already arrived at that the Ben Hiant dolerite magma when quickly cooled solidified as variolite.

Xenoliths

The Ben Hiant dolerite contains in certain places a considerable amount of xenolithic material. At various localities in the hollow north of the summit, and in the long tongue projecting from there towards Loch Mudle, xenoliths of schist are very abundant. The fragments are angular and crowded together in a matrix of dolerite, or occur more sparsely in all stages of resorption (S21456) [NM 5410 6458], (S22456) [NM 5410 6458]. Interesting changes in the dolerite are thus produced.

Another locality where xenoliths are plentiful is on the coast, about 150 yds. north-west of the south-east margin of the intrusion. A number of small basic xenoliths occur, but large elongate blocks of big-felspar basalt up to 8 yds. long are especially conspicuous. The dolerite is either in sharp contact with these large xenoliths or appears to be corroding their margins, enclosing the large felspars as xenocrysts. Acid veins traverse both dolerite and xenoliths. The xenoliths were presumably derived from the adjoining agglomerates, in which large blocks of big-felspar basalt are of common occurrence.

A still larger mass of porphyritic basalt, probably xenolithic, outcrops alongside a stream three quarters of a mile west of the summit of Ben Hiant. It is some 50 yds. long by 20 yds. in breadth, but no contacts with dolerite are seen. J.E.R.

Petrology of Ben Hiant Intrusion

(Anal. II, (Table 2), p. 82)

Normal types

The Ben Hiant mass is a somewhat variable but very beautiful quartz-dolerite. Its structure is that of a nonporphyritic ophitic dolerite having a varying amount of micro-crystalline and semi-glassy mesostatic matter. Its most important crystalline components are olivine, aluminous augite, labradorite felspar, and ilmenite. The base is composed of acid plagioclase and alkali-felspar in skeletal growths, quartz, acicular augite, a little finely divided iron-ore, somewhat abundant apatite, and glass. The olivine is a pale optically positive variety moderately rich in iron, but well removed from the fayalite end of the series. Frequently it is quite fresh (S21449) [NM 5263 6223], (S22296) [NM 5325 6252] or only partly decomposed. Occasionally it builds well-shaped crystals, but more commonly it is quite irregular in form. It was an early product of consolidation but it was not always earlier than felspar, for some lath-shaped crystals of basic plagioclase are frequently enclosed by it in an ophitic fashion. The augite encloses it and the early felspars indiscriminately. In some examples (S22453) [NM 5237 6491], (S21253) [NM 526 629] it is represented by pseudomorphs, and quite commonly it is replaced by a dull-green substance, with low refractive index and birefringence, referable to chlorophaeite (S21253) [NM 526 629], (S22450) [NM 5390 6332].

The augite is a normal aluminous variety containing possibly a small amount of titanium, but the lilac tint indicative of a high titanium content is wanting. The colour is pale greenish-brown in thin section and there is no pronounced pleochroism. In many dolerites where augite is in contact with a siliceous and alkaline mesostasis, it is fringed with a narrow layer of green colour indicating the presence of the alkaline molecule, but this has not been noticed in the case of the Ben Hiant quartz-dolerite.

