Chapter 7 Tertiary igneous rocks, Ardnamurchan and North-west Mull, time sequence

The western portion of the Ardnamurchan peninsula is formed of a complex of vents and intrusions penetrating Tertiary plateau basalt lavas, Mesozoic sediments, and Highland schists. The complex covers a smaller area and is relatively simpler than its neighbour of Central Mull, though built to an essentially similar plan. Its vent-agglomerates are chiefly made up of trachytic and acid materials, together with fragments of big-felspar basalt. Its characteristic intrusions are cone-sheets and ring-dykes.

The complex on three sides is bordered and to some extent encroached upon by the sea. Only its western portion, forming the nose of the peninsula, lies within one-inch Sheet 51, and the remainder extends eastwards for some five miles into Sheet 52. To meet these circumstances a description of the whole complex is given in the present Memoir and is illustrated by a coloured Memoir-map.

North-west Mull, which is included within Sheet 51, is almost entirely covered by the Tertiary plateau lavas. There are, however, numerous north-west dykes belonging to the Mull Swarm, and a few dolerite plugs and basic inclined sheets. The sheets die out southwards, and are probably outlying intrusions from the Ardnamurchan igneous focus. In the Memoir<ref>The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban, *Mem. Geol. Surv.,* 1924. For the sake of brevity this Memoir will be termed in succeeding references 'Tertiary Mull Memoir.</ref> dealing with the Island of Mull as a whole, this north-west portion has been already described. No further reference will be made to it in the present chapter, and attention will be confined to the Ardnamurchan area.

Igneous complex of Ardnamurchan

Igneous activity in Ardnamurchan subsequent to the plateau basalt lavas consisted of a number of intrusive phases. These succeeded one another, in most cases, with a clearly indicated time sequence, though the detailed history of the various phases is often difficult to unravel. The district seems of especial value in that it illustrates in a comparatively simple manner many of the remarkable features of British Tertiary intrusive activity, that attains its grandest expression in Mull and Skye. In both Mull and Ardnamurchan, volcanic vents and hypabyssal and plutonic intrusions occur in arcuate outcrops that are arranged around central points, termed intrusion-centres. Three such centres are recognized in Ardnamurchan, and their close grouping and the concentration of the various intrusive masses permits a very complete time sequence to be worked out for the whole igneous cycle.

The investigation has been immeasurably assisted by the almost entire absence of glacial deposits and the consequent excellence of rock-exposure. The country is rugged and somewhat mountainous, but on the whole is one of comparatively low relief, the highest hill, Ben Hiant, being less than 2000 ft. in height. The low relief renders many features of the igneous geology difficult to elucidate, but has the merit of allowing of easy access; and roads or tracks are available for reaching almost every part of the district.

In the following pages an introductory account of the igneous sequence will first be given. This will be followed by more detailed descriptions, and finally by certain general conclusions in the formulation of which Ardnamurchan will be considered in conjunction with Central Mull.

Statement of the sequence

In Ardnamurchan, basalt lavas are met with as small outliers resting on the pre-Tertiary rocks or as masses contained within volcanic vents of later date. They form a portion, or a continuation, of the plateau group of Mull and Morven.

Subsequently to the lavas, intrusive complexes associated in their earlier stages with volcanic vents were formed around three successive centres (*see* (Plate 2), p. 71). In the earliest complex, around Centre 1, agglomerates and other materials were accumulated within vents, and were followed by arcuate major intrusions and cone-sheets. The major intrusions are few in number, and certain of them are probably true ring-dykes. The more acid masses are characterized by containing xenoliths of schist, which are also found locally in one of the basic intrusions (Ben Hiant). The cone-sheets are abundant, and the majority are relatively massive.

In the next complex, around Centre 2, only one arcuate strip of vent-agglomerate is known (Glas Eilean Vent), which is situated towards the outer margin of the area affected by intrusion. Cone-sheets and ring-dykes are on the other hand well developed, and brecciation by explosive gases frequently accompanies the ring-dykes. Many of the ring-dykes contain abundant igneous xenoliths mainly of cognate fine-grained types. The cone-sheets are thinner than in the preceding phase, but attain a maximum development in point of numbers. The majority, constituting an Outer Set, are concluded to be earlier than all the ring-dykes that belong to Centre 2. The remainder form an Inner Set traversing many of these ring-dykes.

Lastly, Centre 3 came into existence situated midway between the two centres that preceded it, and its intrusions obliterated large portions of the earlier complexes. These intrusions consist almost entirely of ring-dykes, in connexion with which brecciation by explosive gases is rarely found, while igneous xenoliths are only of local occurrence. Cone-sheets are also developed, but are thin and very sparse.

The successive events outlined above may be summarized as follows:

Centre 3 (latest)	Ring-dykes, the outermost and oldest of which is cut by a few thin cone-sheets.
Centre 2	Ring-dykes, the majority of which are earlier than an Inner Set I of cone-sheets, while probably all are later than an encircling Outer Set of very numerous cone-sheets. Linear vent of Glas Eilean, later than Outer Cone-sheets.
Centre 1	Set of massive cone-sheets, and the major intrusions of Ben Hiant Centre 1 and Beinn an Leathaid in part sheet-like. Major dyke-like and plug-like intrusions. Volcanic vents.
Plateau Basalt Lavas	

In addition to the above, there are basic dykes mainly trending north-west, many of which may belong to the Mull Swarm (Figure 49) and (Figure 50). Some, however, together with dykes of acid composition, are referred to an Ardnamurchan suite. As in Central Mull, the dykes, both basic and acid, are of various ages. Some, of big-felspar basalt, are of early date, being invariably cut by the Outer Cone-sheets of Centre 2. Others can be shown to be later than certain of these cone-sheets and earlier than others. Some again traverse the ring-dykes of Centre 3 and are the latest intrusions known.

The regional crustal tensions typical of the Tertiary igneous province of Britain and manifested by the north-westerly dykes must therefore have operated in Ardnamurchan during its period of localized activity. Striking evidence of late crustal stresses is supplied by very numerous crush-lines, some demonstrably tear-faults, that traverse the latest ring-dykes in no less abundance than they do the earlier complexes. The crush-lines are rarely accompanied by dyke-intrusion.

Detailed description of the sequence

The foregoing statement of the igneous history of Ardnamurchan is amplified in the fuller descriptions given below, in which the essentially successive character of the igneous episodes is especially stressed.

Basal Tertiary beds underlie the plateau lavas and are markedly unconformable to the Mesozoic sediments and the schists. They consist of red or greenish mudstone, often ashy in character, below which sandstone, believed to be of Tertiary age, is locally present. A mudstone has also been traced throughout Mull at the base of the lavas, and has been ascribed in the Mull Memoir<ref>G. W. Lee *in* Tertiary Mull Memoir, 1924 p. 59.</ref> to the lateritic decay of a widespread basaltic ash that indicates an initial explosive phase. This is followed both in Mull and Ardnamurchan by the basalt lavas belonging to the great plateau group. Very few ash-intercalations have been found in Mull, and in

Ardnamurchan none at all. The outpouring of each successive flow was frequently followed by an interval long enough for the lava-top to be covered by a layer of red earth or bole as a product of subaerial weathering. In Ardnamurchan only a few hundred feet of the plateau lavas are seen, but in Central Mull upwards of 3,000 feet are preserved. The Ardnamurchan lavas are for the most part identical in composition with the Plateau Type of Mull, being microporphyritic or nonporphyritic olivine-rich basalts. Lavas with little or no olivine allied to the Central Type of Mull are also encountered, and are sometimes porphyritic. They are interbedded with the Plateau Type, and are especially prevalent among lavas that have probably been down-faulted within the volcanic vents.

Whether an Ardnamurchan volcanic focus was in existence during the basalt lava period is indeterminable. The complexes of vents and major intrusions which occupy so large a part of the district are of altogether later date. There is also no definite evidence that the lavas originated by local fissure eruptions, for no demonstrably early dykes of similar composition to the lavas traverse the widely exposed platform of older rocks upon which the lava-outliers rest. Such early dykes as are known are chiefly composed of big-felspar basalt, a rock-type that is also met with as blocks in the vent-agglomerates.

Centre 1

The volcanic vents of Centre 1 constitute the first evidence of the initiation of an Ardnamurchan igneous focus, for so far as known they are altogether earlier than the major intrusions and cone-sheets that are related to the same centre. Among the fragments found in the agglomerates, however, there are intrusive hypabyssal types, such as quartz-dolerite, while other evidence of pre-vent intrusion is supplied by a composite dyke that is cut off by the margin of a vent (p. 347).

