Chapter 16 Tertiary ring-dykes of Centre 2, Ardnamurchan

An early complex of ring-dykes situated in the south-west part of Ardnamurchan and referable to Centre 2 is indicated chiefly by the mapping (*cf. (*Plate 2) and (Plate 5)). The ring-dykes composing this complex are transgressed by the outer margins of two outer ring-dykes of Centre 3, the Quartz-gabbro (A) and the Great Eucrite (E), and there is evidence at contacts of the intrusive nature of these margins. The reference of the Earlier Ring-dykes to the same centre (2) as the majority of the cone-sheets is best indicated by the curving outcrops of the Hypersthene-gabbro (a) and the Old Gabbro (b). The intrusive outer margin of the Hypersthene-gabbro is partly hidden beneath the sea, more especially at Sanna Bay, but is sufficiently complete to show its conformation to Centre 2. It should be added that the two portions of this intrusion separated by Sanna Bay undoubtedly belong to the same ring-dyke, for they are alike in rock-type, which is peculiar to them, and also in having similar fine-grained outer margins of quartz-dolerite. In the case of the Old Gabbro, its margins are largely determined by the contacts of later intrusions, but a portion of its inner wall against older rocks is preserved and indicates a curve of which the centre approximates closely to Centre 2. Other intrusions such as the three narrow, slightly curving, ring-dykes, the Quartz-dolerite (e), Eucrite (f), and Quartz-gabbro (g), immediately within the Hypersthene-gabbro, afford confirmatory evidence, while of still greater significance is the recurrence of cone-sheet intrusion around Centre 2 (Inner Cone-sheets) during the Earlier Ring-dyke period.

The order in which the various ring-dykes of Centre 2 will be described is, so far as can be determined, their order of intrusion (*see* (Table 7), p. 201). The relative ages of some ring-dykes cannot be fixed, though all can be satisfactorily placed in one of two time-groups dated with reference to the Inner Cone-sheets, with the exception perhaps of the Quartz-gabbro of Aodann (d). It has not been found possible in the field to separate this mass from the Quartz-gabbro of Beinn Bhuidhe (h), which is younger than the Inner Cone-sheets, but it is unlikely that they are the same intrusion. The Aodann mass (d) is only cut by one cone-sheet, but may well owe its almost complete freedom from sheets to its central position relatively to the Inner Cone-sheet belt, as is true also of the still earlier Old Gabbro (b) within which the Aodann Quartz-gabbro is situated.

The intrusions to be described in the present chapter are: — (*a*) Hypersthene-gabbro of Ardnamurchan Point; (*b*) Old Gabbro of Lochan an Aodainn.

(A) Hypersthene-gabbro of Ardnamurchan Point

This intrusion is the outermost and largest, perhaps also the earliest, of those belonging to the Earlier Ring-dyke Complex. It forms the nose of the Ardnamurchan peninsula and there occupies somewhat remote country, but it also extends eastwards to the neighbourhood of Kilchoan, where it is within easy access.

The chief importance of this ring-dyke, as already mentioned, lies in the fact that it is the most completely preserved of all those belonging to the Earlier Complex, and thus best demonstrates their conformation to Centre 2. Another point that it serves to prove is that there are cone-sheets of different ages to be referred to this Intrusion-Centre, for it is clearly later than the vast majority of cone-sheets traversing its outer wall, while it is itself cut, along its inner margin, by the Inner Cone-sheets ((Figure 35), p. 259).

A characteristic of the mass, which may be specially referred to here, is its exceptionally wide fine-grained outer margin. Notwithstanding this evidence of relatively rapid marginal consolidation, the intrusion has intensely altered the surrounding country rocks. Another feature of interest is the abundance of xenolithic basic igneous material of fine texture, often in the form of strips or bands that are parallel to adjacent margins of the intrusion and also to flow-banding in the gabbro. So far as this material has been examined microscopically, it is found to be mostly akin in composition to the Hypersthene-gabbro itself. It probably originated as an early injection into the ring cavity, which was broken up and incorporated by the main intruding mass. The elongate strip-like form must be largely original, due to some process of scaling off from the sides of the intrusion-cavity, but it is also in part the result of the streaking-out of the xenolithic rock when in a plastic state.

The typical rock is a pyroxene-rich gabbro, of uniform greyish-brown colour on weathered surfaces, a contrast to the speckled aspect of the eucrites and of many quartz-gabbros. Under the microscope (p. 223), hypersthene is almost invariably found to be present, and though this mineral is often met with in other Ardnamurchan gabbros as an original constituent, it is never, in such cases, of general occurrence, and is rarely conspicuous in amount.

Locally, more basic and also more acid types are met with, usually associated in patchy fashion with the normal type, but sometimes as distinct masses. The more basic types are olivine-rich, and may be termed eucrites (S22666) [NM 4184 6672]; the more acid are quartz-gabbros (S23616) [NM 4174 6747] and (S23622) [NM 4771 6461]. Both types contain hypersthene, thus showing their affinity to the normal rock. A locality where eucrite occurs in considerable amount is south of the Lighthouse, about 150 yds. inland from Port M&igraven. The quartz-gabbro type is a feature of the more immediate neighbourhood of the Lighthouse. Near Kilchoan this type is also seen, for example, in a road-metal pit at a sharp bend in the Achnaha road, 600 yds. north-west of the Free Church. Felspathic quartz-gabbroid portions are there associated with more basic pyroxene-rich portions.

Where these variant types form considerable individual masses, sharp junctions between them and the normal gabbro have been noted. About 600 yds. east of Port Mìn felspathic quartz-gabbro is thus related to the normal hypersthene-gabbro. Again, southeast of Beinn nan Ord, 250 yds. south-east of a small loch, there is a small mass of the eucritic variety in sharp contact with a less basic type (S22674) [NM 4484 6391]. On a steep rock-surface facing south this junction is seen for many yards, and is conspicuous at a distance owing to the colour-contrast between the two rocks. At another point of contact the less basic gabbro is fluxioned, as though the eucrite had solidified first. The above examples indicate that differentiation of the Hypersthene-gabbro magma had taken place to a certain extent previous to its final intrusion. Variant types do not, however, form more than a small fraction of the whole mass.

