Chapter 15 Tertiary ring-dykes of Ardnamurchan introduction

The Ardnamurchan ring-dykes occupy a roughly oval area, 6 miles long by 4 miles across, the longer axis of which extends north-east. They form two distinct complexes, grouped about Centres 2 and 3 (*see* (Plate 2)). The earlier complex lies to the south-west and is in part replaced by the later complex lying to the north-east. To the west and north, the earlier complex is also encroached upon to some extent by the sea.

The present chapter has been written in order to provide a more comprehensive introductory account of the ring-dykes than that given in Chapter 7.

(Table 7) Ring-Dykes of Centres 2 and 3

Index Letter on Map, (Plate 5)	Symbol on MemoirMap	Rock-type and Designation	Relative Ages, as determined by contact relationships (pp. 206,8)	
			Younger than	Older than
		EARLIER COMPLEX, CENTRE 2. *Older than Inner Cone-sheets.*		
a	rE	Hypersthene-gabbro of Ardnamurchan Point	—	c, e, A, C, E.
b	of	Old Gabbro of Lochan an Aodainn	—	c, c′, d, A.
c	qE	Quartz-gabbro of Garbhdhail		c′, f, A.
c′	G	Granophyre of Grigadale	c, b.	? c″.
c″	qE	Older Quartz-gabbro of Beinn Bhuidhe	? c′.	h.
d	qE	Quartz-gabbro of Aodann	b.	j, E.
e	gD	Quartz-dolerite of Sgùrr nam Meann	a.	g.
		Younger than Inner Cone- sheets.		
f	uE	Eucrite of Beinn nan Ord	c.	g, h, A.
g	qE	Quartz-gabbro of Loch Caorach	e, f.	–
g′	qE	Quartz-gabbro of Beinn na Seilg	e, ? f.	–
h	qE	Younger Quartz-gabbro of Beinn Bhuidhe	c″, f.	–
i	fE	Fluxion Gabbro of Portuairk	–	? E
j	G	Felsite, south of Aodann	d.	–
		LATER COMPLEX, CENTRE 3.	Younger than	Older than
A	qE	Quartz-gabbro of Faskadale	a, b, c, f.	E.

B	fE	Fluxion Gabbro of Faskadale	–	? E′
C	4. eD	Gabbro of Plocaig	*a.*	E.
C′	eD	Gabbro, south-east of Rudha Groulin	–	E.
D	eD	Porphyritic Gabbro of Meall nan Con screen	–	E, E′.
E	uE	Great Eucrite	a, d, h, A, C, C′, D.	F, I, K.
E′	uE	Outer Eucrite	? B, D.	? E, F.
F	qE	Quartz-gabbro of Meall an Tarmachain summit	E, E.'	–
F'	qE	Quartz - gabbro, south side of Meall an Tarmachain	–	–
G	bE	Biotite-eucrite	–	I.
H	uE	Inner Eucrite	–	–
I	gD	Quartz-dolerite, veined with· granophyre	E, G.	-
J, J′, J″	qE	Quartz-biotite-gabbro	–	? L, M.
K	fE	Fluxion Biotite-gabbro of Sìthean Mòr	E.	–
L	fE	Fluxion Biotite-gabbro of Glendrian	? J and J′.	M.
M	tH	Tonalite	J′, J″, L.	N.
N	qH	Quartz-monzonite	M.	–

Ring pattern

Each ring-dyke complex is built up of a number of annular or arcuate intrusions, of which the great majority are composed of some variety of gabbro. Until the area was mapped out in detail, the whole massif was believed to consist of a single large intrusion of gabbro, with a small central intrusion of more acid type. Different varieties of gabbro constituting distinct masses in intrusive relationship have now been recognized. Sometimes the fact that one type is intrusive into another can be easily determined; at other times its demonstration is a difficult matter, though indications of age-differences can be obtained. Again, sharp contacts between distinct rock-masses may be located, but no evidence whatever may be forthcoming as to which mass is the younger. It is noteworthy that such differences in the character of contacts are sometimes met with along the same intrusive margin.

The Earlier Ring-dyke Complex has its centre approximately below Aodann (Centre 2 of (Plate 1) II), a point around which the majority of the cone-sheets are also arranged. The Later Complex is to be referred to a centre near Achnaha (Centre 3), situated miles to east-north-east of Centre 2. It will be seen on the Index Map ((Plate 5)) that ring-dykes of Centre 3 are elongated in an east-north-east direction. In Central Mull, a shift of the intrusion-centre has been also demonstrated, in this case in a north-west direction. The intrusions of the later centre there also show bilateral symmetry about the direction of the shift.<ref>Tertiary Mull Memoir, 1924, Plate vi., p. 307.</ref>

The chief varieties of gabbro that constitute individual ring-dykes are:eucrite, quartz-gabbro, hypersthene-gabbro, and fluxion gabbro. Of these, eucrite and quartz-gabbro are almost equal in amount, as measured by area of outcrop, and are much in excess of the other two varieties. Fluxion gabbro occurs not only as distinct intrusions, but also as marginal borders to ring-dykes composed of the other three types. More acid rocks form the central portion of the Later Complex composed of tonalite and quartz-monzonite, and also two small masses of granophyre included with the Earlier Complex. Unlike the other Tertiary plutonic complexes of Britain, granophyre plays but a small part in Ardnamurchan in forming individual intrusions. The granophyric mesostasis of the quartz-gabbros and quartz-dolerites should, however, be taken into account in considering the relative amounts of granophyric and gabbroic materials.

A striking difference between the ring-dyke complexes of Mull and Ardnamurchan is that the narrow screens of older rocks found so frequently in Mull between adjacent intrusions are seldom encountered in Ardnamurchan. The paucity of screens combined with the small range in composition has rendered the mapping in Ardnamurchan extremely difficult. On the other hand, absence of screens affords opportunity for determining the relative ages of contiguous intrusions. Such pre-ring-dyke masses as do occur help considerably in the elucidation of the geology. They not only form screens separating adjoining ring-dykes, but also a roof to the Quartz-gabbro (A).<ref>Index letters applied to ring-dykes in the text are explained on (Table 7). and (Plate 5)., pp. 201–202.</ref> They are greatly contact altered, and one mass, on Meall nan Con, forms the highest ground in the whole massif.

Advantages from the mapping point of view in Ardnamurchan, as compared with Mull, are that exposures are especially good, for the gabbros usually form rocky country, almost devoid of scree and sparse of vegetation; and that the ring-dykes are not cut by many minor intrusions, being for the most part free from cone-sheets.

Denudation has acted to a different degree on the various types intrusive ntrusive rock, so that some masses now stand up as ridges, while others have been weathered down to form hollows. A spectacular example of this differential weathering is afforded by a ring-dyke of eucrite (E), the most important of the ring-dykes of Centre 3. This mass, named the Great Eucrite, forms a complete ring, a mile or more in annular width and with a maximum diameter of 4 miles. It forms a conspicuous circular belt of high ground, and is bounded on its inner side by a ring of crags that enclose a central area of relatively low relief ((Plate 6), p. 321). The central area is carved out in its turn into curving ridges and hollows that mark the course of various ring-intrusions.

The intrusive masses outside the Great Eucrite consist in large part of quartz-gabbro, as a rule weathering easily and forming relatively low ground. But other more resistant types are also found in the Earlier Complex south-west of the Great Eucrite, and there differential weathering has also modelled the country. Outcrops of eucrite (f), hypersthene-gabbro (a), an old gabbro (b), and also older quartz-gabbros (c) and (c″), where indurated by later intrusions in contact, all stand kip to a greater or less extent above adjacent ground occupied by quartz-gabbro, quartz-dolerite, and granophyre.