The largest vent, or group of vents, included in what are termed the Northern Vents, is only in part preserved, for at either end it is bounded to the west by the Ring-dyke Complex of Centre 3, within which remnants of its materials are found as screens or cappings of agglomerate. Moreover, to the north, it is partly hidden under the sea. A considerable proportion of its agglomerate consists of brecciated country rock, mainly schist and basalt lava, but fragments of trachytic and acid volcanic rocks are also present in greater or less abundance almost everywhere. Another feature is the inclusion within the vent-complex of large areas of basalt lavas and considerable masses of Mesozoic sediments which may have slipped down bodily into their present position.

Beyond the southern limit of the Northern Vents is situated a second important vent-complex termed the Ben Hiant Vents. In contrast to the Northern Vents, the Ben Hiant complex is excellently exposed. The evidence on the south-east side of the hill shows fairly conclusively that the complex includes at least two successive volcanic orifices, each of which must have originated in stupendous explosions forming wide, open craters ((Figure 10), p. 122). The later, more southerly vent measures upwards of a mile in width, while its walls, composed partly of plateau basalts and partly of pre-Tertiary rocks, must have risen at least 1100 ft. above the original crater-floor. Within this great cavity a succession of beds of agglomerate and tuff were laid down, and at intervals pitchstone lavas were poured out which are now found as prismatically jointed sheets with amygdaloidal tops, interbedded among the fragmental accumulations. The agglomerate of both Ben Hiant Vents consists for the most part of angular pieces of trachyte, rhyolite and other acid rocks, often vesicular, which in the first instance consolidated presumably as lava in the environment of the crater, and were broken up by subsequent explosions. In addition, large blocks of big-felspar basalt with rounded or sub-rounded outlines may perhaps be bombs, though some are of enormous proportions (Plate 1), B. Fragments of schist such as are locally abundant in the Northern Vents are never found in the Ben Hiant Vents, so that it would appear that the latter vents cleared themselves by particularly powerful or long-sustained explosions.

A plug or crater-infilling of porphyritic dolerite is now found intruded in the agglomerate of the more southerly vent, but of much more importance is a large intrusive mass of non-porphyritic quartz-dolerite, termed the Ben Hiant Intrusion ((Figure 19), p. 160). This mass links the history of the vents with the succeeding period of the cone-sheets of Centre 1. It is of exactly similar chemical composition to the basic cone-sheets, and apophyses extend from it which conform to the strike and dip of cone-sheets in their neighbourhood. It also bears a resemblance to a crater-infilling, for it rises from sea-level as a plug-like mass and then spreads out sideways at a height of 600 to 1000 feet as though occupying a volcanic orifice. Further, there is evidence that a remnant of chilled surface belonging to this upper portion has been preserved as a capping of prismatically jointed variolite that lies along the upper western slopes of Ben Hiant and very clearly grades downwards into the normal dolerite ((Figure 21), p. 167). At sea-level, a thousand feet below, where the intrusion makes contact with its wall of agglomerate, very different conditions prevailed. The edge of the dolerite is there quite unchilled, and its marginal portion is penetrated by acid veins such as characterize the margins of many ring-dykes.

Time relations between the individual major intrusions of Centre 1 cannot be fully determined, since they are rarely seen in contact with one another. Their age relatively to the massive eastern cone-sheets that conform to the same Centre 1s also not directly determinable, except in one case on the south side of Ben Hiant, where a single cone-sheet cuts an outlying portion of the Ben Hiant Intrusion. Many of them are traversed by the Outer Cone-sheets of Centre 2, an observation that fixes a definite upper limit to their age.

Massive cone-sheets developed in the eastern part of the area have just been referred to as conforming to Centre 1, about which they are arranged concentrically. As all other evidence points to Centre 1 being of earlier date than Centre 2, it is probable that these eastern cone-sheets are of earlier date than the cone-sheets farther west, but there is very little direct evidence. Most of the cone-sheets of both areas are-non-porphyritic quartz-dolerite.

Centre 2

The first incident connected with Centre 2 appears to have been a doming up of the country rocks around it, as is indicated by the observed dips of the Mesozoic sediments (Plate 2). Subsequent to this upheaval the main period for cone-sheet intrusion ensued, during which innumerable basic injections took place (*see* (Figure 23), (Figure 24), pp. 174, 175). The cone-sheets belonging to this, the Outer Set of Centre 2, are individually much thinner than the cone-sheets referred to Centre 1. They are mainly composed of nonporphyritic quartz-dolerite, as stated above, but porphyritic varieties become prevalent towards the inner margin of the group. As is true of cone-sheets generally, individuals of this suite always present chilled contacts to older rocks, even where these older rocks are merely earlier members of the same cone-sheet complex. This latter relationship is seen again and again, and gives an impressive demonstration of the essentially successive nature of cone-sheet intrusion.

Some of the cone-sheets of the Outer Set of Centre 2 are composite, with basic marginal portions and acid centres either in sharp though unchilled contact or separated by a passage zone of intermediate composition. In such cases the interval of time between the two injections was evidently brief, and frequently insufficient to allow the basic portion to solidify completely before the acid magma was intruded. There are a few examples of a similar kind among the cone-sheets of Centre 1.

At some time subsequent to the Outer Cone-sheets the linear vent of Glas Eilean was formed, the materials of which consist largely of brecciated country rocks, including cone-sheets, veined by acid tuff. It extends parallel to the trend of the Outer Cone-sheets in its neighbourhood, and thus conforms to Centre 2 ((Figure 13), p. 132).

The relative ages of the Outer Cone-sheets and the Ring-dykes of Centre 2 are determined by the fact that the outermost and probably oldest ring-dyke (the Hypersthene-gabbro, *a* of (Plate 5)) is practically free from all cone-sheets, while the Outer Cone-sheets that traverse the wall-rock outside are contact altered (*see* Fig 28, p. 219).

The intrusion of the Ring-dykes of Centre 2 was interrupted by the injection of the Inner Cone-sheets, belonging to the same centre. These cone-sheets are less abundant than the Outer Set, are much more steeply inclined, and are almost all porphyritic dolerites. No example of composite habit has been noted. The ring-dykes traversed by the Inner Cone-sheets are:the Hypersthene-gabbro (a),<ref>The index-letters applied to individual ring-dykes in this and subsequent chapters are as given on (Plate 5), p. 201, and (Table 8), pp. 201, 202.</ref> a much altered gabbro (*b*), a Granophyre (*c*), Quartz-gabbros (*c′*, *c″*, *d*), and a Quartz-dolerite veined by Granophyre (*e*). The ring-dykes that are uncut by the Inner Cone-sheets are all probably of later date and include:a Eucrite (*f*), and Quartz-gabbros (*g* and *h*). No complete time sequence can be arrived at for these various ring-dykes, but the order in which they are lettered is, so far as determinable, their order of intrusion.

Shattering of ring-dykes is, as already mentioned, more especially a feature of Centre 2. In one case it is evidently due to earth stresses. More frequently it is to be ascribed to the action of explosive gases given off from an intruding magma, and comparable to the brecciation met with in the walls of some volcanic vents, though of an especially intense kind. Shattering by earth stresses is exemplified by the outer margin of the Quartz-gabbro (*c*), which was highly sheared, with the development of flinty crush-rock, prior to the intrusion of the Inner Cone-sheets. Such localized shearing may have been connected with fault-movements along a ring-fissure, but since the ring-dyke now in contact with this margin, the Eucrite (*f*), is of much later date, its exact significance cannot be determined. As an instance of the shattering attributable to explosion, we may cite the Quartz-dolerite (*e*). This ring-dyke was injected along the inner margin of the Hypersthene-gabbro (a). The arc-shaped cavity which the Quartz-dolerite now occupies appears, in part at least, to have resulted from explosions. South of Sanna Bay, for example, its wall composed of the Hypersthene-gabbro is in an absolutely comminuted state, while xenoliths of the broken-up rock are found enclosed in the intruding Quartz-dolerite. The Quartz-dolerite after consolidation was itself brecciated and profusely net-veined by a succeeding granophyre magma ((Figure 34), p. 257). Another instructive example is provided by the Eucrite (*f*), which was shattered throughout much of its length and then granulitized. The shattering extends also to the innermost part of the Quartz-gabbro (*g*) in contact with the Eucrite. The explosive gases and the heat required for the granulitization were presumably derived from some later intrusion which underlies the Eucrite below the present level of denudation.