Marginal Facies

Towards its outer margin, as already stated, the Hypersthene-gabbro becomes much finer grained, and iron-ore is especially characteristic of this portion of the intrusion. This mineral is plentiful, for example, at exposures east of the road leading from Kilchoan to Achnaha and Achosnich, 300 yds. northwest of the Free Church. At its extreme outer margin the rock as a rule is a quartz-dolerite, and consequently more acid than the main mass. This marginal variation is perhaps best seen on the rocky northern coast, east-north-east of Plocaig, where the mass is in contact with the Outer Cone-sheet Complex. Though the cone-sheets are highly granulitized, they are a little difficult to distinguish from the marginal gabbro which is of similar texture. The latter, however, weathers brown in colour, rather than grey, which is the tint of the baked rocks, or else shows the pale, blotchy weathering typical of quartz-dolerite. The marginal rock passes very gradually into coarse-grained normal gabbro internally. Such more acid margins are a recurring feature of the ring-dyke intrusions, and in the present instance, and also in the case of the Tonalite (p. 337), they are definitely chilled. Their probable significance has been already discussed (p. 209).

Another characteristic of the outer margin is a profusion of acid veins, usually not exceeding a few inches in thickness, with which also the bounding wall is sometimes intricately injected. The acid magma concerned was evidently a late product of the crystallization of the mass, and need not necessarily have been derived from the early-crystallized quartz-dolerite margin. The latter consolidated as a definite rock-type and was subsequently veined by acid magma that may have been derived from another portion of the intrusion. The rock of the veins is sometimes a monzonitic type (S21524) [NM 4545 6333], (S21812) [NM 4650 6415], due to the incorporation of previously consolidated gabbroic material (*see* p. 211).

Marginal relations

The outer margin against the earlier bedded rocks that are cut by cone-sheets is continuously preserved on the south side of the intrusion. To west and north, sufficient of this margin has escaped erosion by the sea to demonstrate its curved outline conforming to the Aodann Intrusion-Centre (2). To the east, the course of the intrusion is interrupted by the Later Ring-dykes belonging to Centre 3, and it is therefore not known whether it originally formed a complete ring.

Along its inner margin it is everywhere in contact with later intrusions, and no portion of its original inner wall is preserved. There is, however, evidence of an inner marginal facies close to such contacts. It is therefore concluded that the intrusion in its original form was a ring-dyke, and not a stock of which the central portion has been displaced by later intrusions. Even as a ring-dyke it is of massive proportions, its annular width being about two thirds of a mile, and its external diameter about 41 miles.

Outer margin

In the vertical direction, only a few hundred feet of the outer southern margin of the gabbro is seen. A steep outward inclination is so far demonstrable. Along the inner margin, as will be described later, internal structures such as flow-banding point as a rule to its inclination being steeply inwards. Consequently, we may conclude that the intrusion has steep sides converging upwards. No roof is, however, actually known, unless possibly north of Kilchoan, where basalt lavas on the Glebe Hill, at an altitude of about 150 ft., seem to Overlie the gabbro, which is exposed in valleys on either side. If so, the gabbro must be plunging steeply eastwards under roof in this neighbourhood. For immediately to the west of the Glebe Hill, on the lower eastern slopes of Beinn na Seilg, the gabbro is found at a higher level than the supposed roof. On these slopes the outer margin is transgressive and steep, running straight uphill from a point at about 300 ft. to the l00 ft. contour.

Farther west, south-east of Beinn na Seilg, the twin lochs (Lochain Ghleann Locha) lie in a hollow along the margin of the gabbro, which is bounded by basalt lavas that form steep crags. From this point the margin continues westwards, crossing the summits of hills and ridges that slope steeply southwards towards the sea, and extending southwards for short distances obliquely down the intersecting valleys. A general southerly, *i.e.* outward, inclination of the margin is thus suggested, and this is confirmed by an observed inclination in a much deeper section where the gabbro margin reaches the coast, on the west side of Beinn nan Codhan. The margin there extends, in a horizontal distance of about 500 ft., from the top of a cliff, 400 ft. high, obliquely down to sea-level.

North-west of Beinn nan Codhan, along the western side of the gabbro, there occur within the mass two outcrops of highly granulitized rocks. These consist mainly of baked shale, presumably belonging to the Lower Lias, together with some amygdaloidal basaltic rocks, presumably lavas. It is possible also to detect basic intrusive sheets running north-west, which are interpreted as cone-sheets (p. 180). The junction between the larger outcrop and the gabbro on its inner side is steep, as is plainly seen at its southeast end. The two outcrops appear to be portions of a screen separating the main mass of the Hypersthene-gabbro from an outer arm. The latter forms the ridge of Garbhlach Mhòr, where the gabbro is fine grained and contains plentiful iron-ore. At the north-west end of this ridge, highly baked shales (? Lower Lias) occur at the top of a sea-cliff, and probably form part of the outer wall of the intrusion. The shore below was found unreachable from the landward side, and whether the shales actually extend to there, as mapped, from the cliff summit, is not certain. The curving coast-line around the west side of Garbhlach Mhòr, however, must closely approximate to the outer margin. Farther north, along the shore west of the Lighthouse, the gabbro becomes very fine-grained and assumes the quartz-dolerite facies found in most places along its extreme outer margin. It may thus be inferred that this locality is only a very short way from the actual outer edge of the mass.

Along the rocky, northern side of Sanna Point, the marginal quartz-dolerite facies is again met with. Just east of this, the country rocks, comprising Mesozoic sandstone and limestone profusely intruded by cone-sheets, are seen once more, and form the headland of Rudha an Dùin in Bhàin (*see* one-inch Sheet 51). These rocks are so intensely baked that the chilled edges of the cone-sheets are seldom discernible, but shreds of sediment that occur at intervals show that we are dealing here with a portion of the cone-sheet complex. A steep junction of the gabbro with this complex is on view in the sea-cliff, which is about 20 ft. high, 300 yds. west-southwest of the headland. From this point the margin extends eastwards, and runs out to sea again north of Plocaig. Half a mile east-north-east of Plocaig it turns inland once more, where the customary quartz-dolerite marginal facies is presented against the cone-sheet complex. The margin is again seen a short way inland to the south, on the east side of a hollow that marks a north-west crush-line. Nearby, the Hypersthene-gabbro ends against the Great Eucrite Ring-dyke that belongs to the Later Complex.

Inner margin

As already mentioned, the original inner margin of the Hypersthene-gabbro nowhere exists, for on its inner side the intrusion is everywhere in contact with younger ring-dykes.

Remnants of an inner marginal facies may, however, be recognized in certain banded and fluxioned varieties of the Hypersthene-gabbro. Banded structure is especially well developed in the vicinity of Beinn na Seilg, as, for example, on a more southerly peak of that hill, marked on the Memoir-map by an Ordnance Survey cairn. The bands there incline northwards at angles of 35 to 45 degrees. Westwards, as far as the south-east end of Beinn nan Ord, similar inclinations are found. But eastwards, on a rocky summit east of the southerly peak, the banding is flat or only slightly inclined north-wards. The banding, if due to flow-movements near margins, must be connected with a roof, where flat, or else an inner margin, not the outer, since it is separated from the outer margin by a wide outcrop of unbanded gabbro. The evidence, then, suggests an inward northerly inclination for the inner margin between Beinn na Seilg and Beinn nan Ord, and a flat roof eastwards of Beinn na Seilg. Farther east, on the Glebe Hill, at a much lower level, the intrusion appears to be overlain by roof, as already described (p. 219).