Dyke form

While the mapping of the various intrusions leaves no doubt as to their ring pattern, their dyke form is in most cases a matter of inference. Ring-dyke complexes, however, would appear to be a variety of stock-complex, and typical stocks,<ref> R. A. Daly, Igneous Rocks and their Origin, New York and London, 1914, P. 103.</ref>as well as certain ring-dykes, are known to have steep outwardly inclined walls.

The majority of the ring-dykes in Ardnamurchan are too wide to enable any such generalization as to their inclination to be based on the contacts available. In some cases, indeed, contacts are quite irregular. Where intrusive margins extend up steep hillsides, abruptly crossing the contours, it is evident at any rate that the contact-surfaces of the intrusions concerned must be steep (*see* (Figure 36), p. 264). There is, however, no hill-face sufficiently extensive to enable us to say whether such junctions are in general vertical, or are inclined outwards from or inwards towards the intrusion-centre. Narrow ring-dykes on the other hand are better suited for affording evidence of inclination. In the only example in Ardnamurchan, the Quartz-dolerite (1), contacts with its walls are well exposed at two adjoining points in its course, at which the margins are inclined outwards at an angle of 70 degrees. But, in the absence of observed contacts elsewhere along the outcrop of the ring-dyke, it is not possible to affirm that this is its invariable inclination. In other Tertiary intrusive districts, an outward inclination of narrow ring-dykes has been also noted. In Mull, the Loch Ba Felsite Ring-dyke is seen to be so inclined along part of its course.<ref>W. B. Wright in Tertiary Mull Memoir, 1924, P. 340.</ref> In Slieve Gullion, Ireland, another example has been recorded.<ref>J. E. Richey, Tertiary Ring-dykes of Slieve Gullion, Ireland, Rep. Brit. Assoc., for 1928, 1929, P. 545.</ref> The margins of ring-dykes have therefore been drawn on the section (Figure 27) with outward inclinations, although we consider that further information is required before this generalization can be regarded as established.

Internal structures resulting from the movement of magma and from its consolidation may afford evidence of the form of ring-dykes. Fluxion structures, such as flow-banding and the fluxional arrangement of crystals, are developed locally in the Hypersthene-gabbro (a), in the fluxion gabbros generally, and sometimes in quartz-gabbros and eucrites. Such structures strike, as a rule, parallel to adjoining margins of the intrusions concerned, and are usually either steeply inclined or vertical. The direction of the steeply inclined fluxion-planes sometimes varies without apparent reason either towards or away from the adjoining margin of the intrusion. In such cases, at any rate, it may be inferred that the intrusion is dyke-like in form. Sometimes inclinations as low as 45 degrees or less have been noted, but these are relatively infrequent.

In the Eucrites (E) and (H), pegmatite veins are often abundant, the wider and more persistent of which everywhere run parallel to adjoining margins of the parent intrusion, and are vertical or else highly inclined. Since the veins are evidently the infillings of contraction-cracks developed in the cooling mass, the regularly running individuals may be regarded as an indication of the steep nature of the ring-dykes concerned.

Relative ages of the ring-dykes

The relative ages of the ring-dykes, so far as these can be determined, are indicated by the order in which the ring-dykes are lettered on (Table 7) and (Plate 5). The kind of evidence on which the determinations of age are based is detailed below, while in succeeding chapters full descriptions of individual cases will be given under the heading of the various intrusions concerned.

Where in one intrusion, flow-banding, or a traversing dyke or sheet, is actually seen to be cut off by the margin of another intrusion, the interpretation is obvious. More often, however, relative ages have been deduced from the fact that one intrusion is baked by another at contacts; or that the later intrusion presents a marginal facies or a chilled margin against the earlier; or that the later intrusion bears xenoliths of the earlier. A satisfactory demonstration by such means can only be gained by very careful and close scrutiny in the case of gabbros, and in arriving at our conclusions the microscope has been a valuable aid. On the other hand, where more acid rocks, such as granophyre or tonalite, are in contact with gabbro, or with other acid masses, age relations are usually easily made out. The age of one intrusion relatively to another may also be disclosed by its preceding history. A mass shattered by explosion or sheared by crustal movements may be considered older than an adjoining mass that is quite sound.

The Earlier Complex of Centre 2 is regarded as entirely earlier than the Later Complex of Centre 3, for the outer intrusive margins of the outermost ring-dykes belonging to Centre 3 (A and E) transgress a large number of the cone-sheets and ring-dykes belonging to Centre 2. The Hypersthene-gabbro Ring-dyke (a), perhaps the earliest member of the Earlier Complex, is brecciated and baked at or near contacts with the ring-dykes (A) and (E), at points respectively north of Kilchoan Bay and east of Sanna Bay.

The Quartz-gabbro (c) and the Eucrite (f) are also intruded by the Quartz-gabbro (A). Further, cone-sheets of the Inner Set cutting (c) are baked in proximity to (A), which they do not penetrate. The Quartz-gabbro lettered (h) is probably later than any of the other intrusions grouped with the Earlier Ring-dykes. South of Sanna Bay, near Achosnich, an outer intrusive margin of the Great Eucrite (E) is seen against it. It may be mentioned that (E) in its turn is undoubtedly cut by two of the intrusions within it, the Quartz-dolerite (I) and the Fluxion Biotite-gabbro (k), and is earlier than perhaps all the ring-dykes which it encloses.

If we examine each intrusive complex in turn, it is found that in a general way the intrusions of the Later Complex are successively younger as we proceed inwards towards the intrusion-centre, but that in the Earlier Complex this rule is not strictly applicable.

In the Earlier Complex an aid to the determination of relative ages is the fact that while many of the ring-dykes are cut by the Inner Cone-sheets of Centre 2, some are later than them (*see* (Table 7)). Among those that are cut, either the Hypersthene-gabbro (a) or the Old Gabbro (b) is the oldest. The flow-banding in (a) is transgressed by the outer margin of the Quartz-dolerite (e), which also contains xenoliths of (a). Both (a) and (b) are intruded by the Quartz-gabbro (c), while (b) is also intruded by the Granophyre (c′), and internally by the Quartz-gabbro (d). Chilled margins, bearing xenocrysts of the Old Gabbro, determine the above relations of the quartz-gabbros. The Granophyre (c′) is very clearly chilled at contact with the Old Gabbro, and is also intrusive in the Quartz-gabbro (c). The relative ages of (c) and (e) cannot be directly determined. To the south, where they come nearest to one another, though still separated by (f) and (g), the Quartz-gabbro (c) seems the older, for it is full of lines of shear and contains much flinty-crush material, while the Quartz-dolerite (e) is unaffected by earth-stresses. The exact position of the short contact between (c) and (d) has not been fixed, and their relative ages have not been determined. The Quartz-gabbro (d) is only cut by a single Inner Cone-sheet, but like the Old Gabbro (b) it evidently owes its freedom from these intrusions to its central position in the complex.

The two ring-dykes (f) and (g) lying immediately within the Quartz-dolerite (e) are not cut by the Inner Cone-sheets, and though no actual truncation of a cone-sheet by a margin of these ring-dykes has been located, such truncation is practically certain in the case of the Eucrite (f). This intrusion is in turn probably earlier than its neighbour, the Quartz-gabbro (g), which presents a margin of quartz-dolerite against it at one contact noted. The Quartz-gabbro (g′) also appears to be younger than the Eucrite (f). The Quartz-gabbro (h) is intrusive against the Eucrite (f) which is baked in consequence. It also presents a chilled margin against the Quartz-gabbro (c″), and the latter, together with Inner Cone-sheets traversing it, is highly baked in the neighbourhood. The Quartz-gabbro (h) is therefore regarded as later than the Quartz-gabbros (c and c″), which are earlier than the Inner Cone-sheets, though it was not found possible in the field to fix the mutual boundary between (h) and (d). The Quartz-gabbros (g) and (h) are thus the latest intrusions belonging to the Earlier Complex. The Quartz-gabbro (h) may, however, have been wrongly grouped with the Earlier Complex, for it is possible that it is a continuation of the Quartz-gabbro (A) reappearing from below ground (*see* p. 255).