The felspars are small, twinned, and somewhat irregularly rounded lath-shaped crystals of labradorite, which seldom if ever show a porphyritic tendency. They are usually zoned by increasingly acid varieties culminating in oligoclase, and, as might be expected, these crystals present rather indefinite boundaries to the mesostasis when they are in contact with it. The mesostasis is a very interesting and important part of the rock. It is variable both as regards quantity and distribution, and the variation appears to be related to the structure of the more coarsely crystalline portions of the rock. Where the amount of mesostasis is small or segregated into lakes (S21449) [NM 5263 6223], (S21454) [NM 5352 6407], the rock has a well-marked ophitic structure, but where the distribution is more general and the amount greater (S22453) [NM 5237 6491], (S22454) [NM 5312 6409], the rock has a finer texture and a tendency to assume a glomero-porphyritic structure. The mesostasis itself consists largely of alkali-felspar and quartz. The felspar exists chiefly as skeletal growths of orthoclase with some albite, and to some extent is an obvious product of the devitrification of an alkaline glass. It also forms feathery growths with quartz (S22450) [NM 5390 6332], and merges insensibly into a residual pale-brown glass (S22454) [NM 5312 6409]. The mesostasis invariably carries acicular crystals of augite, sometimes of minute dimensions. The larger crystals of augite are columnar in habit and are studded with magnetite along their margins (S22453) [NM 5237 6491], after the manner of the columnar augites of the quartz-dolerites of Mull.<ref>H. H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924, p. 302.</ref> One of the most striking features of the mesostasis is the great concentration of apatite which has been effected within it and which shows as abundant slender crystals of this mineral. A similar concentration of apatite in a residual partial magma is a more or less constant feature of the quartz-dolerites, and was discussed in connexion with rocks of this class in Mu11.<ref>H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924*.,* p. 329. a. H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924, pp. 304–305.</ref> Although differing in certain respects from the bulk of the cone-sheets (p. 159), the Ben Hiant quartz-dolerite is clearly a representative of the same magma-type. It will be seen from a comparison of analyses (p. 82), that the average cone-sheet and the Ben Hiant quartz-dolerite are for all practical purposes of identical composition, and thus the rocks must be regarded as having been furnished by the same magma, or by similar magmas that had reached the same stage in their respective courses of differentiation. Further, it is quite clear that the Ben Hiant Intrusion is representative of a moderately basic phase of the Normal Magma-Series ((Figure 6), p. 80).

Variolite

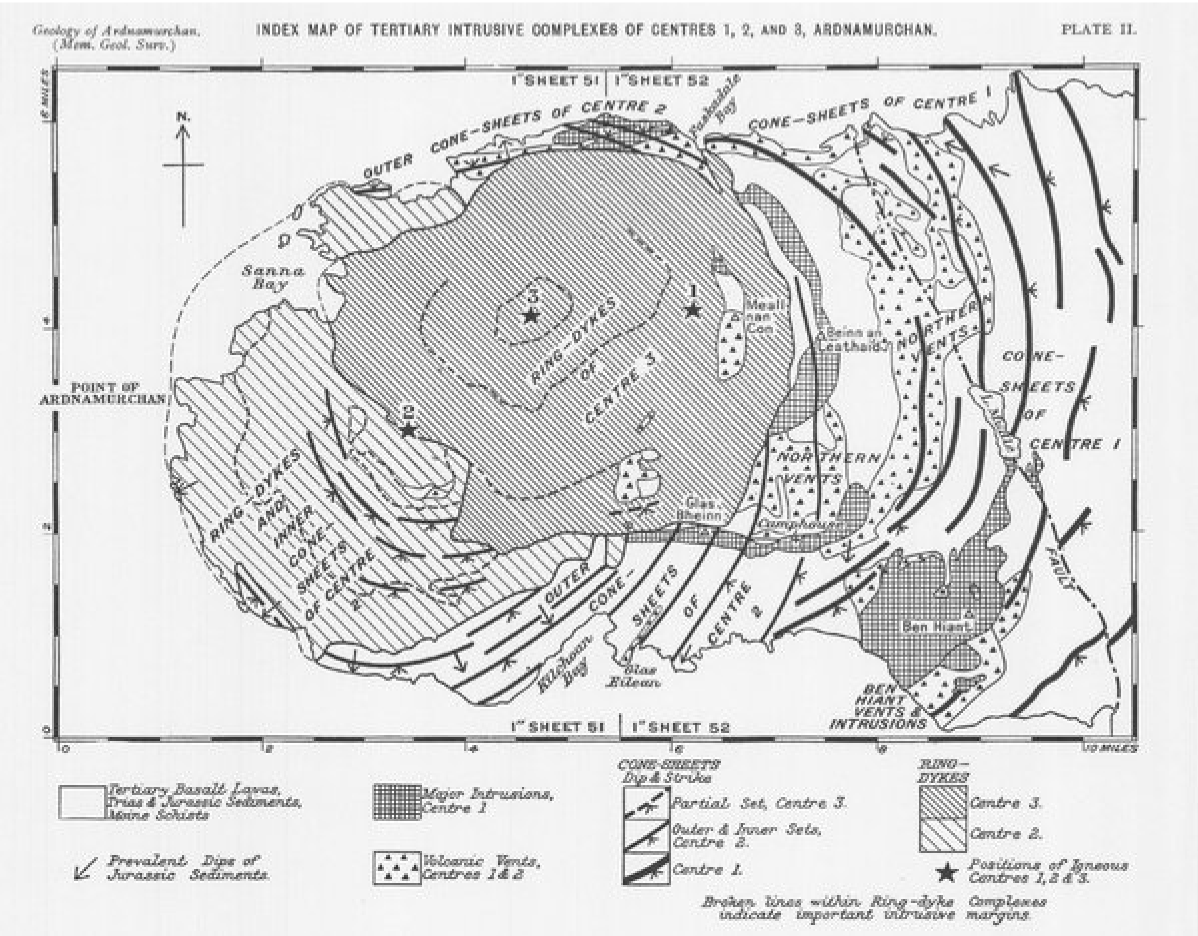
Aportion of the Ben Hiant mass, possibly a rapidly chilled part of the intrusion, is an aphanitic rock with a most beautifully developed variolitic structure ((Figure 22), B.). The bulk of this variolite when examined microscopically exhibits a structure that is practically identical with that of the variolitic cone-sheets of Cruachan Dearg in Mull.<ref>H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924, pp. 302–303.</ref> In its most completely variolitic development, in the flat capping mentioned above, it is of uniform texture in the hand-specimen. It shows, however, small glomero-porphyritic groups of augite and felspar which become increasingly numerous and more coarsely crystalline as the normal quartz-dolerite is approached.