East of Druim Reidh-dhalach, 150 yds. south-west of two adjoining lochs (Lochain Dubha), the inner junction against the Quartz-dolerite Ring-dyke (e) runs close to a hollow, along which the Hypersthene-gabbro is very fine grained and rich in iron-ore. When traced away from this margin, up the slope of Druim Reidh-dhalach, the gabbro grades into the normal coarse-grained type.

Farther north-west, fluxion gabbro, with sharply defined felspar plates in parallel orientation, occurs all along the inner margin, from where an outlying mass of the Hypersthene-gabbro is surrounded by the later Quartz-dolerite northwards to the coast, east of the Lighthouse. The observed inclinations of fluxion are consistently eastwards at high angles of about 70 degrees. Similar fluxion gabbro is often met with elsewhere in the ring-dyke complex, either as marginal fringes to gabbro and eucrite intrusions, or as individual intrusive masses. In the present case the fluxion type is marginal, for its gradation into the normal hypersthene-gabbro of the interior is evident. Alternating belts of the two types occur along the inner margin east of the Lighthouse, on the right side of a stream that enters the sea east of the Lighthouse pier, and south of a patch of raised-beach deposits.

The inclination of fluxion eastwards of the Lighthouse, then, suggests a steep inclination of the inner gabbro margin inwards and eastwards towards the Intrusion-Centre of Aodann. Other evidence of this from the vicinity will be stated below.

Xenolithic inclusions

Xenoliths are very common, and sometimes abundant. In their present condition they may be described as basic granulites. Originally, as the microscope shows, their rock-types were various. Fine-grained hypersthene-gabbro is most common (S23633) [NM 4769 6450], which is apparently consanguinous with the intrusion itself. Other types identified by Dr. Thomas are olivine-gabbro (S22667) [NM 4168 6674], porphyritic gabbro (S22631) [NM 4247 6812] with its felspar phenocrysts plainly seen in the field to have been drawn out by flow-movement (Eilean Carrach), and quartz-dolerite of cone-sheet type (S22278) [NM 4653 6410]. The xenoliths occur as irregular masses, or angular fragments, or else as elongate bands. Contacts with the enclosing gabbro are in general perfectly sharp, and there is seldom any sign of absorption by the gabbro magma. The xenolithic bands or strips are of much interest. They are very numerous, for example, along the banded inner margin on Beinn na Seilg, and may be conveniently examined on the rocky summit east of the south peak and north of the twin lochs (Lochain Ghleann Locha). The bands are a foot or so across and keep a constant width for several yards; they are here either flat or else gently inclined northwards. At first sight, indeed, they look like basic intrusive sheets in the gabbro, and usually their minute felspars are orientated parallel to the surface of the band, as though arranged by flow-movement. But on closer examination it is found that their margins are quite unchilled and are, indeed, interbanded with coarser gabbroic material, as though these margins were viscous and were subjected to slight intermixture and flow-movement with gabbro-magma in contact. This opinion is confirmed by the fact that the xenolithic sheets are arranged parallel to the flow-banding in the surrounding gabbro and follow its changes of direction. Further, they, in common with the gabbro, are traversed by acid veinings due to a residual acid portion of the gabbro magma. Another good locality for xenolithic sheets is between Garbhlach Mhòr and the Lighthouse, near to the outer

margin of the intrusion. The xenolithic sheets are consistently inclined to the north of east at 60 degrees, and in direction they are parallel to the course of the ring-dyke. Their degree of inclination may well be a measure of the inclination of the wall at this point in its course. If so, the local inclination is inwards. The gabbro is also characterized hereabouts by close-set joints that are parallel to the xenolithic sheets. The joints are to be attributed to the contraction of the gabbro mass on solidifying, and are presumably parallel to the gabbro margin. The xenolithic sheets range up to 20 ft. in width, but are more usually about 4 ft. They have perhaps been drawn out to some extent by flow-movement when in a plastic condition, for a platy structure parallel to their surface is very marked. The thicker individuals can be traced for 50 yds. and upwards along the rocky headland of Dubh Rudha Mòr, north of Port Mìn.

Interesting xenoliths of sapphire-spinel rock are associated with highly granulitized fine-grained gabbro at the outer margin of the Hypersthene-gabbro just north of Glebe Hill. They are described in detail below (p. 233).

Age relations

The Hypersthene-gabbro is younger than the Outer Set of Cone-sheets, and older than at any rate the great majority of the ring-dykes.

The relations to the Outer Cone-sheets have already been fully discussed (p. 182), while along its inner margin the Hypersthene-gabbro is everywhere in contact with ring-dykes younger than itself, as will be described under the various later intrusions concerned (*see (*Table 7), p. 201). The only important ring-dyke of the Earlier Complex with which age relations cannot be established is the Old Gabbro (b) of Lochan an Aodainn. Both of these intrusions are, however, of early date, and lithologically they have points of resemblance, both being usually pyroxene-rich gabbros. The Old Gabbro is therefore described next. J.E.R.

Petrology of hypersthene-gabbro

(Anal. II, (Table 4), p. 85)

Normal types

The gabbro that constitutes the outermost member of the ring-dyke complex of Centre 2 is a slightly variable rock as regards composition and texture, but on the whole shows a remarkable consistency in its mineral assemblage. The mass is characterized by the general prevalence of a rhombic pyroxene (hypersthene) in sufficient quantity to entitle the rock to the name hypersthene-gabbro or hypersthene-eucrite. In this respect it differs from most of the Tertiary gabbros of Britain, for, while they frequently contain rhombic pyroxenes, such minerals usually fall within the category of accessory constituents, and do not appear to play an essential part in the rock's constitution.

In the hand-specimen the rock shows some textural variation. Usually it is a moderately compact rock of a medium to dark-grey colour, with its light and dark minerals in about equal proportions collected into areas measuring a quarter of an inch or so across.

The coarseness, however, varies gradually from place to place without apparent plan, and occasionally the rock may become so coarse that individual crystals reach several inches in greatest dimension.

Microscopic examination of a number of specimens selected from the interior of the intrusion, along the length of its outcrop, demonstrates the general basic nature of the mass, which is composed of olivine, hypersthene, augite, and a basic plagioclase felspar. Accessory minerals such as iron-ore and apatite are most often either poorly represented or absent, but iron-ore on occasions shows segregation into well-defined patches.