In the Later Ring-dyke Complex, the Quartz-gabbro (A) and probably also the Fluxion Gabbro (B) are earlier than the Great Eucrite (E). In the case of the Interior Complex, enclosed by and perhaps altogether later than (E), relative ages are sometimes difficult or impossible to establish. Though sharp contacts can be found between the Biotite-eucrite (G) and Inner Eucrite (H), and between the Quartz-biotite-gabbro (J) and Fluxion Biotite-gabbro (L), no direct evidence of their relative ages has been obtained. The masses (J), (J′), and (J″), being similar coarse-textured quartzbiotite-gabbros, may well be portions of one intrusion separated by the Fluxion Biotite-gabbro (L). It is therefore not unlikely that the Fluxion Biotite-gabbro (L) is later than these masses. It is at any rate certain that the narrow ring-dyke (I) is later than the intrusions which it traverses (E and G); that the Fluxion Biotite-gabbro (K) is later than the Great Eucrite (E), against which it is chilled and xenoliths of which it encloses; that the Tonalite (M) is later than the intrusions outside it, and than its elongate enclosure (J″); and that the little central mass of Quartz-monzonite (N) is later still. All these intrusions present well-chilled margins to those named as earlier.

As already stated, the recognition of adjoining masses as distinct intrusions is held to depend primarily on the observation of sharp contacts between them. In a few of the rock-masses that have been mapped out from their neighbours, no such sharp contacts have been located, but since successive intrusion can be so frequently proved in the Ardnamurchan Ring-dyke Complexes it is likely that these doubtful cases are also due to separate intrusive acts. The Biotite-eucrite (G), for example, that borders the inner margin of the Great Eucrite (E), though with difficulty separated from the Eucrite in mapping, may with reason be regarded as a separate injection and not as an inner marginal modification of the Eucrite. Along the outer margin of the Eucrite no such marginal type is found, and further, biotite-bearing intrusions are characteristic of practically the whole Interior Complex in which the Biotiteeucrite is located.

Order of intrusion of rock-types and problems of their differentiation

The complete magmatic sequence of Ardnamurchan has been already stated in Chapter 8, where the problem of differentiation has been also discussed. Here we shall add such information concerning the field-occurrence of ring-dykes as may have bearing on the larger question.

It is evident that the same types of intrusive rock recur repeatedly among the ring-dykes. If we omit the rocks of the Interior Complex, which fall into a group by themselves, we may classify the various types as (I) basic gabbros, including eucrite and hypersthene-gabbro, and (2) quartz-gabbros and granophyre. Up to the Great Eucrite of Centre 3, an order of intrusion as set out below can be established, beginning with the oldest (a):

1 = Basic gabbros, etc. 2 = Quartz-gabbros, Intrusion-letter on Index Map, (Plate 5).

1	a (Hypersthene-gabbro) and ? b (Old Gabbro). c (Quartz-gabbro).
2	c′ (Granophyre).
2	c″ d (Quartz-gabbros).
2	e (Quartz-dolerite veined by granophyre).
1	f (Eucrite).
2	(Quartz-gabbros)
2	(Quartz-gabbros)
2	(Quartz-gabbros)
1	E′, E(Eucrite).

Subsequent to, and enclosed by, the Great Eucrite (E), come the intrusions of the Interior Complex. Differentiation here has followed a different course. Unlike the great majority of the preceding ring-dykes, these are all, with the exception of the Inner Eucrite (H), characterized by containing biotite in greater or less amount. So far as their relative ages have been determined, an order of increasing acidity is indicated. The Great Eucrite (E) is followed by a Fluxion Biotite-gabbro slightly less basic (K), and the period ends with the intrusion of Tonalite (M) cutting another Fluxion Biotite-gabbro (L), and lastly the intrusion of Quartz-monzonite (N).

The course taken by differentiation within the magma reservoir is to some extent indicated by a study of differentiates within individual intrusive masses. The products of such partial differentiation may be classified according to their formation (i) before the intruding magma reached its final position, (2) after movements of intrusion had ceased and while the mass was still largely fluid, and (3) after the main period of consolidation, when only a small residuum of the magma remained uncrystallized. Instances of the foregoing are cited below.

(1) Fine-grained margins of some intrusions are found to be more acid than the main body. For example, the Tonalite (M) of Centre 3 possesses a fine-grained, chilled margin of quartz-monzonite. The Hypersthene-gabbro (a) also bears in most places a very fine-grained, more acid margin, composed of quartz-dolerite. This is contrary to expectation if the rock were differentiating in place, for then the marginal and earliest crystallized portion should be, if anything, more basic than the interior. If it were not for the obviously chilled nature of these more acid margins, they might possibly be ascribed to gravitational differentiation below an overhanging bounding wall. As it is, they seem only explicable by supposing that the intruding magma possessed a differentiated more acid upper portion which was intruded first and formed a lining to the walls of the intrusion-cavity. Similarly, along the outer margin of the Great Eucrite the normal eucrite of the interior usually passes rapidly into somewhat finer-grained quartz-gabbro that contains iron-ore in lieu of olivine, but is on the whole of eucritic aspect. Such quartz-gabbro occurs along margins against highly baked walls of basalt lava and agglomerate, as well as against older quartz-gabbro, where the occurrence gives at first sight an appearance of gradation from one mass into the other. Field-appearances support the view that the acid nature of this marginal facies is original and not due to migration of acid magma from the interior portions of the consolidating mass to the margin. The intermixture of the granophyric and gabbroid materials of the marginal quartz-gabbro is exceedingly intimate.

The heterogeneous nature internally of some intrusions may be due to partial differentiation at any stage, or to admixture of two different magmas that were simultaneously injected. In the Hypersthene-gabbro (a), masses of allivalitic gabbro and quartz-gabbro in the interior of the intrusion are found to have sharply defined mutual margins (p. 218). Their differentiation must have taken place before their final injection. Quartz-gabbros very usually contain basic portions that can only be called eucrite. The eucrite masses, on the other hand, are noticeably less variable in the field than the quartz-gabbros and hypersthene-gabbro, though differing considerably from one place to another in the relative amounts of their constituent olivine, augite, and felspar.

The Fluxion Biotite-gabbro of Sìthean Mòr, where banded with, and adjoining a mass of quartz-biotite-gabbro, seems to afford an example of intermixture (p. 330). Admixture or interpenetration of acid and basic differentiates before intrusion has been suggested by Dr. Thomas to account for various hybrid-like masses of the ring-dyke assemblage (pp. 291 and 340, and *see* p. 102).

(2) There appears to be one case in Ardnamurchan of a kind of gravitational differentiation, in the upper portion of the Quartz-gabbro (A), where it passes westwards under a roof formed of the Earlier Ring-dyke Complex. Immediately beneath this roof the rock is a basic granophyre. Downhill, the granophyre grades fairly rapidly into acid quartz-gabbro, and this gives place to normal quartz-gabbro at yet lower levels. From microscopic examination, Dr. Thomas describes the more acid, higher-level types as granophyre-gabbro hybrids (p. 287). But the amount of granophyric material decreases markedly in proportion to the depth below the roof, and it seems a case of the lighter granophyric portion of a quartz-gabbro magma having separated gravitationally from the crystallizing gabbroid portion, either subsequent to intrusion or before the magma had reached its final position. If such a separation of the granophyric portion. of a quartz-gabbro magma were effected at greater depth, either distinct intrusions of granophyre might result (p. 95), or re-mixture of granophyric and gabbroic differentiates might take place, probably giving rise to hybrids (p. 102).