Microscopically, the variolite (S22451) [NM 5306 6297], (S24235) [NM 531 630] consists of slender blade-like crystals of yellowish-brown augite, elongated parallel to the *c* axis, long rods of magnetite which often connect transversely the augite blades, and a fine feathery growth of oligoclase-andesine felspar in the form of slender skeletal crystals frequently with forked terminations and glass inclusions. As noted in the case of the variolites of Cruachan Dearg in Mull, the felspar occasionally aids in determining the variolitic structure, but more frequently forms radial or feathery groups that have no definite relation to the disposition of the early augites. In this part of the matrix, however, we may note an approach to the cervicorn structure so characteristically developed in certain of the cone-sheets of Mull.<ref>H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924, pp 302–303.</ref>

The variolite contains a few small glomero-porphyritic groups of brownish aluminous augite and labradorite felspar, also isolated felspars of similar composition. The augite is subophitic with respect to felspar, but hypidiomorphic towards the variolitic base. The felspars when in contact with the variolitic matrix generally have long skeletal outgrowths, and show other signs of rapid growth under conditions of chilling.

The passage from variolite to quartz-dolerite is illustrated by a suite of specially collected specimens. Proceeding downwards towards the normal quartz-dolerite the variolite becomes more obviously crystalline through the greater abundance of glomeroporphyritic patches and the relative subordination of the variolitic matrix (S24236) [NM 531 630]. The same mineralogical and structural features obtain, however, and the observed differences, at any rate for some distance, are merely of degree. The individuals comprising the crystal groups are now of larger dimensions, and the augite is more coarsely ophitic. The variolitic structure of the matrix, as outlined by blade-like augite and rods of magnetite, becomes somewhat less definite, and the place of much of the blade-like augite appears to be taken by thicker and less frequent columnar crystals that are intimately associated with magnetite (S24237) [NM 531 630]. At the same time the ultimate felspathic base, while still retaining a feathery intersertal crystalline texture, becomes more alkaline in character, and shows a tendency to approximate to the composition of the normal mesostasis of the quartz-dolerite and to separate free quartz. Olivine also begins to make an appearance, chiefly as small crystals in the matrix (S24237) [NM 531 630]. The rod structure of the magnetite still persists. Still nearer the normal quartz-dolerite the matrix is more reduced in bulk. It no longer has a true variolitic structure, but exhibits an abundance of skeletal growths of acid plagioclase felspar and plentiful magnetite in a brownish glass that yields quartz as a product of devitrification. Semi-columnar crystals of augite are of frequent occurrence in an unaltered condition, but traversing the same glassy matrix are deep yellowish-brown platy pseudomorphs which I regard as representing fayalite (S24239) [NM 531 630]. The crystallization of fayalite from siliceous melts is well known, both in natural and artificial processes, and from the habit and nature of the pseudomorphs it would appear to have been the ferrosilicate that crystallized in the acid base of the rock under description. The glomero-porphyritic grouping of the more basic plagioclase and ophitic augite is the dominant feature of the mass as it approaches the quartz-dolerite type, but there is also a more marked tendency to a columnar crystallization of augite in the matrix. The mesostasis still retains a subvariolitic structure, but this is outlined by what I consider to have been fayalite rather than by augite as was the case in the more basic and more rapidly chilled variolites.