As might be expected, in addition to textural variation, there is considerable variation in the relative abundance of the respective mineral constituents. In some parts olivine occurs in profusion and rhombic pyroxene is poorly represented; elsewhere hypersthene is more abundant than olivine, while in most other cases these two minerals occur in approximately equal proportions. Thus some portions of the mass might be referred to as olivine-gabbro with subordinate

hypersthene, and others as hypersthene-gabbro with subordinate olivine. It is, of course, not unusual to find some sort of interdependence between these two minerals in rocks of gabbroic composition, especially where there is a tendency for some parts of the mass in question to pass into rocks referable to the quartz-gabbros, by the development of an interstitial acid residuum.

In the normal rock, olivine is usually in excess of rhombic pyroxene. It is a colourless variety occurring in rounded or subidiomorphic grains and crystals reaching a millimetre or so in diameter, or forming glomero-porphyritic groups two or three times this size (S22388) [NM 446 642]. Generally it is in a fresh condition, but when pseudomorphed it gives rise to so much finely divided magnetite (S22666) [NM 4184 6672] that the pseudomorphs are rendered almost opaque. This fact leads to the assumption that the olivine is a variety fairly rich in iron, a surmise strengthened by the optically negative character of the mineral. It is generally quite definitely the earliest product of consolidation, behaving poecilitically towards late - formed pyroxenes and felspar (S21506) [NM 4690 6446], and seldom showing simultaneous crystallization with any other constituent.

Hypersthene is the usual rhombic pyroxene, and occurs commonly in close association with olivine (S21589) [NM 4762 6491]. It is strongly pleochroic in shades of pink and green, and is frequently associated with a little biotite with or without attendant iron-ore.

The felspars are for the most part somewhat small crystals, much twinned and zoned, which form interlocking and mutually interfering aggregates. The zoning of felspars is a common feature of the normal gabbros and less basic eucrites, but is less common in the more basic eucrites and peridotites (allivalites, etc.). The felspars of the Hypersthene-gabbro cover a fairly wide range in composition. Initially they are mostly a basic labradorite or bytownite, optically negative in character. Commonly the zoning by less basic species is more or less peripheral, and oligoclase when present forms but a thin and almost negligible ultimate layer on the earlier, more basic, individuals. All the same, this zoning of the felspar is sufficiently pronounced to give the completed crystals a bulk-composition of normal labradorite.

The monoclinic pyroxene is a normal aluminous augite, and is an invariable constituent of the gabbro. It occurs in fair quantity and is always ophitically related to the felspar or poecilitically to olivine. Usually it has a greenish tint, but shows no pleochroism. A diallagic structure is often absent, but at other times it may affect the whole or part of an individual crystal.

Of the rocks more than usually rich in olivine, that represented by the analysis given on p. 85 and collected from the south-west of Beinn na Seilg may be regarded as typical. Other examples may be noted from Beinn nan Codhan and the neighbourhood of Ardnamurchan Point.

The analysed rock (S22821) [NM 450 638] contains the usual ferriferous olivine in rounded crystals and grains, associated with a small amount of hypersthene and enclosed in a coarse mass of ophitically related augite and basic labradorite. The augite exhibits ' schillerization and shows local corrosion, presumably by acid final products of consolidation.

Very beautiful examples of the olivine-rich variety occur in the neighbourhood of Beinn nan Codhan (S23624) [NM 4438 6299], (S23625) [NM 4499 6364]. Their more definitely eucritic nature is shown not only by the abundance of olivine but by much of the felspar having an optically negative sign. The olivine when decomposed yields the usual magnetite-rich pseudomorphs (S23624) [NM 4438 6299], and the hypersthene where altered passes into fibrous actinolitic hornblende. Towards Ardnamurchan Point occur similar basic types that carry much fresh olivine. In some instances (S21552) [NM 4296 6806] they show the unusual feature of having their olivine in part moulded upon an early generation of basic felspar, while others show a slight segregation of iron-ore following on the crystallization of olivine (S23619) [NM 4203 6657], which mineral, together with some felspar, is included poecilitically.

In yet another variety of the gabbro, hypersthene is abnormally abundant and, like the augite, builds large masses that behave ophitically towards the larger felspars (S21500) [NM 4353 6323], (S22272) [NM 4475 6990], and often enclose a host of smaller individuals in poecilitic fashion (S22376) [NM 4195 6705]. The hypersthene shows the usual pleochroism

and often exhibits a schiller-structure.

A somewhat fine-grained type, extremely rich in hypersthene and relatively poor in olivine, with local segregation of iron-ore, comes from the north-west end of Druim Reidh-dhalach to the south-east of Ardnamurchan Point (S23618) [NM 421 649].

To the east of Sanna, in the neighbourhood of Plocaig, on the north coast, the gabbro is mainly of the olivine-rich variety (S22264) [NM 4546 6995], (S22266) [NM 4543 7012] but locally contains abundant strongly pleochroic hypersthene (S21550) [NM 4575 7021]. In this portion of its outcrop it is in contact with the Great Eucrite of Centre 3, and the schillerization and turbidity of its felspars (S22265) [NM 4546 6998], (S21550) [NM 4575 7021] suggest that it has to some extent been affected by metamorphism brought about by the later intrusion.

Marginal facies

A feature of the Hypersthene-gabbro is an outer marginal facies that is finer in texture, and in bulk-composition considerably less basic, than the main part of the intrusion. The rocks in this marginal portion of the mass, though frequently veined by later acid material, do not in themselves show a macroscopic patchy development of acid and basic material such as is a feature of basic rocks that have been permeated by a later and more acid magma. They have the appearance in the field of more or less normal quartz-gabbros and quartz-dolerites. The microscope, however, reveals the fact that on a microscopic scale we have in reality basic material involved and enveloped by an acid magma, or partial magma, that has disturbed the original set of equilibria, and brought about recrystallization and mineralogical adjustments. In some cases these are so extreme and so evidently connected with the migration of acid matter that the processes involved are akin to those of hybridization. At the same time it is impossible to connect this acidification, or abnormally acid character of the marginal portion of the gabbro, with any definitely later intrusion of acid magma, and we are forced to the conclusion that it has been produced by a partial magma for which the Hypersthene-gabbro is alone responsible.

In the rocks of this marginal zone olivine or its pseudomorphs are entirely wanting, and thus it would appear that the original rock was less basic than the normal gabbro of the interior of the mass.

As exemplified by a number of specimens collected mainly in the neighbourhood of Ardnamurchan and Sanna Points, the rocks are composed of augite, plagioclase felspar, rhombic pyroxene, and iron-ore in varying proportions, with an irregularly distributed base of alkali-felspar and quartz.