In the case of the Central Ring Complex of Arran the interconnexion of explosive brecciation and igneous intrusion has also been advocated by Dr. G. W. Tyrrell,<ref>G. W. Tyrrell, The Geology of Arran, *Mem. Geol. Surv.,* 1928, p. 168.</ref> while at Slieve Gullion in Ireland an example of alternating explosive and intrusive phases referable to a single ring-fissure, has been recorded by the writer,<ref>J. E. Richey, Tertiary Ring-dykes of Slieve Gullion, Ireland, *Rep. Brit. Assoc.* for 1928, 1929, p. 544.</ref> following on the work of Nolan.<ref>J.Nolan, On the Ancient Volcanic District of Slieve Gullion, *Geol. Mag.,* 1878, p. 445.</ref>

Centre 3

The ring-dykes which almost entirely constitute the complex of Centre 3 can be arranged fairly definitely in a time sequence, the older intrusions occurring at the periphery and the youngest in the interior. In the peripheral group the Quartz-gabbro (A), and probably the Fluxion Gabbro (B), are earlier than the Great Eucrite (E). This Eucrite is in turn earlier than probably all the ring-dykes of the interior.

Except for a narrow ring-dyke of eucrite (H) the Interior Complex within the Great Eucrite consists entirely of biotite-bearing ring-dykes including :Biotite-eucrite (G); Quartz-dolerite veined with Granophyre (I); Quartz-biotite-gabbros (J, J′, J″); Fluxion Biotite-gabbros (K, L); Tonalite (M); and a small central boss of Quartz-monzonite (N). The Great Eucrite (E) is seen to be cut by the Quartz-dolerite (I) and by the Fluxion Biotite-gabbro (K). Another Fluxion Biotite-gabbro (L) forms a practically complete ring-outcrop around the Tonalite (M), by which it is cut. The Tonalite is also demonstrably later than the Quartz-biotite-gabbros (J′, J″). The small central boss of Quartz-monzonite is later still.

In the case of Centre 3, as in Centre 2, ring-dyke intrusion was interrupted by the injection of basic cone-sheets. These traverse the southern portion of the Quartz-gabbro (A) ((Figure 39), p. 286), and appear to be a partially developed set. Individual cone-sheets near to the Great Eucrite (E) are highly contact altered, and for this reason the set as a whole is considered to be pre-Great Eucrite in age.

The prolonged time required for the formation of the two ring-dyke complexes may be appreciated in various ways. For instance, if we consider the order of intrusion of the various magma-types, we find that there has been repeated alternation, mainly of acid and basic gabbros (p. 209). Thus differentiation repeatedly affected the contents of the underground magma-reservoir during the formation of the ring-dykes. Again, the consolidation of a large individual mass such as the Great Eucrite (E) must have taken a considerable period for its completion. Its margins are unchilled, and its coarsely-crystallized minerals suggest slow cooling under plutonic conditions. A final phase of its crystallization, when the contained fluxes became concentrated, is represented by very coarse-textured areas of gabbro-pegmatite that occur throughout the intrusion, and also by abundant gabbro-pegmatite veins. There are differences in detail in regard to the cooling conditions of the various ring-dykes. For instance, the Hypersthene-gabbro (a) possesses a wide outer margin of finely-crystallized rock, which gradually passes into normal coarsely-crystallized gabbro towards the interior of the mass. The fact remains that the coarse interior must have taken a very long time to consolidate.

Ring-dykes as a rule produce much more marked contact alteration where adjacent to sediments, ashes, lavas or minor intrusions than where they come against earlier members of the ring-dyke complex. This is in keeping with general experience of plutonic contacts in other districts. It is evidently difficult to produce notable change in a fresh coarsely-crystalline igneous rock by reheating under,plutonic conditions. The careful examination that has been made of the various ring-dyke contacts shown in (Plate 5) demonstrates, however, that the time-interval between successive injections was always long enough to permit complete crystallization of the earlier of the two intrusions met with at any particular junction. Such considerations, on the basis of probabilities, lead us to the conclusion that the interval between two injections must, as a general rule, have extended considerably beyond the time taken in consolidation. An exception is provided by one of the ring-dykes of the Interior Complex of Centre 3, the Sìthean Mòr· Fluxion Biotite-gabbro (K), that is accompanied along part of its outer margin by a mass of quartz-biotite-gabbro (not shown separately in (Plate 5)). Between the two kinds of gabbro there is an interbanded junction with alternate bands composed of the fluxioned and quartz-bearing gabbros, and each variety of band becomes thicker towards the mass to which it corresponds ((Figure 47), p. 330). The most obvious explanation seems to be that the injection of the two gabbros in this particular case followed one another so closely that they became interbanded along their mutual junction.'

General conclusions

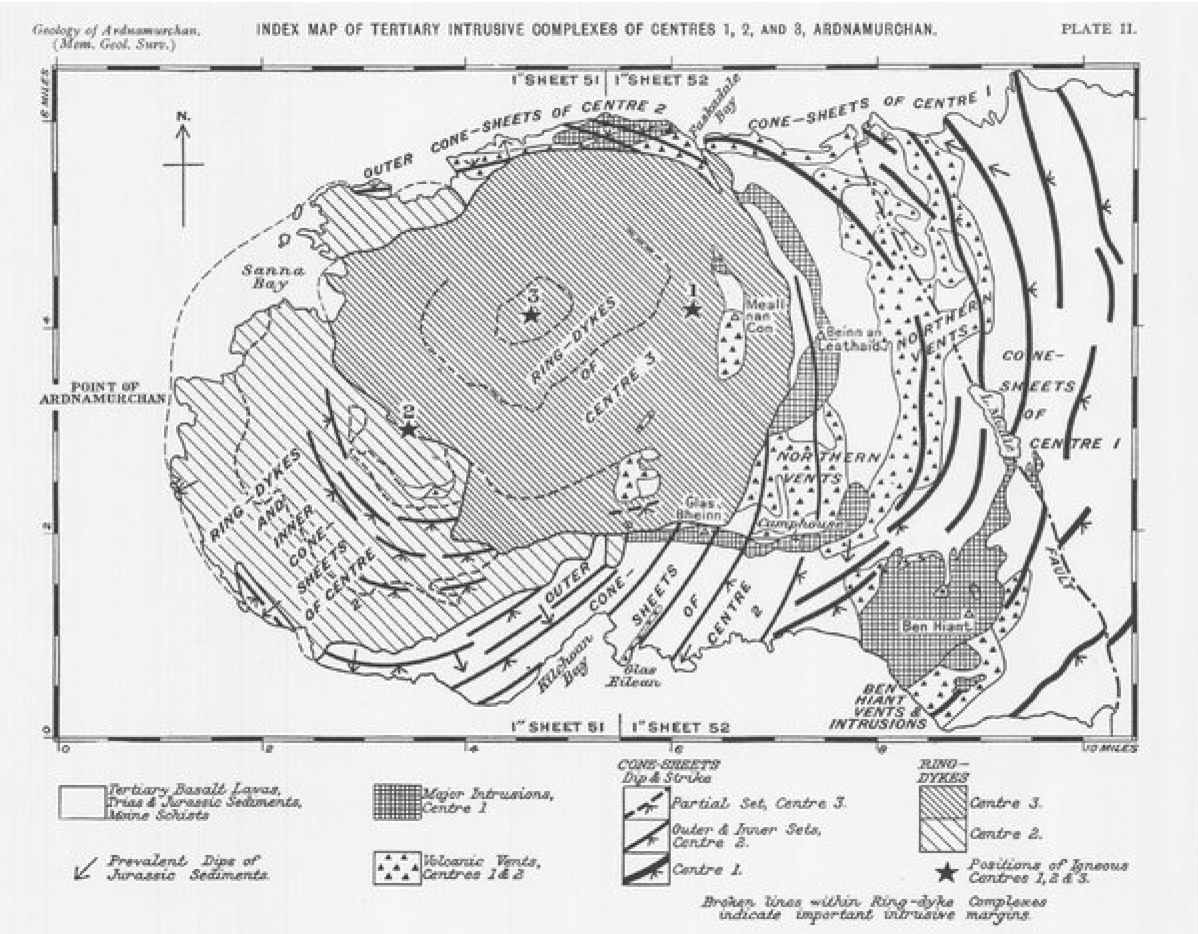
The foregoing account summarizes the main features of the Ardnamurchan igneous period, and will suffice to show that this period, as in the case of every other Tertiary intrusive district of Britain, is remarkable for the number and variety of its successive episodes. Yet the details that we are able to unravel at the present level of denudation can only furnish us with a partial history of all that took place within the extreme vertical limits of the complex; for these limits may be regarded as set by the top of the parent magma-reservoir and that other remote level, the ground-surface as it existed when igneous activity came to an end.