To sum up the gradual changes from the true variolite to the normal quartz-dolerite, there appears to be a thick variolitic portion, which gives place in a distance of a few feet to the normal type by a gradual increase in the coarser crystalline elements, accompanied by a steady but slight increase in the siliceous character of the residuum. This gradual change in the composition and bulk of the residuum is accompanied by a gradual suppression of the true variolitic, in favour of a skeletal, type of crystallization and a development of fayalite. A marked tendency to the development of variolitic structure is also exhibited by certain glassy auto-intrusive sheets (S21452) [NM 5203 6321] (p. 168) that occur within the Ben Hiant main intrusion. H.H.T.



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

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 .

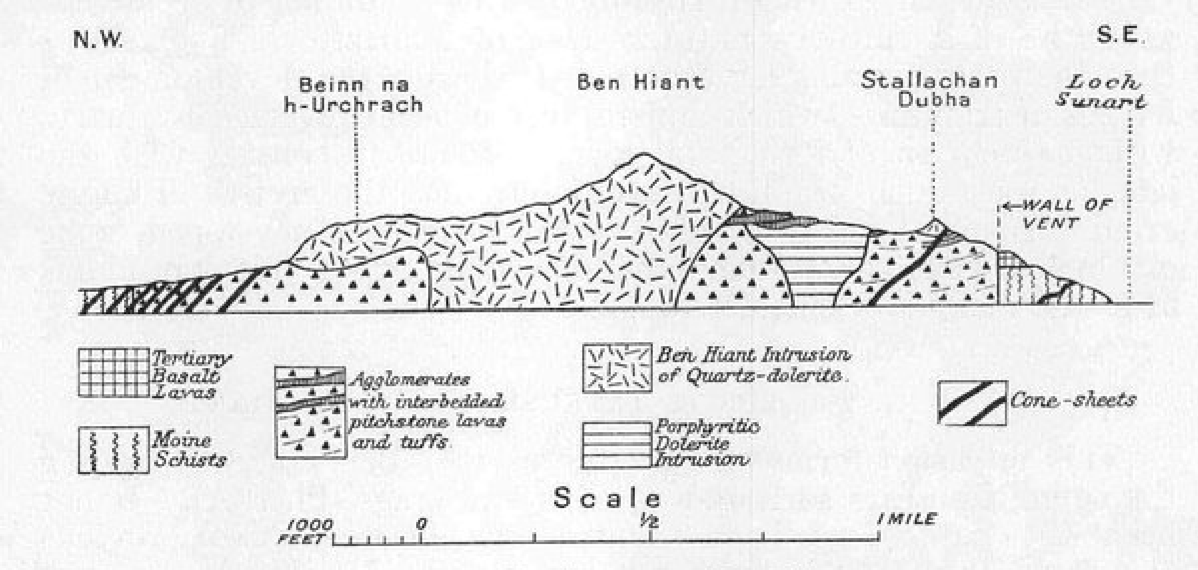


FIG. 19.—Section across Ben Hiant.

(Figure 19) Section across Ben Hiant.