(3) Residual acid magma remaining after the main consolidation of a gabbro intrusion finds its way into joints and cracks, chiefly developed in marginal portions of the mass, and forms veins. Such late differentiates suggest one possible mode of origin for the latest of the ring-dykes characterized by containing biotite, which form the Interior Complex. It is true that the veins are as a rule different in type from the rocks of the Interior Complex, for the final differentiates of the normal gabbros do not seem to produce directly biotite-bearing types. But frequently, as Dr. Thomas has found, in such acid veins as are charged with xenolithic material, or appear to have reacted on their walls, biotite and hornblende occur, and the rock-type may approximate closely to tonalite or quartz-monzonite.

Dr. Thomas has stated elsewhere his reasons for regarding the Interior Complex, that constitutes the Tonalite and Quartz-monzonite Magma-Series, as due to hybridization (p. 98). In agreement with the field evidence, he regards the postulated intermixture of the acid and basic materials as having been most completely carried out before the intrusion of the resulting hybrid. The field evidence that requires this condition is as follows:-

1. There can be no doubt that the Interior Complex is composed of a number of distinct intrusions differing from one another in rock-type. They cannot be attributed to hybridization *in situ.*
2. None of the masses contain xenoliths except locally, and for these xenoliths a local origin can be practically demonstrated. There is, therefore, no positive evidence that the postulated intermixture underground was between acid magma and *solidified* gabbro or eucrite. Gabbroid material involved may, however, have been xenocrystal, and all traces of megascopic xenolithic structure may have been obliterated.
3. Fine textures are met with either as marginal facies, *e.g.* to the Fluxion Biotite-gabbro (K) and to the Tonalite (M), or as typical of a whole mass, *e.g.* the Quartz-dolerite (I). This would appear to show conclusively that the magma was in these cases at least essentially a liquid when intruded.
4. It may be further remarked that, so far as age relations can be determined, the intrusions appear to follow one another in an orderly succession from basic to acid.

Characteristics of the ring-dykes and their bearing on the problems of ring-dyke intrusion

Crustal stresses developed in the roof of a magma-reservoir have been postulated by Mr. E. M. Anderson to account for the localization of the ring-dykes and cone-sheets of Mull around definite centres.<ref>Tertiary Mull Memoir, 1924, pp. 11–12.</ref> This postulate may be taken as a reasonable hypothesis, and it is now our object to set out the facts concerning the Ardnamurchan ring-dykes which are to be thereby explained.

Perhaps the characteristic of most general interest in Ardnamurchan is the repeated shifting of the locus of igneous activity, as shown by the three main intrusion-centres that the detailed mapping has determined. The lateral shift has not been great, no more than 3 miles from the earliest centre (1) to the second, and miles from the second to the third.

The intrusion-centres are of successive ages. The intrusions belonging to each centre are also successive, and indicate prolonged periods during which the crustal stresses remained unchanged in their incidence; for, the concentricity of the intrusions belonging to the same Centre 1s in most cases a notable feature. In ground-plan, the Earlier Ring-dyke Complex (Centre 2) appears to have been roughly circular, while the Later Complex (Centre 3), taken as a whole, possesses bilateral symmetry about an east-north-east axis, the direction towards which the shifting of the intrusion-centre took place. The diameter of each of the two ring-dyke complexes is, however, not far different, being about 4 or 5 miles. As regards the relative ages of component intrusions, there is a tendency at any rate for the Later Ring-dyke Complex to be built up from without inwards, with the older intrusions at the periphery and the younger nearer to the centre. Another feature of the ring-dykes of the Later Centre 1s that many of them form incomplete rings, discontinuous along the northern side of the complex.

A feature of major importance concerning the intrusion of the Later Ring-dykes is their replacement of a large portion of the Earlier Complex, and also of a great segment of the country cut by cone-sheets and agglomerate-vents. The earlier rock-masses have not been pushed to one side, as will be plain from an inspection of the Memoir-map and of (Plate 2), p. 71. It will be seen that the strike of the Outer Cone-sheets of Centre 2 does not change in any way with reference to the intrusive outer edge of the Later Complex. Their orientation is evidently unaffected by the intrusion of the ring-dykes.

The annular width of ring-dykes keeps remarkably constant for each individual intrusion (see (Plate 5)). Exceptions to this rule do occur, such as the Faskadale Quartz-gabbro (A), which widens out greatly to the west, but they are, on the whole, infrequent. If we attempt to classify the Ardnamurchan ring-dykes according to their annular width, they seem to group themselves into three subdivisions:(i) narrow ring-dykes, represented by (I), about 100 ft. wide; (2) ring-dykes of intermediate width, represented by (e), (f), (g), etc., usually about 500 to 1000 ft. wide; (3) broad ring-dykes such as (a) and (E) up to a mile in width.

Now there can be no reasonable doubt that the intrusion of a ring-dyke is preceded by ring-fracturing. The narrow ring-dyke of Quartz-dolerite veined by granophyre (I), is a good example of such a ring-fracture infilled by magma. At its north-eastern extremity, where it cuts the Great Eucrite (E), it has diminished from its usual width of some 100 ft. to only 3 ft. of breccia veined by quartz-dolerite and granophyre. The breccia consists of eucrite-like gabbro, and its clean-cut junctions with the eucrite walls are inclined outwards from the intrusion-centre of Achnaha at 70°. The breccia could not be traced farther, and this ring-fracture is therefore, so far as known, incomplete. The breccia presumably represents an initial stage in the intrusion of the ring-dyke, and it may be noted that xenoliths of eucrite-like gabbro are to be found in the ring-dyke elsewhere.

As regards the ring-dykes of intermediate width, their course is also evidently determined by ring-fissures. In the case of the Eucrite of Beinn nan Ord (f), it will be seen that it not only follows a ring-pattern but also possesses on its inner side two radially-projecting arms, which are directed towards Centre 2. It seems clear that earth-stresses must have here produced a ring-fissure with inwardly projecting radial fissures prior to the injection of the eucrite magma. Minor irregularities in the ground-plan of such intrusions may be attributed to modifications of the fissure-walls by the intruding magmas or by explosive gases derived from them.

In the case of the broad ring-dykes, it would seem necessary in some instances for two parallel ring-fractures to develop and either to coalesce upwards or to become connected by cross-fracture, and so allow the country rocks between freedom to subside. The only example in Ardnamurchan of a ring-dyke with portions of a roof preserved is the Quartz-gabbro of Faskadale (A). In other cases, such as the Great Eucrite, where no original inner margin of the ring-dyke is known to have existed, a stock-like intrusion may have been formed in the first instance, and the central portion may have been subsequently cut out by a ring-fracture and replaced by succeeding ring-dyke intrusions.

The part that brecciation by explosive gases may play in the enlargement of ring-fissures is suggested by the association of vents and major intrusions in the complex of Centre 1, and by the frequent brecciation of the walls of ring-dykes belonging to Centre 2.