In the case of intrusive igneous rocks, little can, as a general rule, be inferred with confidence concerning those portions which continue downwards below the present level of observation or which have been removed by erosion. The sequence of events as demonstrable at the present denudation-surface in Ardnamurchan is, however, suggestive of the growth of a volcanic pile above the area affected by intrusion. The volcanic vents of Centre 1 have presumably been formed at a relatively higher crustal level than the ring-dykes of Centres 2 and 3. They offer a striking contrast to the coarsely crystallized ring-dykes of Centre 3, which at a long subsequent date were intruded through them. We are led to assume that volcanic accumulations extended to a very considerable height above the level now exposed, in order to allow of the deep-seated crystallization usually manifested by the ring-dykes.<ref>For a more comprehensive introductory account of the ring-dykes, *see* Chap. 15.</ref> In the case of Centre 2, however, the intense brecciation that accompanies many of its ring-dykes points to relatively superficial conditions. Further, to this centre belongs the linear vent of Glas Eilean, situated towards the outer limit of the belt of Outer Cone-sheets that encircle the ring-dykes. It would seem quite probable that such a linear vent may be guided by a ring-fissure below ground, and logically that some of the ring-dykes of Centre 2 continued upwards into arcuate vents.

Later still in the history of Ardnamurchan we find that the complex of Centre 3 is almost entirely composed of ring-dykes, and that these are rarely accompanied by brecciation. The complex as a whole would thus appear to be more deep-seated than that of Centre 2. On the other hand, it may be possible that this rarity of brecciation is due to the ring-fractures that preceded intrusion being connected by cross roof-fractures instead of continuing upwards to the ground-surface. One of the outermost of the ring-dykes of Centre 3 — the Quartz-gabbro (A) — is indeed seen to extend under a roof of older rocks, and along this part of its course at least cannot have had any connexion with the surface.

Present-day research certainly tends to reaffirm the conception of Judd that in Ardnamurchan, as in other Tertiary intrusive districts of the West Highlands, what we now see exposed is the 'basal wreck' of a great volcano.<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, p. 220.</ref> But the subservience of the observed intrusive phenomena to well-defined laws and their essentially successive character are the features which recent work has more especially emphasized. Arcuate fissures resulting from the relief of localized earth stresses and subsequently filled with magma would appear to indicate very precisely the existence and location of an underground magma-reservoir (*see* (Figure 5)). The three successive complexes in Ardnamurchan manifest a shifting of the locus of intrusion and seem to show that successive magma-reservoirs differing but little in position were formed. There can be little doubt that the reservoirs underlying the various intrusive districts of Britain came into existence in the first instance by the underground displacement of country rock.<ref>*See* H. H. Thomas, *Pres. Address, Sect. C, Rep. Brit. Assoc.* for 1927 (Leeds), p. 45</ref> It must also be admitted that each of the successive reservoirs of Ardnamurchan remained constant as regards position for a prolonged time, during, in fact, the related periods of intrusion. The existence of such successive reservoirs for lengthy periods is perhaps the most interesting point that the Ardnamurchan district appears to us definitely to prove.

Essentially similar conclusions have been arrived at from a study of Central Mull. There it has been found that two successive centres of intrusion were established along a south-east–northwest line. Explosion-vents, cone-sheets, and ring-dykes are associated with both centres. An early Kilauean phase of vulcanicity, connected with the south-east centre, is demonstrated by a localized development of pillow lavas marking the site of an oft-renewed crater-lake. It is true that at both the Mull centres, a prevalence of screens of older rocks (basalt lavas, agglomerates, etc.), between neighbouring ring-dykes, made it impossible to work out a time sequence for many of the individual intrusions. It is, however, fully evident that in Central Mull as in Ardnamurchan each complex must have taken a prolonged period for its development. J.E.R.



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

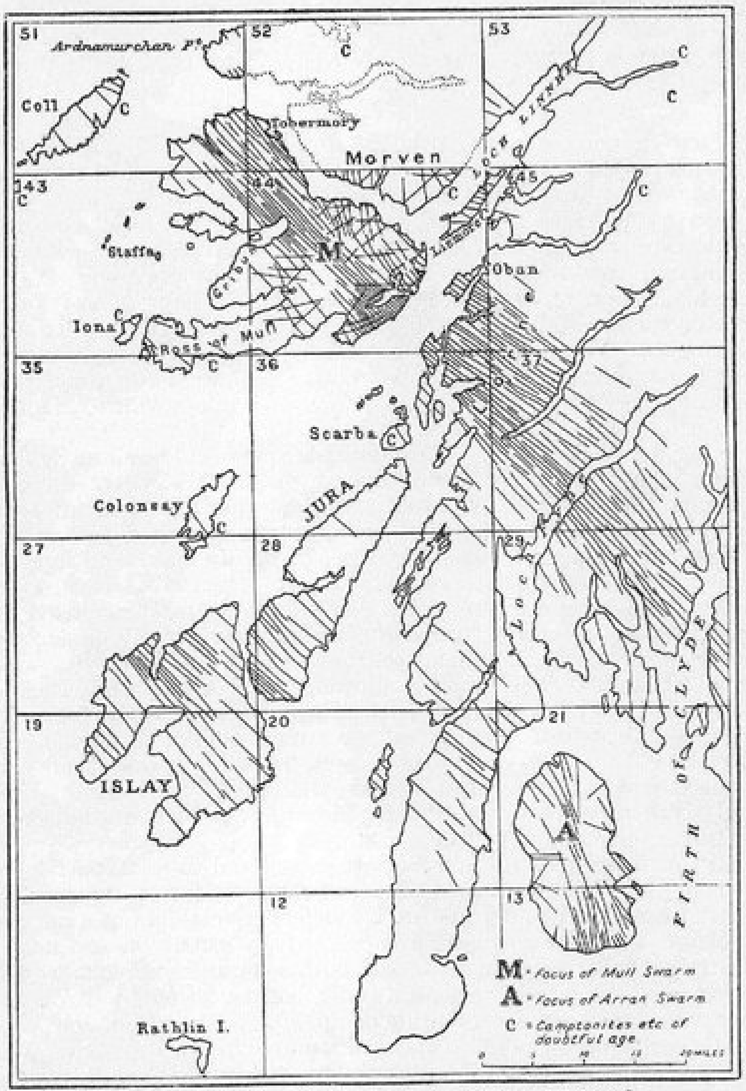


FIG. 49.—*Tertiary Dykes of the South-West Highlands.*
Only about one dyke in every ten or fifteen in shown.
Quoted from 'Tertiary Mull Memoir,' 1924, *Fig.* 60, *p.* 357.

(Figure 49) Tertiary Dykes of the South-West Highlands. Only about one dyke in every ten or fifteen in shown. Quoted from Tertiary Mull Memoir, 1924, (Figure 60), p357.