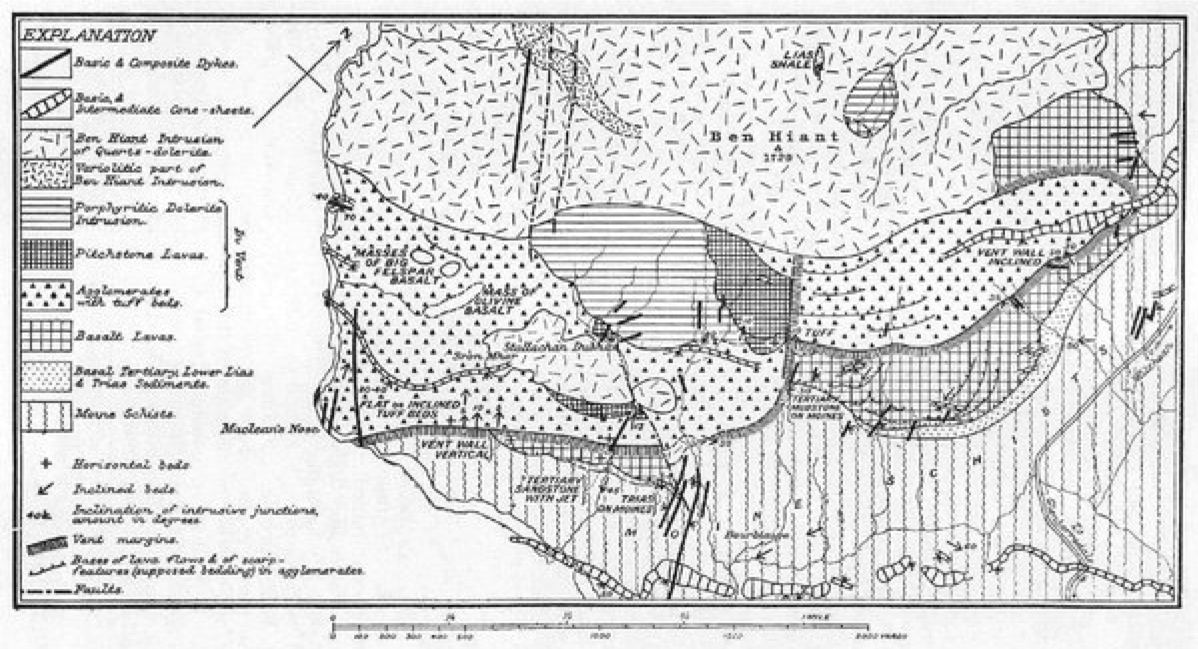


FIG. 10.—Map of Vent-Complex, eastern side of Ben Hiant.