A striking example of a ring-dyke that has incorporated brecciated rocks similar to those forming its wall is afforded by the Quartz-dolerite of Sgùrr nam Meann. All along its outer margin against the Hypersthene-gabbro (a), the Quartz-dolerite contains xenoliths of the older rock. In fact, south of Sauna Bay, its margin is crowded with xenocrysts and shattered xenoliths resembling the shattered and contact-altered Hypersthene-gabbro alongside. The inference is that brecciation of the Hypersthene-gabbro by explosive gases was followed by the inclusion of fragments in the Quartz-dolerite magma. A ring-fissure may have been in this case enlarged by explosion, and the debris partly blown upwards to the surface as volcanic ejactamenta, and partly enclosed in the uprising magma. The Quartz-dolerite is itself almost everywhere brecciated, and its fragments re-cemented by an incoming granophyre magma ((Figure 34), p. 257). Explosive gases proceeding from the acid magma are presumably the cause of this later brecciation. The net-veining by granophyre must have led to a great increase in the volume of the ring-dyke, and the increase may possibly have been accommodated by upward movements of these igneous breccias.

Another example of an intrusive margin that is replete with xenolithic material derived from older rocks in contact, is supplied by an older Quartz-gabbro (c), next to the Old Gabbro (b). The latter is metamorphosed throughout, and is dull-black in colour, owing to the turbidity of its felspars. The same black colour characterizes the Quartz-gabbro alongside, and becomes most pronounced close to contacts with the Old Gabbro. Under the microscope, the marginal rock is found to contain a large amount of turbid felspar and altered augite, apparently as xenocrysts. It seems that here again brecciation of the Old Gabbro preceded the intrusion of the Quartz-gabbro, by which the brecciated material was enclosed. For the marginal Quartz-gabbro is definitely finer-grained than the main body, and there could not have been time after its intrusion for extensive disruption of the Old Gabbro.

Throughout this older Quartz-gabbro generally, as well as in other quartz-gabbros such as (d) and (A), a common type consists of coarse-grained acidified gabbro interspersed with fine-grained quartz-gabbro. Sometimes the coarse acidified gabbro occurs as obvious xenoliths, with sharply defined edges against the finer-grained type. It is believed that we have in such cases an old gabbro broken up and acidified by more acid magma (*see* p. 252). The localities where this variety has been chiefly noticed are in intrusions (c) and (d), on either side of the Old Gabbro (b), and in the Faskadale Quartz-gabbro (A), north of where it cuts across the Hypersthene-gabbro (a), north of Kilchoan Bay.

Still more intense brecciation affects the Eucrite of Beinn nan Ord (f), along part of its course (*see* (Figure 37), p. 266). Its component minerals are found under the microscope to have been shattered into fragments, often without losing their individual crystalline form. After brecciation, they have been reheated and so granulitized. Hot explosive gases are regarded as the cause of this phenomenon, followed by an acid magma that is now locally found as granophyre minutely veining the brecciated rocks. The gases seem to have been confined to the ring-fissure occupied by the Eucrite at the present denudation-level, and were probably derived from a more acid magma underground; for the Eucrite is brecciated along at least 2 miles of its length, while the adjacent and later Quartz-gabbro of Loch Caorach (g) is only affected in the neighbourhood of its junction with the Eucrite.

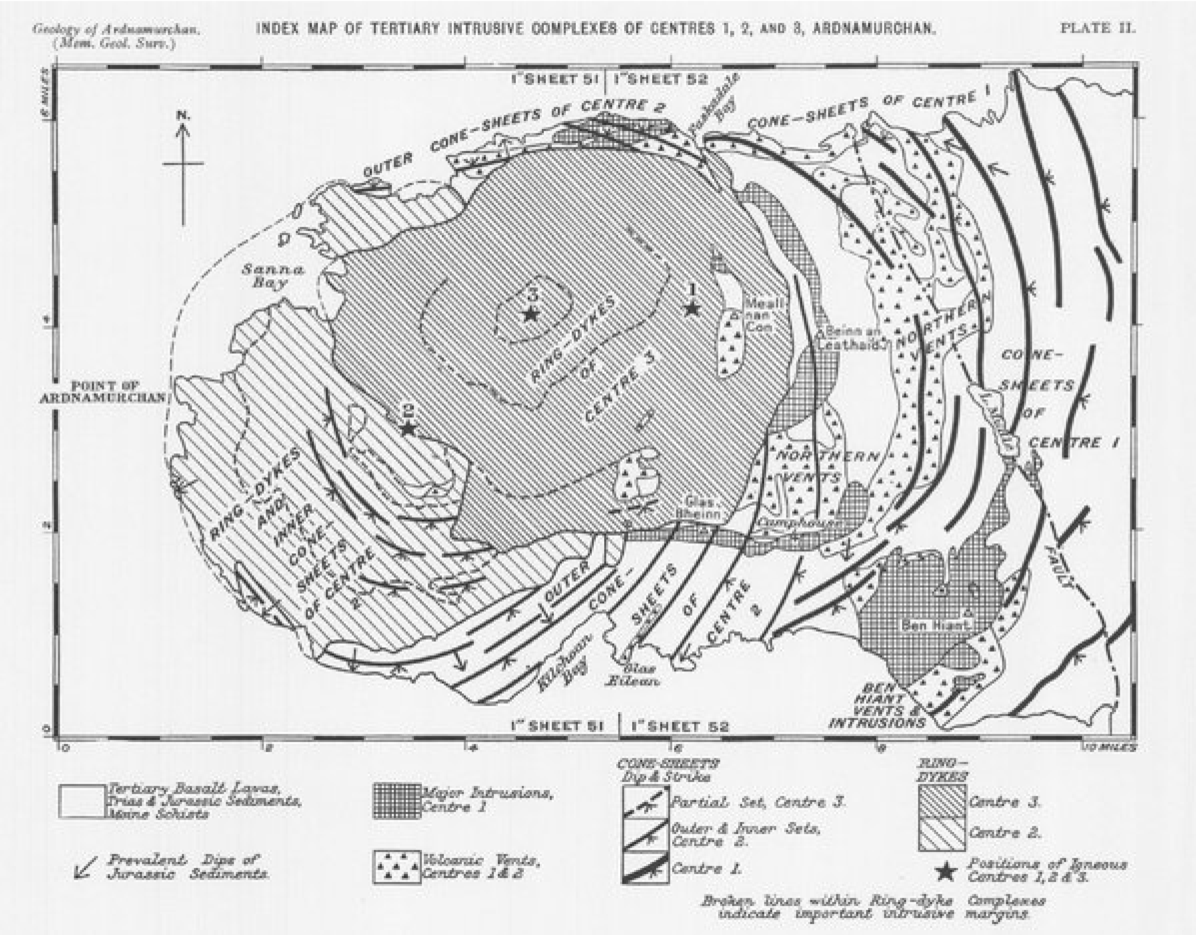
A comparison has been already made between such brecciated ring-dykes and the breccias found in the linear vent of Glas Eilean, south of Kilchoan (p. 77). To the writer, the evidence in Ardnamurchan suggests, though it cannot prove, that there is a connexion between ring-dykes and linear-vents filled with volcanic breccias, and that while the foundering of country rock *en masse* may have made room for ring-dykes in some cases, in others country rock may have been brecciated by gases derived from an intruding magma, partly ejected from volcanic orifices, and partly incorporated as xenoliths in the ring-dyke (*see* p. 75).