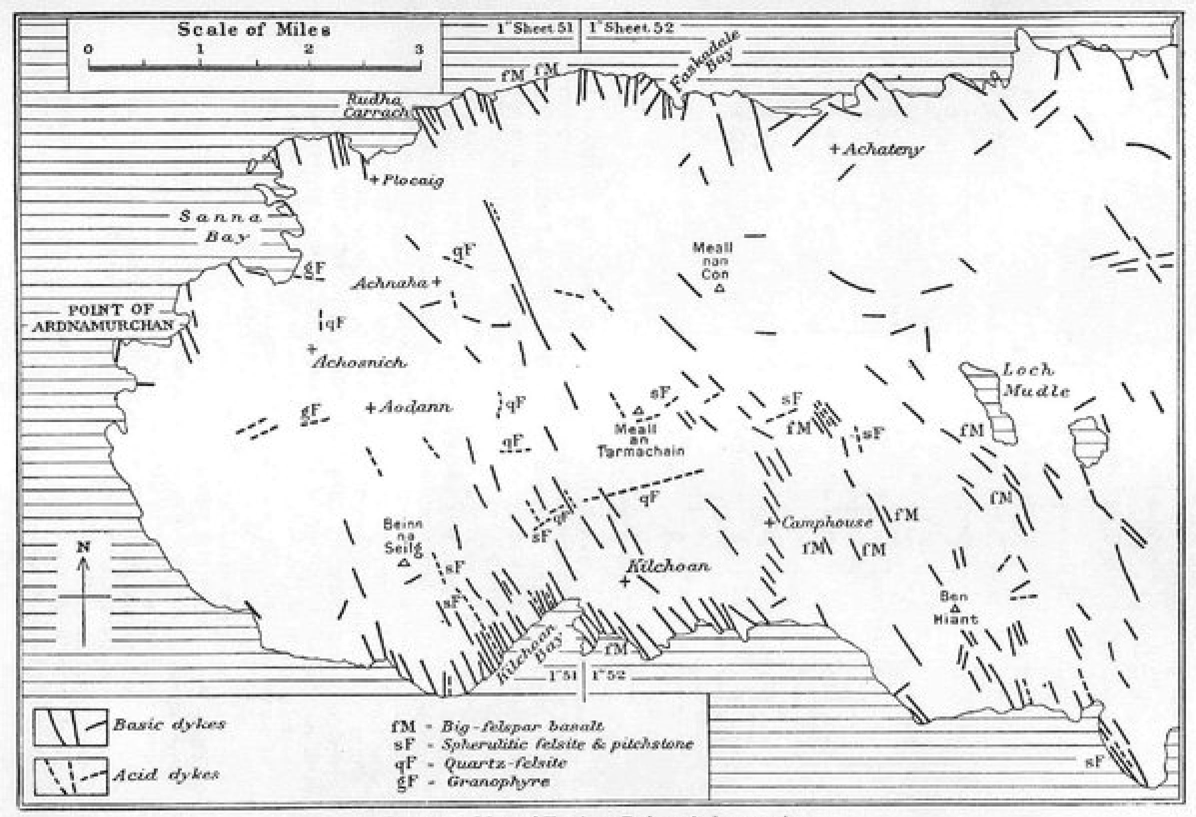


FIG. 50.—Map of Tertiary Dykes, Ardnamurchan.

(Figure 50) Map of Tertiary Dykes, Ardnamurchan.

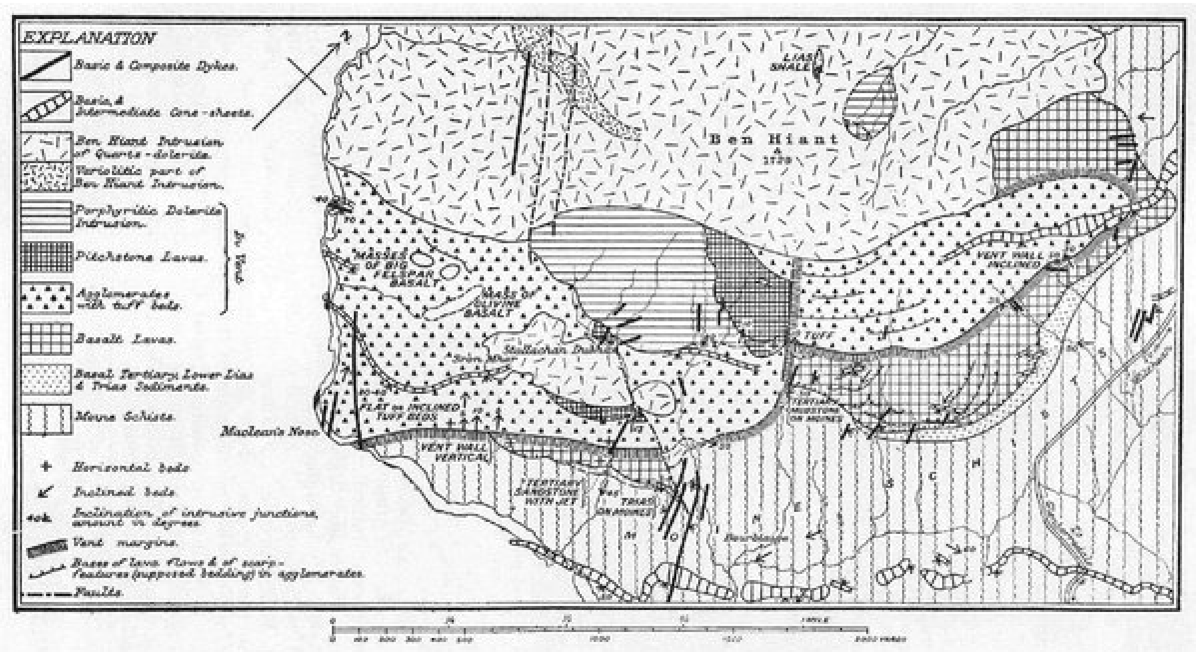
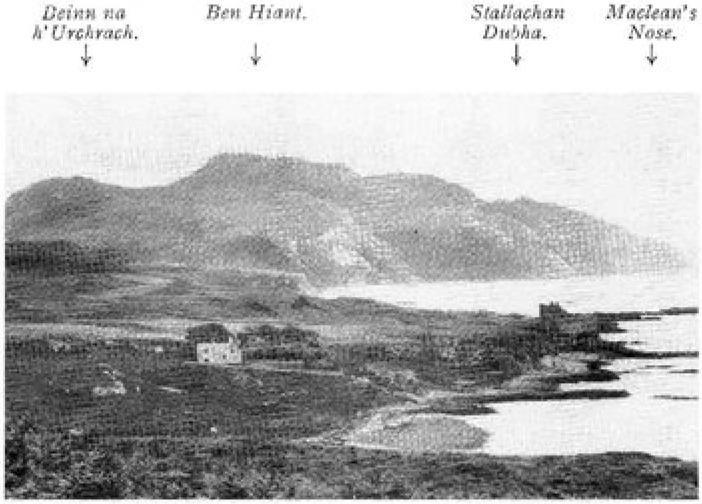


FIG. 10.—Map of Vent-Complex, eastern side of Ben Hiant.

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

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 .

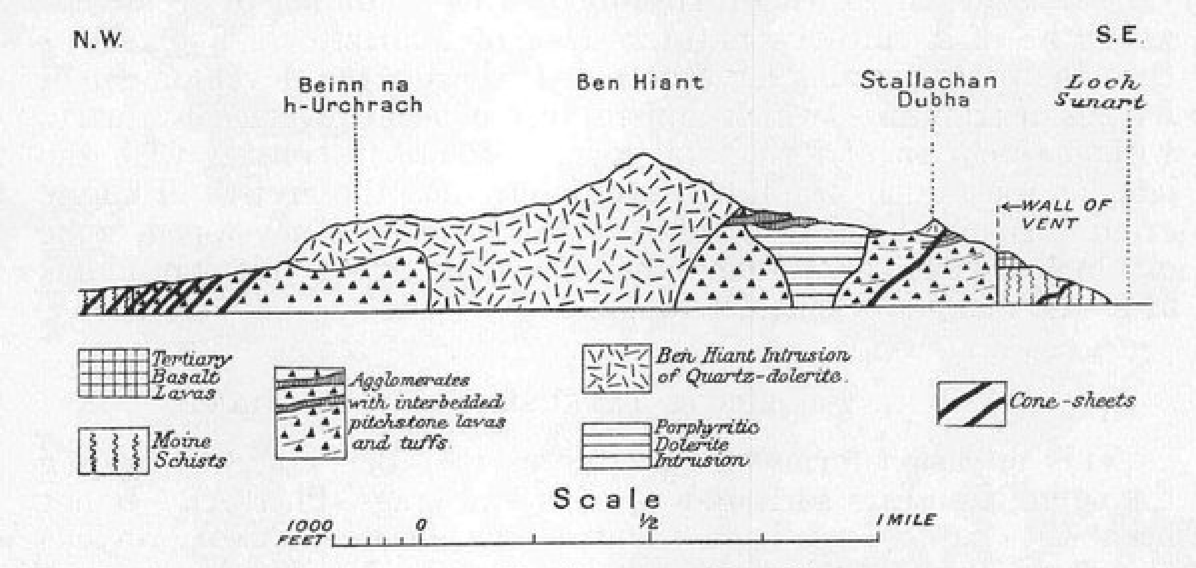


FIG. 19.—*Section across Ben Hiant.*

(Figure 19) Section across Ben Hiant.