The augite appears to be for the most part an original constituent and, where least affected by contiguous acid material, is a brownish variety that occurs in coarsely ophitic relationship with moderately basic labradorite felspars, after the manner of augite in the normal dolerites or olivine-free gabbros. It usually has a pronounced diallagic structure that has contributed largely to its turbidity and general brown colour. The original felspars are fairly large zoned individuals of labradorite. Hypersthene appears to have been a universal constituent, and in some cases still exists in a fresh condition (S23622) [NM 4771 6461]. Generally, however, the rhombic pyroxene is now represented by pseudomorphs, in fibrous hornblende and other decomposition products, which show that the individuals reached considerable dimensions and, like the augites, were often ophitically related to the original felspars (S22269) [NM 4425 7041] and (S22269A) [NM 4425 7041]. Iron-ore is a moderately abundant constituent (S23615) [NM 4150 6740], (S22271) [NM 4419 7036] and in certain cases builds large plates referable to ilmenite (S22270) [NM 4420 7045]. In their original condition, therefore, the rocks were probably olivine-free hypersthene dolerites or gabbros.

The outstanding character, however, of these marginal types is their microscopic permeation by an apatite-rich acid partial magma that has reacted upon, and modified to a varying degree, the original constituents. The amount of acid material present in any section is far from constant, here collecting into small insignificant areas, and there reducing the rock to an almost granophyric condition (S23614) [NM 4601 7029]. The acid material itself has invariably solidified as a micrographic growth of alkali-felspar and quartz which is charged with needles of apatite, a mineral that is poorly represented in the normal dolerites and gabbros of Ardnamurchan.

In addition to permeating the rocks in the form of granophyric matter this acid material has been able to react upon the original minerals, and marked changes are to be noted, particularly in the augite and early felspars. The augite assumes a patchy appearance due largely to resorption, the local obliteration of the original schiller-structure, and the regrowth of a greenish unschillered augite that encloses small grains of magnetite and flakes of biotite (S23615) [NM 4150 6740]. At the same time, the original ophitic structure is to some extent destroyed and the boundaries of the crystals rendered less definite and regular. The felspars exhibit the effects of marked resorption and a general acidification. Felspars, or parts of felspar crystals, that have escaped the processes of resorption and acidified regrowth, either show a characteristic turbidity and schillerization (S23614) [NM 4601 7029], (S22271) [NM 4419 7036] or have suffered albitization (S22270) [NM 4420 7045]. Almost all felspars in those rocks that contain much micrographic matter have suffered resorption and regrowth with less basic varieties that range to oligoclase-albite in composition (S21558) [NM 4408 7037]. In the regrown portion of the felspars it is not uncommon to find needles of apatite, a mineral essentially a product of the partial magma, and in one instance a group of blue tourmaline needles, indicating the active presence of mineralizers, has been detected in a similar position.

On and near its inner margin the Hypersthene-gabbro shows a similar type of acidification to that encountered in the outer marginal zone, but in addition is characterized by a fluxional arrangeinfirt of its constituents. Augites are deschillerized with the microscopic crystallization of magnetite and biotite within their boundaries, and old felspars are albitized, shattered, and regrown (S23621) [NM 4189 6618]. Possibly the rock has been affected in some measure by the adjacent later Quartz-dolerite Ring-dyke (e).

A representative of the Hypersthene-gabbro, more than usually rich in iron-ore, occurs near the inner margin of the intrusion, 700 yds. southward of Loch Caorach (S21517) [NM 4351 6476]. It is a somewhat abnormal granulitic doleritic type, consisting mainly of ophitic to granular diallagic augite, intimately intergrown with magnetite that forms perhaps io to 20 per cent. of the mass, and labradorite felspar as somewhat small twinned crystals.

Acid veins

The acid veins (p. 218) that characteristically cut the outer margin of the gabbro and often pierce its bounding wall represent a late migration of acid magma that was the final product of consolidation of the gabbro mass. They have compositional similarity to the acid patches described above, but are related to the gabbro in the same way as fine-textured aplitic veins are related to many of the larger granitic intrusions. In their least contaminated form they were either granophyric or aplitic in character (S23616) [NM 4174 6747], but in almost every case they have been basified to some extent by the complete or partial assimilation of basic material. Where relatively unmodified, they consist of somewhat stumpy crystals of oligoclase-albite felspars distributed through a mosaic of perthitic alkali-felspar and quartz, which carries moderately abundant apatite (S21524) [NM 4545 6333]. The oligoclase crystals have an average length of about half a millimetre and are two or three times as long as broad. They are usually turbid but show traces of lamellar twinning. Quartz is abundant and has quite irregular form.

Although often not in obvious micrographic intergrowth with alkali-felspar, adjacent areas of quartz have simultaneous extinction and thus a granophyric structure is indicated.

In other cases a fine granophyric matrix is the rule. Contamination by partial assimilation is to be inferred by the occurrence of occasional undissolved patches of augite and iron-ore of gabbroic Or doleritic origin, and remnants of modified basic felspars derived from a similar or identical source. It appears almost certain that all the augite encountered in these rocks is xenocrystal in character.

The effects of more complete assimilation of basic material are to be noted in the crystallization throughout the rock of a greenish hornblende, often intergrown with, or fringing, the xenocrystal augites; patches of biotite; and a rhombic pyroxene, frequently in well-shaped crystals but usually pseudomorphed. In other cases the rocks are replete with undigested basic material in the form of augite, iron-ore, and basic plagioclase, of gabbro derivation. Augitic clots have generally given rise to areas rich in well-crystallized greenish hornblende (S21520) [NM 4268 6799], while the matrix carries hornblende, biotite, and rhombic pyroxene, as the results of more complete assimilation.

Sometimes the more basic felspars are edged with perthitic orthoclase and surrounded by micropegmatite (S21812) [NM 4650 6415]. On occasions, when these veins carry an unusual amount of xenolithic basic material, there has been a widespread crystallization of rhombic pyroxene (hypersthene) in small crystals and grains as the result of acidification (S21522) [NM 4716 6440].

It will be seen that many of these rocks reproduce the character of gabbro-granophyre hybrids in the production of a pyrogenetic hornblende and rhombic pyroxene, and, in a measure, recall the mineralogical associations met with in the Tonalite and Quartz-monzonite of the Interior Complex of Centre 3 (pp. 338, 341).

A remarkable type in the outer marginal zone of the Hypersthene-gabbro is a pyroxenic rock abundantly, rich in a peculiar augite ((Figure 30) B). It is dark grey-green in colour, finely crystalline in aspect, and carries crystals of sphene visible to the unaided eye. The augite builds mutually interfering, somewhat elongated, crystals of a dirty brownish-green colour with an occasional tinge of olive green. It is strongly pleochroic in tones of olive-green and bright yellow-brown and is comparable in most respects to the augite described from the so-called Augite-diorite of Camphouse (p. 153). The other constituents are subordinate in amount and consist of labradorite felspar, in small elongated crystals ophitically enclosed by the augite, occasional scattered granules of magnetite, and a few large patches of pale brownish sphene. Apatite is represented by a. small number of somewhat large turbid crystals.