A stage in the infilling of ring-dyke cavities with subsequent brecciation is indicated by igneous xenoliths enclosed in ring-dykes, more especially in those belonging to Centre 2. The majority of the xenoliths, to judge from such examples as have been microscopically examined, would seem to be consanguinous to the particular intrusion enclosing them. In the Hypersthene-gabbro (a), Dr. Thomas finds that hypersthene-bearing granulites are prevalent. In the Quartz-gabbro (A), fine-grained quartz-gabbro occurs locally as xenoliths. In the Eucrite of Beinn nan Ord (f), and occasionally in the Great Eucrite (E), fine-grained olivine-rich eucritic types are found. There is a resemblance between such cognate xenoliths and the fine-grained margins of the enveloping intrusion. For example, they are mostly non-porphyritic in the Hypersthene-gabbro of which the fine-grained margins are also non-porphyritic; while porphyritic xenolithic strips are found in the southern part of the Great Eucrite, and in this instance, porphyritic fine-grained gabbro occurs around its southern edge, which probably forms part of an early chilled margin. So it seems as if the first influx of magma into ring-fissure or ring-cavity became quickly consolidated, and was broken up and incorporated as xenoliths in the subsequent intrusion of the main mass. Such accidental xenoliths as occur, usually resemble the cone-sheets, or, less often, basalt lava.

Brecciation due to crustal stresses is met with occasionally. The linear arrangement of such crushed material, and its association with black flinty crush-rock, distinguish it from the brecciation that is attributed to explosion. The

Quartz-gabbro (c) affords a striking example of such crushing, which was effected during the Earlier Ring-dyke period. In this case the gabbro, where it is much sheared and traversed by bands of flinty-crush, is cut by minor intrusions, including Inner Cone-sheets, which are quite uncrushed but have suffered baking. These minor intrusions are earlier than the adjoining Beinn nan Ord Eucrite (f), to which their contact alteration would appear to be due. Possibly the marginal flinty crush-rock developed in this old Quartz-gabbro may be the result of cauldron-subsidence. If so, the centrally sunken block may have included also the Granophyre (c′), the Old Gabbro (b), and the Quartz-gabbros (c″) and (d). The sheared margin of this block is, however, only seen in two places, at the north and south ends of the Beinn nan Ord ridge. Elsewhere, if it once existed, it may have been obliterated by younger intrusions.

In conclusion, it is noteworthy that ring-dyke fissures must have been formed again and again in Ardnamurchan, and that such fissures have nowhere been detected unfilled by magma. Unlike the cone-sheet fissures, they would seem to have been accompanied in all cases by magmatic intrusion. J.E.R.



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

TABLE VII

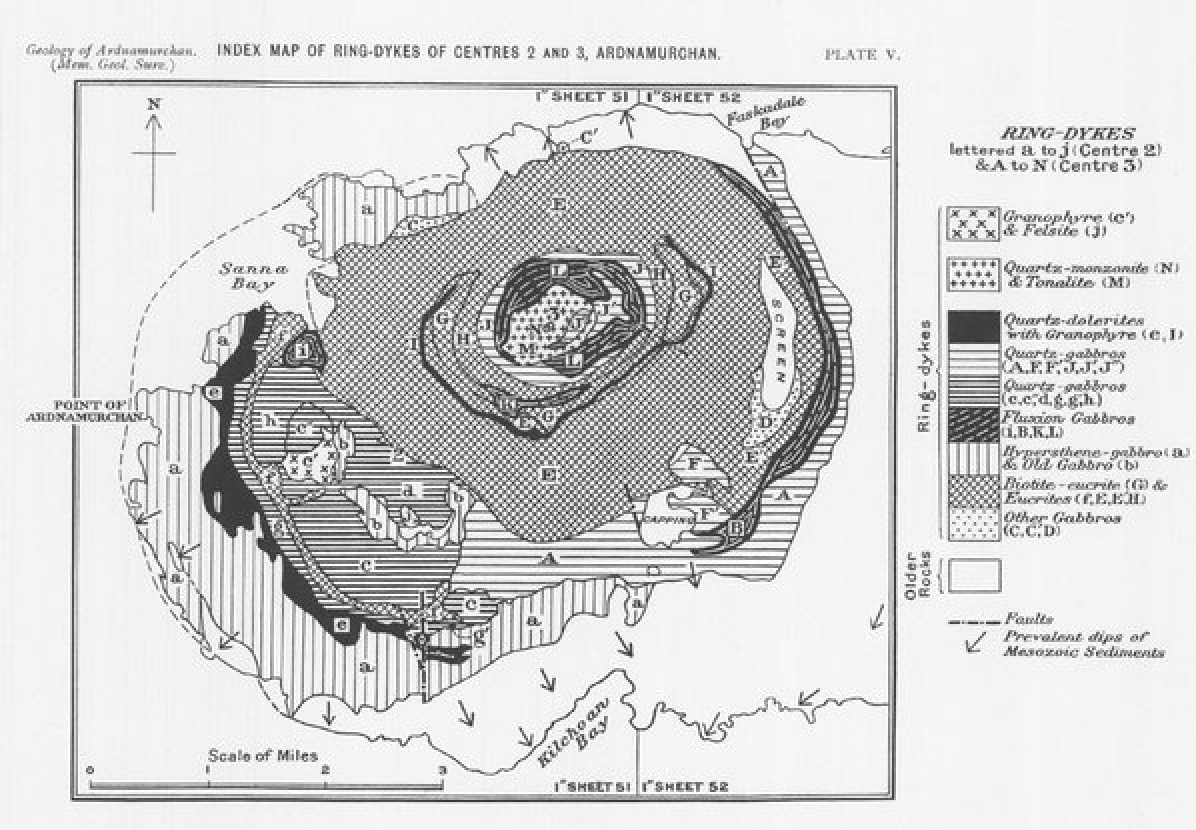
RING-DYKES OF CENTRES 2 AND 3

Index Letter on Map, Pl. V.	Symbol on Memoir-Map.	Rock-type and Designation.	Relative Ages, as determined by contact relationships (pp. 206–8)	
			Younger than	Older than
		EARLIER COMPLEX, CENTRE 2.		
		Older than Inner Cone-sheets.		
a	rE	Hypersthene-gabbro of Ardnamurchan Point	—	c, e, A, C, E.
b	oE	Old Gabbro of Lochan an Aodainn	—	c, c', d, A.
c	qE	Quartz-gabbro of Garbhdhail	b.	c', f, A.
c'	G	Granophyre of Grigadale	c, b.	? c''.
c''	qE	Older Quartz-gabbro of Beinn Bhuidhe	? c'.	h.
d	qE	Quartz-gabbro of Aodann	b.	j, E.
e	gD	Quartz-dolerite of Sgùrr nam Meann	a.	g.
		Younger than Inner Cone-sheets.		
f	uE	Eucrite of Beinn nan Ord	c.	g, h, A.
g	qE	Quartz-gabbro of Loch Caorach	e, f.	—
g'	qE	Quartz-gabbro of Beinn na Seilg	e, ? f.	—
h	qE	Younger Quartz-gabbro of Beinn Bhuidhe	c'', f.	—
i	fE	Fluxion Gabbro of Portuairk	—	? E
j	G	Felsite, south of Aodann	d.	—

RING-DYKES OF CENTRES 2 AND 3

Index Letter on Map, Pl. V.	Symbol on Memoir-Map.	Rock-type and Designation.	Relative Ages, as determined by contact relationships (pp. 206–8)	
			Younger than	Older than
		LATER COMPLEX, CENTRE 3.		
A	qE	Quartz-gabbro of Faskadale	a, b, c, f.	E.
B	fE	Fluxion Gabbro of Faskadale	—	? E'
C	eD	Gabbro of Plocaig....	a.	E.
C'	eD	Gabbro, south-east of Rudha Groulin	—	E.
D	eD	Porphyritic Gabbro of Meall nan Con screen	—	E, E'.
E	uE	Great Eucrite	a, d, h, A, C, C', D.	F, I, K.
E'	uE	Outer Eucrite	? B, D.	? E, F.
F	qE	Quartz-gabbro of Meall an Tarmachain summit	E, E.'	—
F'	qE	Quartz-gabbro, south side of Meall an Tarmachain	—	—
G	bE	Biotite-eucrite	—	I.
H	uE	Inner Eucrite	—	—
I	gD	Quartz-dolerite, veined with granophyre	E, G.	—
J, J', J''	qE	Quartz-biotite-gabbro	—	? L, M.
K	fE	Fluxion Biotite-gabbro of Sìthean Mòr	E.	—
L	fE	Fluxion Biotite-gabbro of Glendrian	? J and J'.	M.
M	tH	Tonalite	J', J'', L.	N.
N	qH	Quartz-monzonite	M.	—