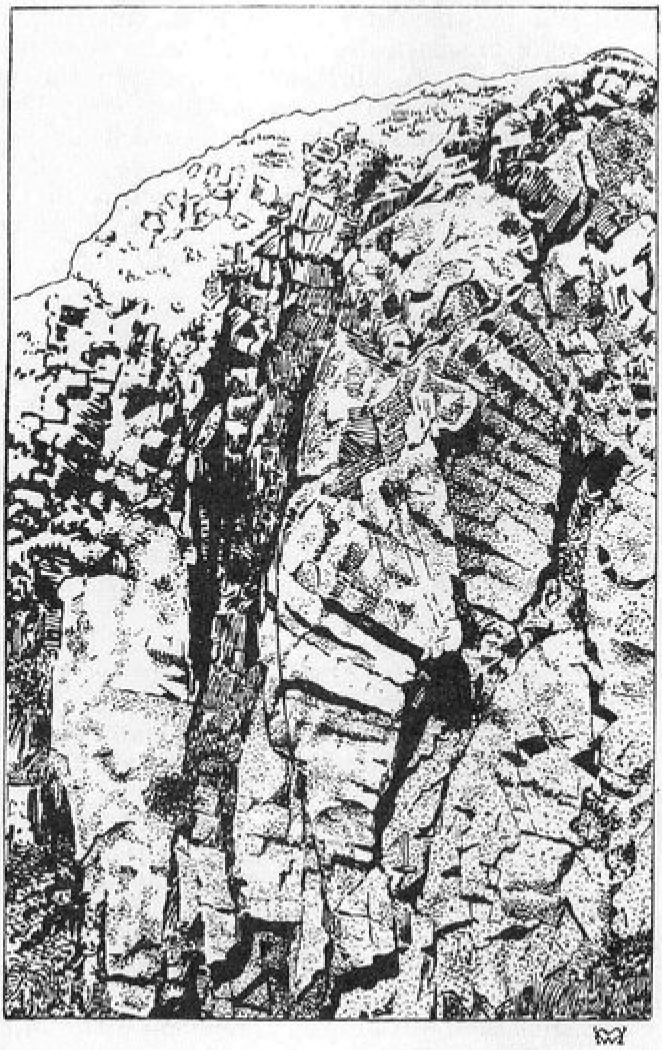


FIG 21..—*Twenty-foot cliff of columnar variolite (part of Ben Hiant Intrusion), traversed by crush-line, south-west side of Ben Hiant.*

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.

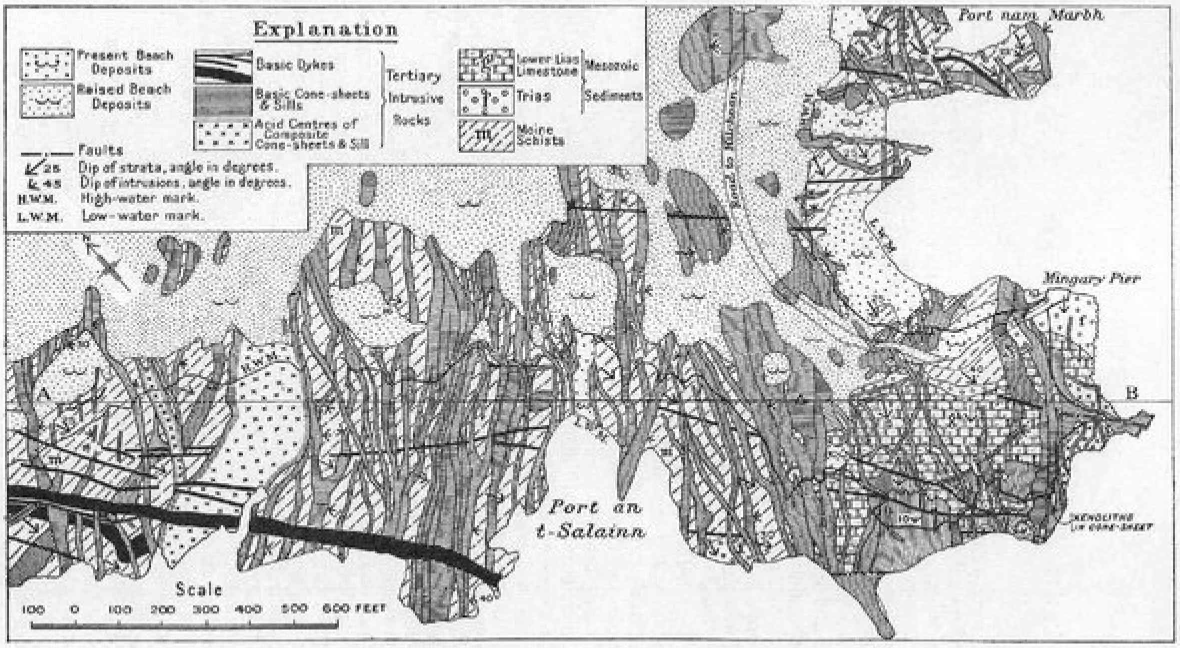


FIG. 23.—*Map of Outer Cone-sheets of Centre 2, shore south of Kilchoan.*

(Figure 23) Map of Outer Cone-sheets of Centre 2, shore south of Kilchoan.

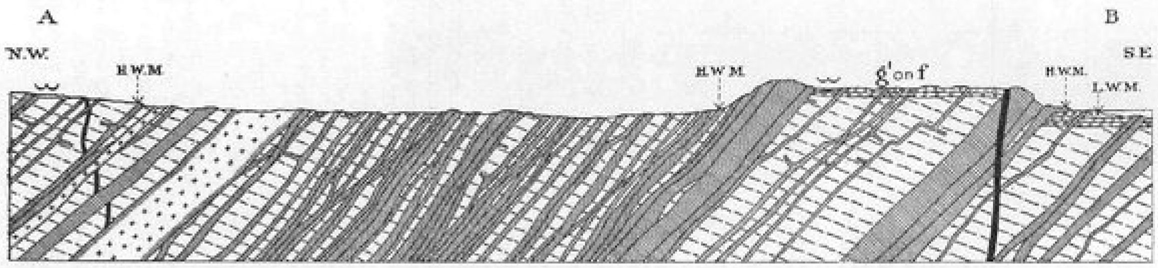


FIG. 24.—*Section along line A–B of Fig. 23.*

(Figure 24) Section along line A-B of (Figure 23) (Map of Outer Cone-sheets of Centre 2, shore south of Kilchoan).