The rock carries locally an acid mesostasis that consists mainly of feathery aggregates of alkali-felspar, but contains abundant minute acicular prisms and grains of augite, needles of apatite, and finely divided magnetite. This acid matter is out of sympathy with the rest of the rock, and has produced marginal resorption of the larger augites and acidification of the felspar.

The rock as a whole is presumably a basic band, or granulite, in the Hypersthene-gabbro which has suffered hybridization by acid emanations from the surrounding intrusion. It is so similar to the Camphouse Augite-diorite, the hybridized cone-sheets lying to the south-east of Rudha Groulin (S22636) [NM 4740 7084], p. 155), and the Hypersthene-gabbro itself on the shore west of Sanna where hybridized by acid emanations from the Great Eucrite (p. 311), that it must have had a similar origin.

Granulites and xenolithic masses

Throughout the Hypersthene-gabbro, but perhaps more frequently near the margins, we encounter sheet-like strips of dark-grey fine-textured rocks that are now more or less reduced to the condition of granulites by the metamorphic action of the intruded mass in which they lie. These granulitic strips are sharply marked off from the rock that envelops them, and in the majority of cases it is evident that they are remnants of rock-masses that were solid before the intrusion of the gabbro as a whole. It is equally clear that not all of them had the same origin, although they are generally similar in their mode of occurrence. Many are of gabbro, but others may be referred to early cone-sheets or even basalt lavas.

As a group they are similar in all respects to the granulitic masses that occur "within the gabbros of Skye,<ref>A. Harker, The Tertiary Igneous Rocks of Skye, *Mem. Geol. Surv.,* 1904, pp. 115, 116.</ref> and in the marginal portion of the Eucrite of Ben Buie in Mul1,<ref>H. H. Thomas *in* Tertiary Mull Memoir, 1924, pp. 252, 253.</ref> which in the latter instance were regarded as metamorphosed remnants of some early basic intrusion or intrusions.

In the case of Ardnamurchan, the evidence supplied by the Hypersthene-gabbro and by other units of the plutonic complex tends to show that very frequently the major intrusions had early-consolidated margins against the country rock which became involved, granulitized, or otherwise modified by the continued uprise of magma from below. Sometimes the effects were purely thermal, but at other times differentiation, progressing concurrently with intrusion, produced a magma that was capable of interaction with the already solid margins, and thus special mineralogical readjustments were effected.

Dealing first with those granulites which from their composition and structure must have been solid igneous rocks prior to the intrusion of the main gabbro-mass, we encounter a variety of types that cover a moderately wide range in composition. This range of composition, however, is really no more marked than, and is of a similar order to, that

exhibited by the main mass of the intrusion. Usually the granulites are at least as basic as the gabbro that envelops them, and quite commonly they are more so. There appear to us to be good reasons for regarding most of these inclusions as cognate to the main intrusion and not as of accidental type. There are, however, xenoliths of obviously unrelated character, among which one interesting type carries sapphire.

The fine-textured gabbro of the western coast, to the south of the Lighthouse, is replete with granulitic masses, and it is from here that many of our best examples have been gathered.

The degree to which granulitization has proceeded in these masses is somewhat variable, but it appears to bear little or no relation to the position that the included mass occupies with respect to the margins of the intrusion. If, however, any generalization may be suggested it is that those masses which occur well within the intrusion, in what may be termed its outer central portion, are more finely textured and more completely recrystallized than are those which are situated nearer to the outer margin.

The gabbro in the immediate proximity of such masses shows no signs of chilling, and the junction of the two rocks, although clearly defined, is of the welded type. It is probable, however, in fact almost certain, that the greater part of the granulitization was effected in many instances before the included mass reached its present position, and possibly before it was stripped from the solid wall of which it originally formed a part. This view is strengthened by the fact that many of the masses had been shattered and otherwise broken up before a granulitic structure was impressed upon them. Specimens of such masses, collected not far within the outer edge of the gabbro, are of a moderately coarse-textured hypersthenebearing rock that has been shattered and then granulitized (S22670) [NM 4149 6623]. It is the crushed portions that have responded most readily to the granulitizing influence, and thus the fractures left by the crushing have been largely healed, but not completely obliterated, by the recrystallization. The original larger felspathic components of the rock have suffered little internal change, but they have been extended by subsequent growths that took place concurrently with the granulitization of the body of the rock. The augite has granulitized into small irregular ophitic and poecilitic patches that enclose granules of felspar, and iron-ore is more generally distributed. Hypersthene builds ophitic masses which, in some instances, are products of recrystallization, but in others probably remnants of the original hypersthene of the gabbro. In the crushed and more completely granulitized portions, the rock consists of a mass of water-clear prisms and grains of a moderately basic labradorite, with granules of augite, rhombic pyroxene, and magnetite.

Another strip of granulite (S22671) [NM 4149 6623] from an adjacent part of the gabbro is of finer texture and has been completely recrystallized. It consists of a mosaic of clear unzoned labradorite through which are scattered small irregular plates of poecilitic augite with diallagic structure, and a few small patches of opaque iron-ore which enclose granules of felspar after the manner of the augite. Other granulitic strips are of the granulitic gabbro type (S22668) [NM 4168 6674], (S22669) [NM 4160 6677], (S23631) [NM 4353 6323], (S23632) [NM 4351 6336], (S22281) [NM 4542 6358], but others again (S22667) [NM 4168 6674], (S23620) [NM 4223 6631], (S23633) [NM 4769 6450] are finer-textured rocks with a typically developed fine granulitic structure throughout. In these we meet with some mineralogical as well as structural differences, chiefly due to the respective parts played by olivine and pyroxene, but in a less degree to slight original differences in composition. In some instances, in which olivine is the dominant ferromagnesian constituent (S23620) [NM 4223 6631], the rocks may with propriety be described as olivine-granulites, for they consist of a granular aggregate of colourless olivine, basic plagioclase, and magnetite ((Figure 31) B). Such rocks are granulitic representatives of the allivalitic varieties of the normal gabbro. In other cases, rocks of almost equally basic character (S23633) [NM 4769 6450] have olivine replaced by hypersthene, and consist of a fine-textured granular aggregate of highly pleochroic hypersthene, basic plagioclase, and magnetite. A section across the junction of such a granulite with the gabbro shows a sudden change from the fine-textured well-granulitized rock to a normal moderately coarse hypersthene-gabbro that contains large areas of hypersthene and diallagic augite.