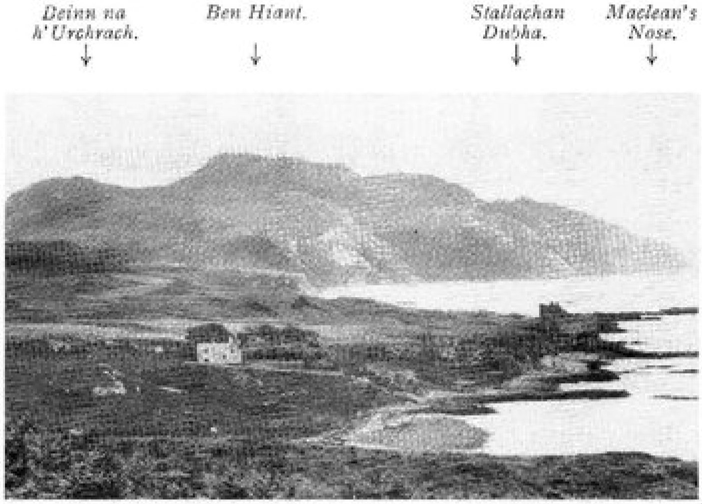
(Table 7) Ring-dykes of Centres 2 and 3.



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

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

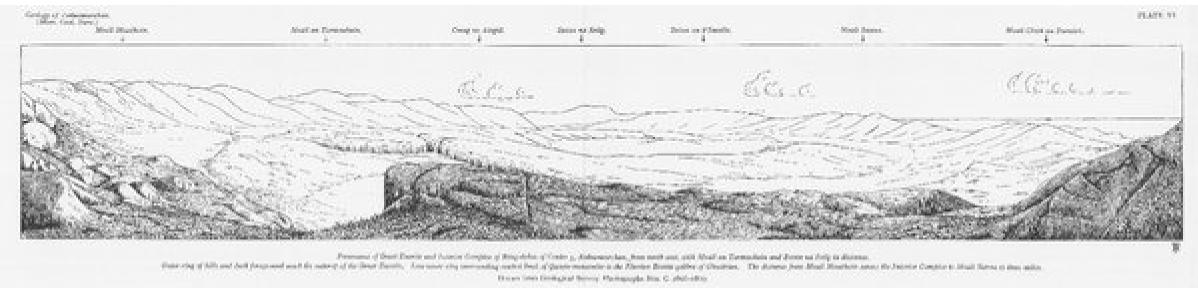
PLATE I.



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 .



(Plate 6) Panorama of Great Eucrite and Interior Complex of Ring-dykes of Centre 3, Ardnamurchan, from north-east, with Meall an Tarmachain and Beinn na Seilg in distance. Outer ring of hills and dark foreground mark the outcrop of the Great Eucrite. Low inner ring surrounding central knob of Quartz-monzonite is the Fluxion Biotite-gabbro of Glendrian. The distance from Meall Meadhoin across the Interior Complex to Meall Sanna is three miles. Drawn from Geological

Survey Photographs Nos. C2806, C2807, C2808, C2809.

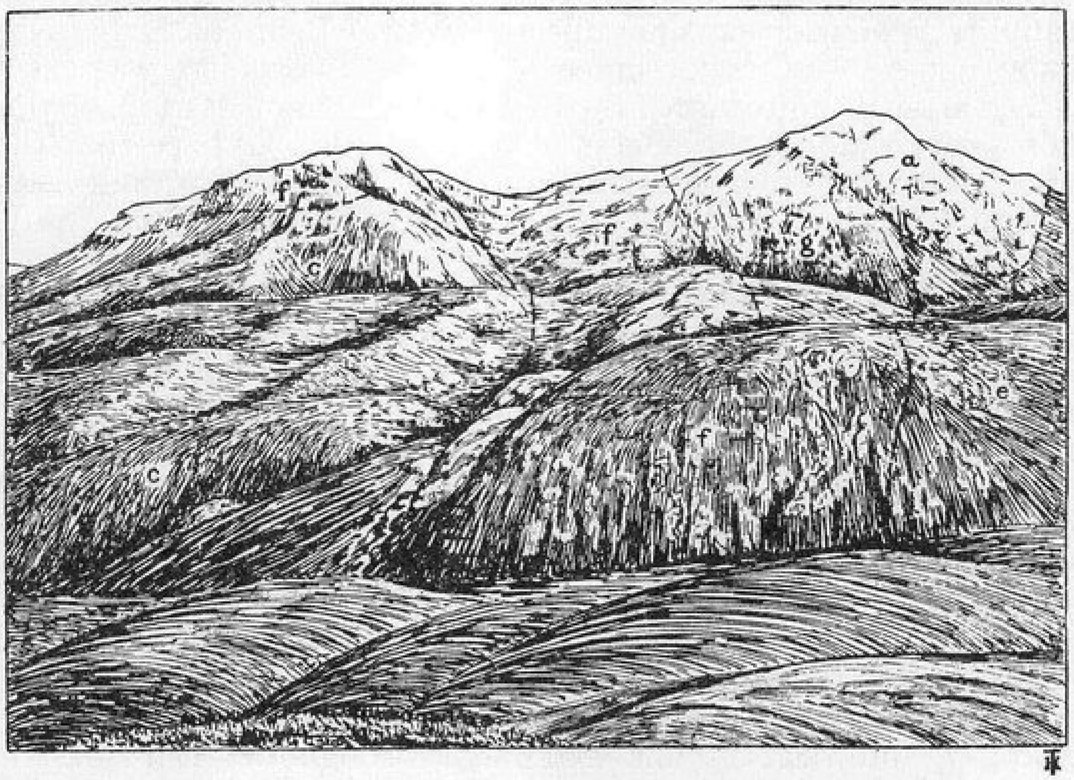


FIG. 36.—*View of the western side of Beinn na Seilg.*
a, *Hypersthene-gabbro.* c, *Quartz-gabbro of Garbh-dhail.* e, *Quartz-dolerite of Sgùrr nam Meann.* f, *Eucrite of Beinn nan Ord.* g′, *Quartz-gabbro of Beinn na Seilg.* *Broken lines indicate margins of ring-dykes (not shown in foreground).*

(Figure 36) View of the western side of Beinn na Seilg. a, Hypersthene-gabbro. c, Quartz-gabbro of Garbh-dhail. e, Quartz-dolerite of Sgitrr nam Meann. f, Eucrite of Beinn nan Ord. g′, Quartz-gabbro of Beinn na Selig. Broken lines indicate margins of ring-dykes (not shown in foreground).