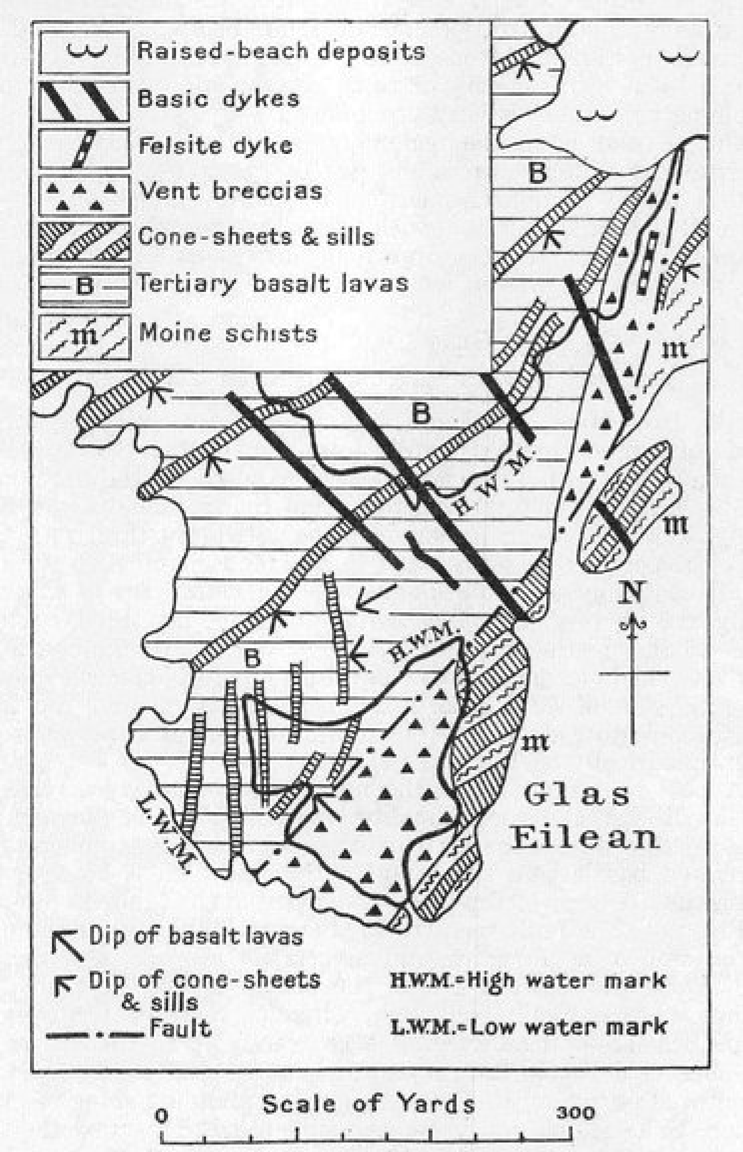
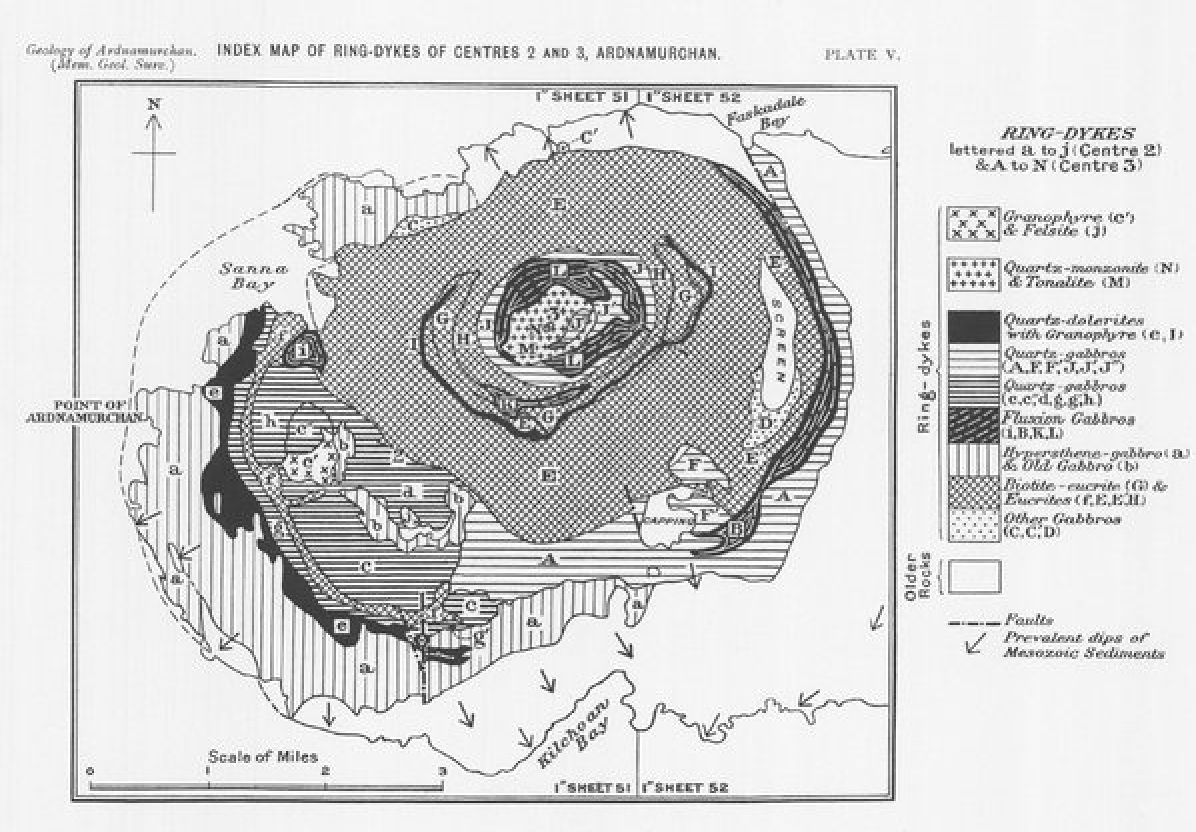


FIG. 13.—*Map of Glas Eilean Vent, south of Kilchoan.*

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



(Plate 5) Geology of Ardnamurchan. Index Map of ring-dykes of Centres 2 and 3, Ardnamurchan. (Mem. Geol. Surv.)

TABLE VIII

DATA CONCERNING MULL DYKE-SWARM

Locality.	Breadth of Swarm or Portion of Swarm Examined.	Number of Dykes.	Total Aggregate Thickness of Dykes.	Average Individual Thickness.	Average Number per mile.	Average Aggregate Thickness per mile.	Amount of Crustal Stretch due to Dyke-Intrusion.
S.-Central * Mull.	12½ mls.	375	2504 ft.	5·8 ft.	30	200 ft.	1 in 25
N.-Central * Mull.	1¼ mls.	142	817 ft.	5·8 ft.	114	654 ft.	1 in 8
North-west Mull.	5 mls.	62	480 ft.	7·7 ft.	12	96 ft.	1 in 55
South-west Ardnamurchan.	1½ mls.	36	272 ft.	7·5 ft.	24	180 ft.	1 in 30

* Data from 'Tertiary Mull Memoir,' p. 360.

(Table 8) Data concerning Mull Dyke-swarm.

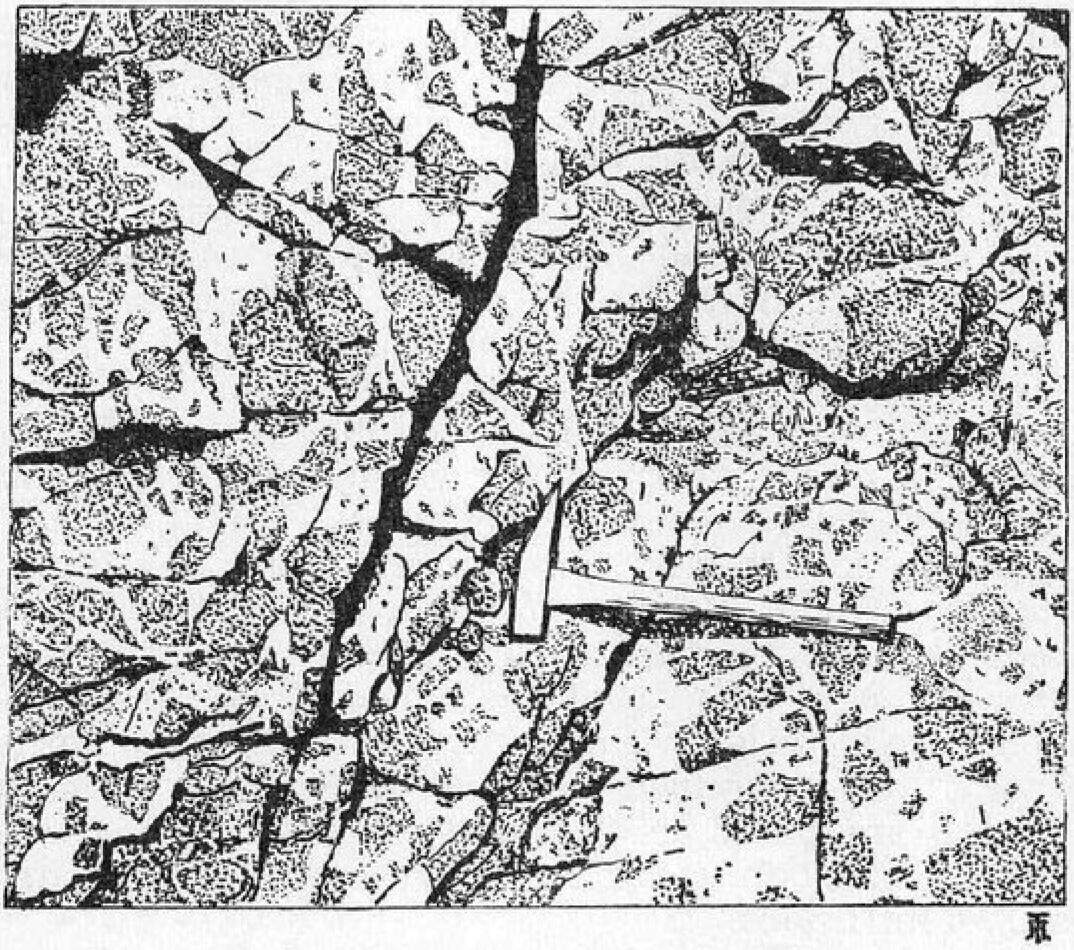


FIG. 34.—*Quartz-dolerite net-veined by granophyre, Sgùrr nam Meann Ring-dyke, on shore south-west of Sgùrr nam Meann.*
Drawn from Geological Survey Photograph, No. C. 2773.

(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.