Yet another type of fine-grained granulite (S22667) [NM 4168 6674], which reproduces in some measure the mineralogical characters of the preceding, contains abundant olivine as well as pyroxene, but in this case the pyroxene is a monoclinic variety.

All these types are moderately rich in ferromagnesian constituents and fairly basic plagioclase, and are just such as would arise simply from the granulitization of fine-textured basic portions of the gabbro. The possibility, however, of some of them being recrystallized basalt lavas must not be lost sight of.

The coarser-textured masses that occur as included strips are certainly recrystallized rocks for the most part, and are best designated granulitic gabbros, but even these have a generally less coarse texture than the rock that envelops them. In most of these, hypersthene is well represented, in some cases being a product of recrystallization and in others probably original (S23631) [NM 4353 6323]. Some of the rocks are unusually felspathic (S22668) [NM 4168 6674] and consist mainly of partly recrystallized labradorite zoned to oligoclase, in fairly large interlocking individuals.

Near the inner margin of the gabbro mass, where some of these granulitic masses come within the influence of the Quartz-dolerite Ring-dyke of Sgarr nam Meann, they have had further contact alteration and occasional modification by acid juices. In such cases (S23634) [NM 4190 6609] there has often been a development of biotite or dark-green hornblende as the results of interaction.

Turning now to those masses which we have reason to believe are of accidental xenolithic character, there are certain fine-textured granulites with porphyritic felspar which are in all probability included basalt lavas. Their type of granulitization and their constituent minerals are the same as those of the granulites described above, but their structure is somewhat different. They frequently show a banding (S22631) [NM 4247 6812], the bands being composed either almost entirely of felspar or of olivine, hypersthene, and magnetite. In the field, the structure of one such rock suggests that the felspathic bands are due to the drawing out and recrystallization of original felspar phenocrysts (pp. 221–2).

Some of the most interesting accidental xenolithic masses, however, are certain fine-textured, dark-grey rocks that occur at the outer margin of the Hypersthene-gabbro, on the northern flank of Glebe Hill, three quarters of a mile north-west of Kilchoan. These xenoliths are individually several feet in extent and are remarkable for containing abundant plates of deep-blue sapphire visible to the naked eye, and which may attain 2 or 3 millimetres in width. They are associated with a compact dark-grey hypersthene-olivinegranulite (S27208) [NM 4805 6478], very similar in type to those met with as inclusions in certain of the other gabbro masses and forming portions of Meall nan Con Screen ((Figure 31) A, p. 230). This fine-grained granulite is perhaps an early consolidated portion of the Hypersthene-gabbro which has gathered to itself masses of aluminous country rock, and which has been metamorphosed 'by the later intrusion of the main mass of the gabbro. The sapphire-bearing rock is compact and very fine grained for the most part, but locally exhibits small felspathic areas reminiscent of the anorthite-sapphire-spinel assemblage that was so characteristic a feature of the sapphire-bearing xenoliths of Mull.<ref>H. H. Thomas, On Certain Xenolithic Tertiary Minor Intrusions in the Island of Mull, *Quart. Journ. Geol. Soc.,* vol. lxxviii., 1922, p. 229. *See also* Tertiary Mull Memoir, 1924, pp. 274–279.</ref>

The sapphire-bearing xenoliths, where in contact with the hypersthene-granulite, show a narrow reaction zone, about four inches in width, traversed by a banding that is parallel to the outer margin of the included mass. This is evidently a reaction zone between the aluminous rock and the granulite. Microscopically the xenolith is found to be composed, in the main, of a deep sage-green spinellid that is opaque except in the thinnest sections, a water-clear basic plagioclase, and blue to colourless corundum. The rock is non-magnetic and therefore it would appear that the spinellid is entirely an iron-alumina variety allied to the pleonastehercynite that occurred in the Mull aluminous xenoliths. The spinel exists as minute octahedra and also as irregular grains that may coalesce into quite large masses. Although mainly concentrated in what appears to be a devitrified glassy matrix, it also occurs indiscriminately scattered through the felspar and corundum, and was thus an early precipitation. Its abundance is responsible for the extremely dark colour and high density of the rock as a whole.

The corundum builds small well-shaped hexagonal basal plates modified by rhombohedra and without any obvious development of prism-faces ((Figure 32) A). The crystals average about 0.5 millimetres in breadth and are usually about four times as broad as they are thick. As is a common feature of sapphire the intensity of blue colour often varies considerably in different parts of the same crystal and in different individuals. Some crystals are deep blue, others feebly or unequally tinted. The deeply-coloured crystals exhibit the usual pleochroism in shades of blue and greenish-blue: ω=sapphire blue; ε = pale greenish-blue to sea-green. Where most abundantly developed, like the spinellid, it has a yellowish crypto-crystalline matrix that suggests a devitrified glass (S24490) [NM 4805 6478] and (S24490B.) [NM 4805

6478]. Some areas of the xenoliths are predominantly felspathic, and in these spinel is, generally speaking, more abundant than corundum (S24491) [NM 4805 6478]. The felspar forms a mosaic of much twinned small crystals of approximately anorthite composition, but there has usually been some regrowth of the early-formed individuals with the addition of a less basic species. The basic portions of the crystals are frequently charged with slender needles of mullite<ref>N. L. Bowen, J. W. Greig, and E. G. Zies, Mullite, a silicate of alumina, *Journ. Wash. Acad. Sci., vol. xiv* 5924, p. 583.</ref> (S24490) [NM 4805 6478] after the manner of the anorthite in the Mull xenoliths. No unaltered cordierite has been detected, but certain micaceous pseudomorphs in the matrix of the sapphire-rich portions of the rock, that is to say in those parts that appear to have experienced actual fusion, suggest its presence.

The nature of the original rock that furnished the xenoliths is somewhat obscure, but the high alumina and iron content, especially the former, would render the possibility of its having been igneous exceedingly remote. It is obvious that transfusion from the surrounding gabbro-granulite has been of very limited extent and thus the composition of the xenoliths may be regarded as unchanged. The only rock that app ars to have an initial composition likely to yield such a mineral assemblage when metamorphosed is some such highly aluminous and ferruginous deposit as bole, and I would suggest that such was the original nature of the mass. This view is perhaps strengthened by the close proximity of basalt lavas, and by the absence of any highly aluminous deposits from amongst the pre-Tertiary sediments of Ardnamurchan.