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

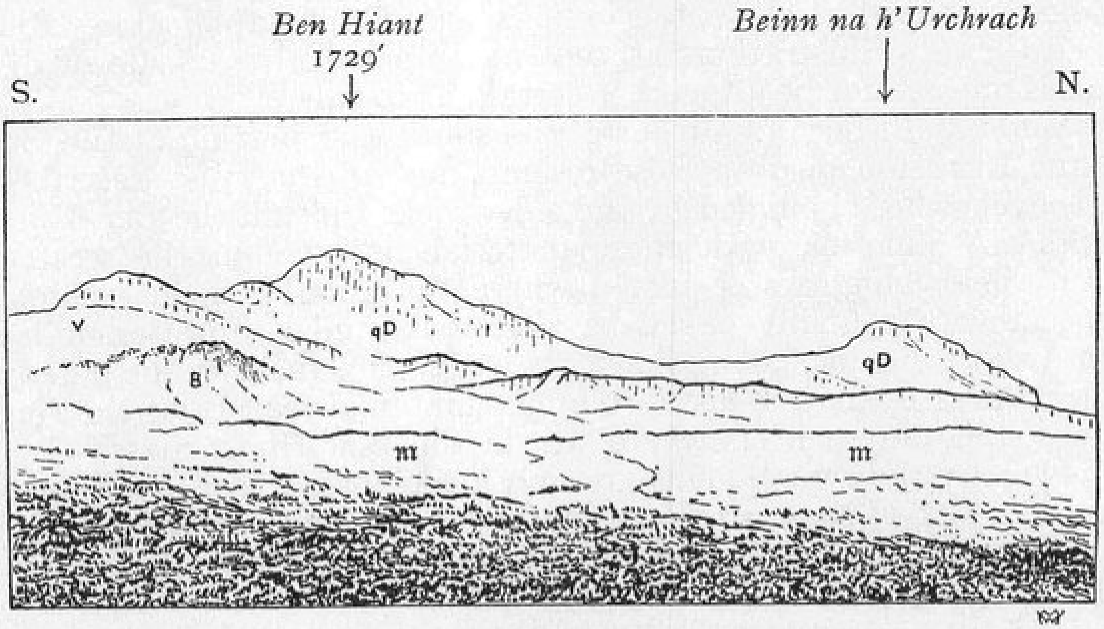


FIG. 20.—*View of Ben Hiant from east.*

m, *Moine Schists.* B, *Tertiary basalt lava.* V, *Vent-agglomerate.*
qD, *Ben Hiant Intrusion.*

(Figure 20) View of Ben Hiant from east, in, Moine Schists. B, Tertiary basalt lava. V, Vent-agglomerate. qD, Ben Hiant Intrusion.

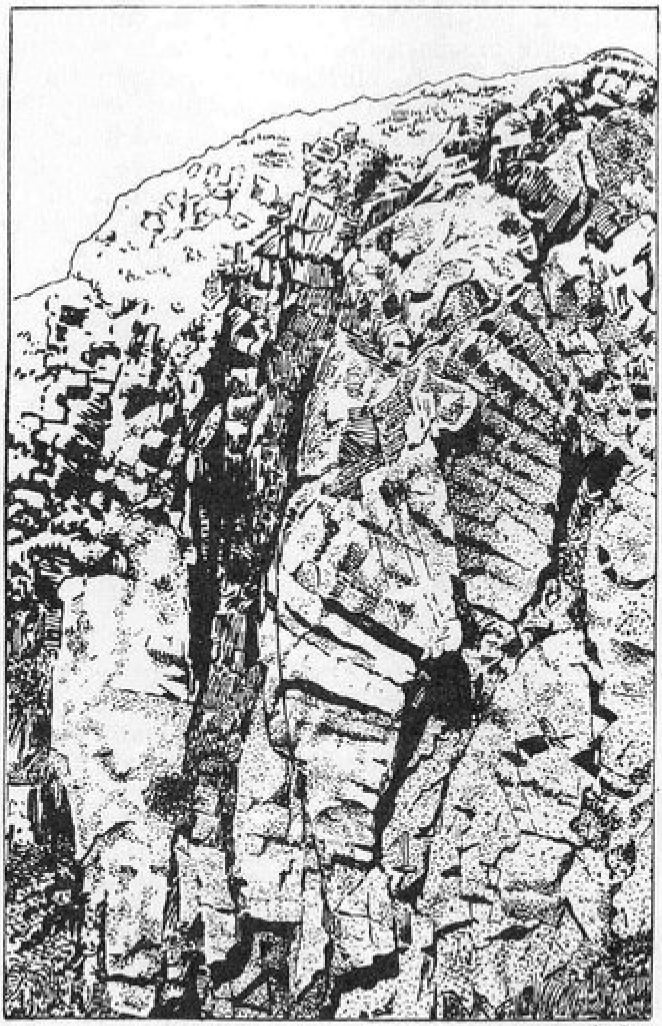


Fig 21..—*Twenty-foot cliff of columnar variolite (part of Ben Hiant Intrusion), traversed by crush-line, south-west side of Ben Hiant.*

Drawn from Geological Survey Photograph No. C. 2852.

(Figure 21) Twenty-foot cliff of columnar variolite (part of Ben Hiant Intrusion), traversed by crush-line, southwest side of Ben Hiant. Drawn from Geological Survey Photograph No. C. 2852.

TABLE II

NON-PORPHYRITIC CENTRAL MAGMA-TYPE (*see* Fig. 6).