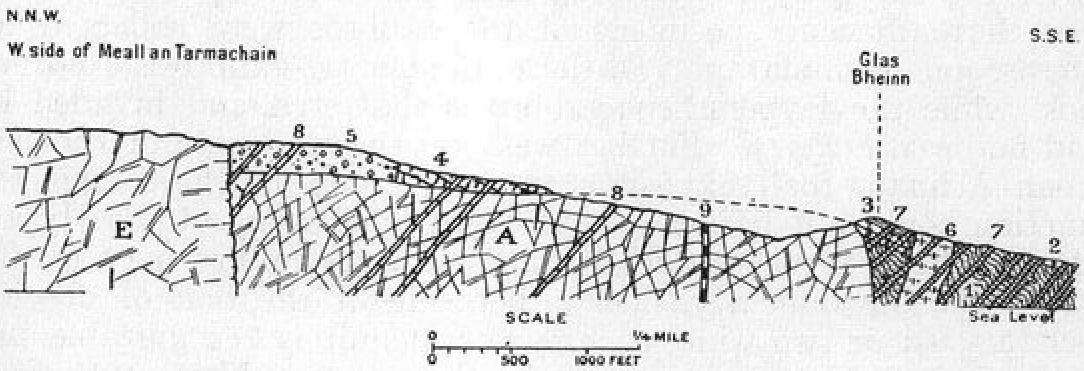
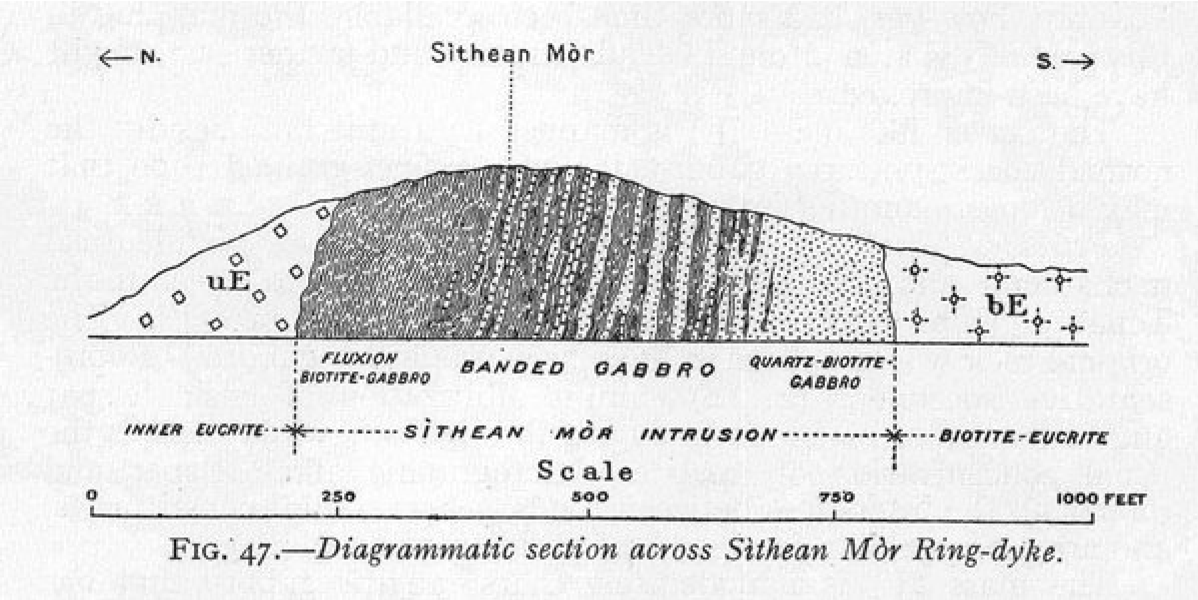


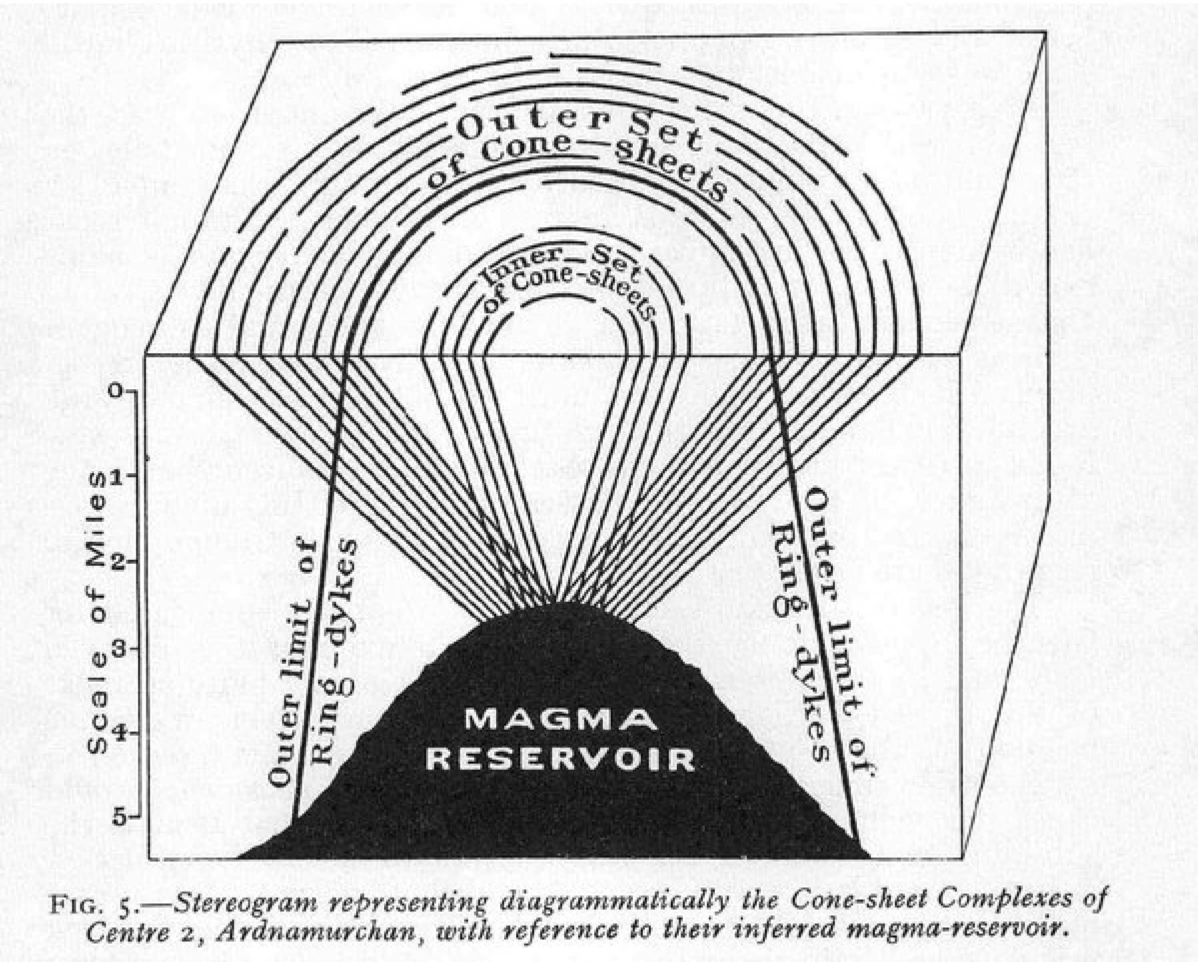
FIG. 39.—*Section from Meall an Tarmachain to Glas Bheinn, north of Kilchoan.*
1, *Moine Schists.* 2, *Trias.* 3, *Lower Lias (limestone and shale).* 4, *Tertiary basalt lavas.* 5, *Vent-agglomerate (Centre 1).* 6, *Porphyritic Dolerite of Glas Bheinn (Centre 1).* 7, *Outer Cone-sheets of Centre 2.* 8, *Cone-sheets (Centre 3).* 9, *Quartz-felsite dyke.* A, *Quartz-gabbro Ring-dyke (Centre 3).* E, *Great Eucrite Ring-dyke (Centre 3).*

(Figure 39) Section from Meall an Tarmachain to Glas Bheinn, north of Kilchoan. 1, Moine Schists. 2, Trias. 3, Lower Lias (limestone and shale). 4, Tertiary basalt lavas. 5, Vent-agglomerate (Centre 1). 6, Porphyritic Dolerite of Glas Bheinn (Centre 1). 7, Outer Cone-sheets of Centre 2. 8, Cone-sheets (Centre 3). 9, Quartz-felsite dyke. A, Quartz-gabbro

Ring-dyke (Centre 3). E, Great Eucrite Ring-dyke (Centre 3).



(Figure 47) Diagrammatic section across Sìthean Mòr Ring-dyke.



(Figure 5) Stereogram representing diagrammatically the Cone-sheet Complexes of Centre 2, Ardnamurchan, with reference to their inferred magma-reservoir.