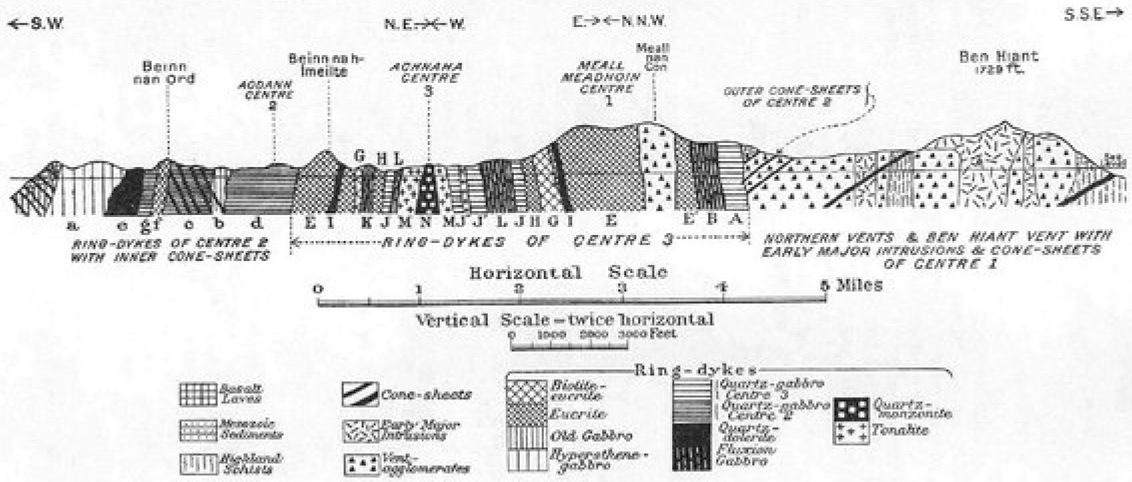


FIG. 27.—*Section across Tertiary Intrusive Complex of Ardnamurchan.*
Index-letters for ring-dykes are explained in Table VII, pp. 201–202.

(Figure 27) Section across Tertiary Intrusive Complex of Ardnamurchan. Index-letters for ring-dykes are explained in (Table 7), pp. 201–202.

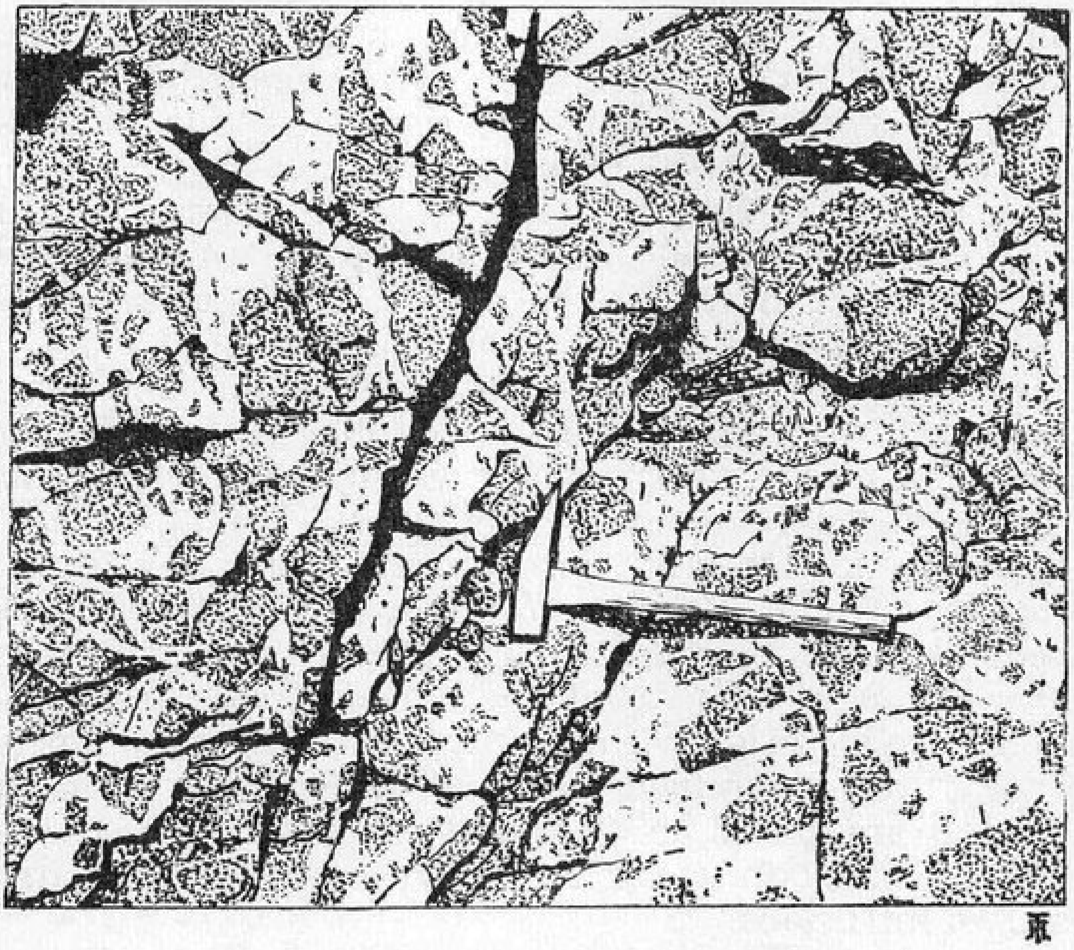


FIG. 34.—*Quartz-dolerite net-veined by granophyre, Sgùrr nam Meann Ring-dyke, on shore south-west of Sgùrr nam Meann.* Drawn from Geological Survey Photograph, No. C. 2773.

(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.

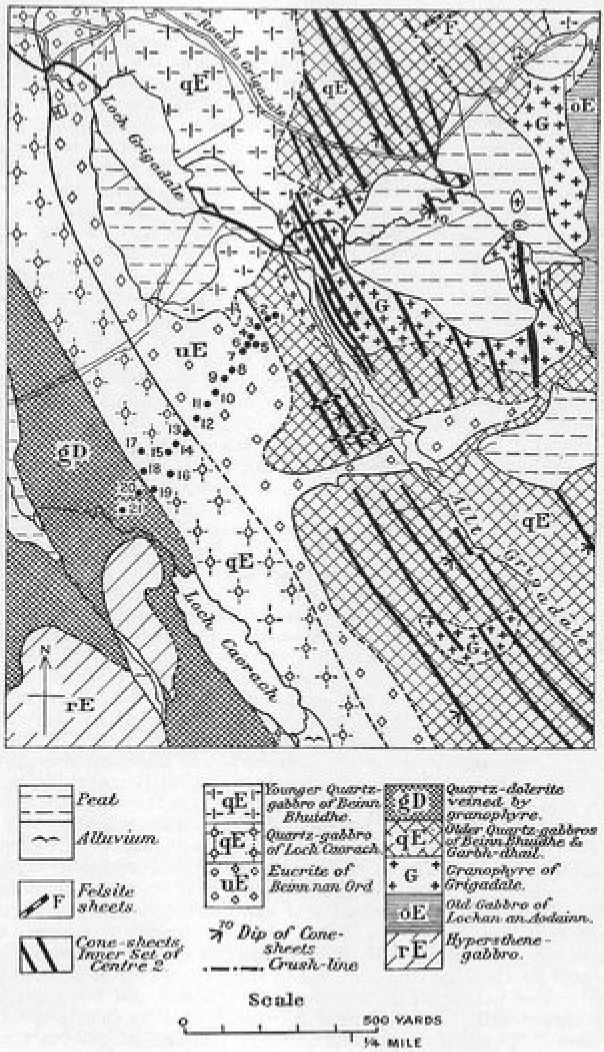


FIG. 37.—*Map of portion of Ring-dyke Complex of Centre 2, north of Beinn nan Ord.*

NOTE.—Localities of a serial collection of rock-specimens are indicated by black dots numbered 1–21 (*see* pp. 268–270, 274, 275).

(Figure 37) Map of portion of Ring-dyke Complex of Centre 2, north of Beinn nan Ord. Note. Localities of a serial collection of rock-specimens are indicated by black dots numbered 1–21 (see pp. 268–270, 274, 275).