	Quartz-dolerite.					
	I.	II.	III.	IV.	A.	
SiO_2	50·10	50·67	50·79	51·06	52·16	SiO_2
Al_2O_3	12·08	11·89	12·10	11·79	11·95	Al_2O_3
Fe_2O_3	4·35	8·61	4·10	3·41	4·86	Fe_2O_3
FeO	11·18	7·08	11·29	11·68	9·92	FeO
MgO	3·93	3·94	4·02	4·35	3·77	MgO
CaO	8·85	7·75	8·05	7·57	7·14	CaO
Na_2O	3·06	2·94	3·50	3·36	2·36	Na_2O
K_2O	0·96	1·50	1·30	1·23	1·74	K_2O
$H_2O > 105°$ ..	1·01	0·77	0·23	0·92	1·95	$H_2O > 105°$
$H_2O < 105°$ ..	0·53	1·05	1·56	0·56	0·56	$H_2O < 105°$
TiO_2	2·98	2·88	2·46	3·10	3·25	TiO_2
P_2O_5	0·17	0·55	0·22	0·23	0·24	P_2O_5
MnO	0·25	0·20	0·26	0·20	0·18	MnO
CO_2	trace	0·21	0·17	—	0·18	CO_2
FeS_2	0·28	0·02	0·28	—	—	FeS_2
Fe_7S_8	0·02	—	—	—	—	Fe_7S_8
SO_3	—	0·38	trace	—	—	SO_3
S	—	—	—	0·11	0·18	S
Cr_2O_3	trace	trace	0·02	—	—	Cr_2O_3
(Co, Ni)O ..	—	0·00	—	—	—	(Co, Ni)O
BaO	0·05	0·02	trace	0·00	—	BaO
LiO	—	0·00	trace	—	—	Li_2O
Cl	—	—	—	0·00	—	Cl
C	—	—	0·04	—	—	C
Organic matter	—	0·01	—	—	—	Organic matter
	99·80	100·47	100·39	99·57	100·44	

I. (22819; Lab. No. 788.) Quartz-dolerite, Talaidh type. Cone-sheet, Centre 2, Ardnamurchan. Quarry west of crofts at Tom a'Chroch-aidh, ½ mile E. of Kilchoan. *Anal.* B. E. Dixon.

(Table 2) Non-porphyritic Central Magma-Type (see (Figure 6)).

	Plateau Type	Non-Porphyritic Central Type		Intermediate & Sub-Acid Types			Acid Type	
%								%
SiO_2	45	47	50	55	60	65	70	SiO_2
Al_2O_3	15	14	13	13	13	12	12	Al_2O_3
$FeO + Fe_2O_3$	13	13	13	11	8	6	4	$FeO + Fe_2O_3$
MgO	8	6·5	5	4	3	1·7	0·3	MgO
CaO	9	10	10	7	5	3	1·5	CaO
Na_2O	2·5	2·6	2·8	3	3·3	3·5	3·3	Na_2O
K_2O	0·5	0·7	1·2	1·7	2·2	3	4	K_2O
TiO_2	2·5	2·5	2·5	1·8	1·2	1·0	0·5	TiO_2

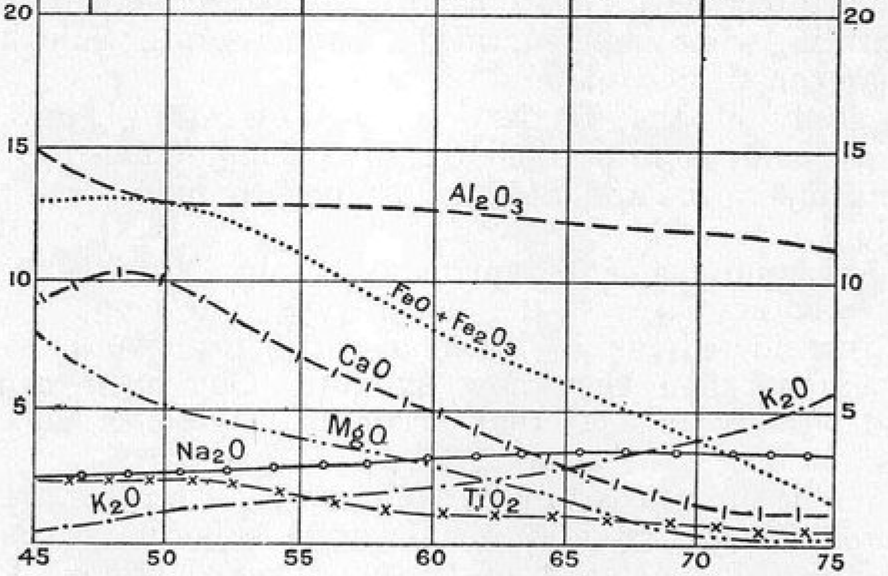


FIG. 6.—*Variation-Diagram, Normal Magma-Series.*

(Figure 6) Variation-diagram, Normal Magma-Series.

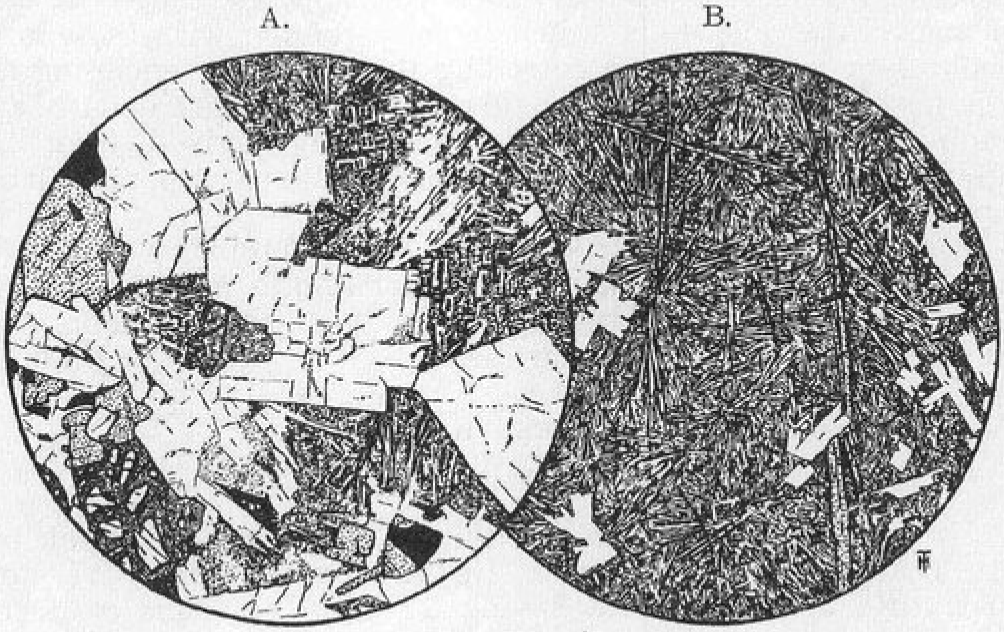


FIG. 22.—*Ben Hiant Intrusion.*

A. (22296) × 20. *Quartz-dolerite. The section shows partly decomposed olivine, labradorite felspar, augite, and ilmenite in a matrix of skeletal felspars, acicular augite, quartz and iron-ore.*
B. (24235) × 20. *Variolite. Small phenocrysts of labradorite felspar in a base consisting of blade-like crystals of yellowish-brown augite, long rods of magnetite, and a fine feathery crystallization of oligoclase-andesine felspar.*

(Figure 22) Ben Hiant Intrusion. A. (S22296) [NM 5325 6252] × 20. Quartz-dolerite. The section shows partly decomposed olivine, labradorite felspar, augite, and ilmenite in a matrix of skeletal felspars, acicular augite, quartz and iron-ore. B. (S24235) [NM 531 630] × 20. Variolite. Small phenocrysts of labradorite felspar in a base consisting of blade-like crystals of yellowish-brown augite, long rods of magnetite, and a fine feathery crystallization of oligoclase-andesine felspar.