Contact-metamorphism of country rocks

The metamorphic effects produced by the intrusion of the Hypersthene-gabbro can be studied to advantage along its southern margin towards Beinn nan Codhan, and north-west of Kilchoan, along the eastern side of the Kilchoan–Achnaha road. Here, a variety of rock-types are involved which include Lower Lias shales and limestone, limestones of Inferior Oolite age, and Tertiary basalt lavas, tuffs, and cone-sheets. The metamorphism is of a fairly high grade, and considering the steep inclination of the intrusive junction, at any rate west of the Kilchoan–Achnaha road, its effects are in evidence over a surprisingly wide zone, a quarter of a mile or more in breadth.

The Lower Lias sediments (Pabba shales) are well exposed on Dubh Chreag, three quarters of a mile east of Beinn nan Codhan. Under the influence of the intruded gabbro they have passed from their usual soft, dark-grey condition into medium-grey finely-crystalline splintery rocks, strikingly different in appearance to their unaltered representatives in other parts of the district (p. 41).

These shales are composed largely of detritus from an old land-surface of schists and gneisses and have given rise to contact-rocks of rather peculiar type. Close to the gabbro-contact they were possibly more chloritic and sericitic than the other members of the series, and are now reduced to the condition of hypersthene-biotite hornfelses (S23626) [NM 4524 6345], (S23629) [NM 4513 6346], (S21501) [NM 4528 6342]. Under the microscope, viewed with ordinary light, the most conspicuous constituents are biotite in sponge-like masses, magnetite, and hypersthene in small patches and hypidiomorphic grains. These are set in a colourless base that consists mainly of felspar with what appears to be cordierite. The biotite is intensely pleochroic and of a rich red-brown colour. The hypersthene is a deeply-coloured variety, and even the small granules exhibit an intense pleochroism from bluish-green to pink. It occurs as scattered hypidiomorphic granules for the most part, but may also form moderately large ophitic patches and granular streaks (S23629) [NM 4513 6346]. Apatite occurs as slender needles. The base has almost the appearance of a crystallized melt, and it is certain that the rock narrowly escaped fusion into buchite. It consists of minute stumpy prisms of labradorite-andesine felspar, frequently zoned with oligoclase, in an ultimate base of alkali-felspar with a little quartz. Occasionally a micrographic intergrowth of the last-named minerals can be detected. In addition, the felspathic base includes a number of minute rectangular pinitic pseudomorphs that, in such an association, are most probably after cordierite (S23626) [NM 4524 6345], (S21501) [NM 4528 6342], but no unaltered examples of this mineral have been noted. These biotite-hypersthene-cordierite hornfelses are similar to those met with, and described by Dr. Tilley<ref>C. E. Tilley, Contact-Metamorphism in the Comrie Area of the Perthshire Highlands, *Quart. Journ. Geol. Soc.*, vol. lxxx., 1924, p. 22.</ref> in the Comrie region and which he attributes to the metamorphism of chloritic sericitic sediments. In the altered Liassic shales spinel appears to be unrepresented. A fair quantity of an opaque mineral scattered throughout the rock as minute grains is probably magnetite. The absence of spinel may be due to a silica content slightly higher than that of the sediments which have given rise to the hornfelses of Dr. Tilley's Class 4.

More calcareous bands in the Lower Lias (probably the Broad-ford Beds, p. 41), have been converted into hornfelses that are usually rich in monoclinic pyroxene. One such rock from Dubh Chreag (S23627) [NM 4511 6337], some hundred yards from the gabbro margin, consists essentially of a monoclinic pyroxene, green hornblende, a basic plagioclase, and large sponge-like crystals of sphene.

The pyroxene is almost colourless in thin section, but locally takes on a pinkish-brown tint reminiscent of hypersthene. Its extinction and other optical properties, however, are those of a monoclinic variety, and it is presumably a diopside of somewhat unusual tint. The hornblende is actinolitic and occurs either in association with the pyroxene or as small isolated individuals.

The sphene, which is one of the larger components of the rock and poecilitically encloses felspar, is strongly pleochroic after the usual manner of metamorphic examples of this mineral. In this particular instance garnets are absent, but in other cases, when the original rock was still more calcareous, the hornfelses are garnetiferous, and tremolite is a common constituent. Such a rock (S22628) [NM 4731 6727], from the same locality as the above, consists of small colourless garnets and small granules of lime-felspar (near anorthite in composition), set in a matrix that consists mainly of tremolite and actinolitic hornblende.

The purer limestones of the Inferior Oolite, which succeed the Lias towards the south and are thus still further removed from the gabbro margin, show the results of fairly intense thermal alteration.

They have been marmorized with the formation of various lime silicates. As represented on the coast to the north-west of Sròn Bheag (S22440) [NM 457 624] and half a mile from the gabbro, the rock is a dirty-white to grey, speckled and streaked, fine-grained crystalline limestone of somewhat variable texture. It consists of recrystallized calcite with which are associated small irregularly formed pale-yellow to colourless garnets, and minute elongated crystals of diopside and tremolite.

The Tertiary lavas and cone-sheets that come within the influence of the gabbro have likewise suffered considerable alteration of a type recurring in the lavas and cone-sheets that form portions of screens at various localities within the main plutonic area (p. 313). The actual contact-effects of the gabbro on these rocks, however, can be studied to best advantage in the strip of basalt lavas which occurs to the south-east of Beinn na Seilg, and in the variety of rocks that flank the Kilchoan–Achnaha road, north of the Free Church, on the western slope of Glebe Hill north-west of Kilchoan.

In this section the most noticeable changes in the hand-specimen are an increased toughness of the rocks as the gabbro is approached and the development of a more obvious crystalline texture. In addition, small brown scales and patches of finely-divided biotite make their appearance and represent a change in the body of the rock, or the metamorphosis of chlorite-filled vesicles in the case of the lavas. Generally speaking, the texture of the metamorphosed rocks becomes coarser and recrystallization more marked as the gabbro-contact is approached.

On the Achnaha road, the basalt lavas are of both porphyritic and non-porphyritic types, and they are usually amygdaloidal. They are now completely granulitized. The original augite has either largely redistributed itself as small granules, or has passed over into granular rhombic pyroxene. Frequently, regenerated pyroxene may be seen stringing the larger felspars in an irregular manner, developed along cleavage lines (S22239) [NM 4788 6444], (S22240) [NM 4788 6444], or following the course of albitization. All chlorite has been converted into biotite, but some of the mica has reverted to the original mineral as the result of weathering. Biotite has developed in the neighbourhood of iron-ores, and the vesicles are either entirely occupied by this mineral or are lined with biotite, while their central portions are occupied by granular pyroxene (S22243) [NM 4794 6451]. There is usually a well-marked albitization of the larger felspars that have escaped recrystallization, and this applies more particularly to the porphyritic lavas.

The cone-sheets, as might be expected, exhibit changes of a similar order to those presented by the metamorphosed lavas, and which may best be described as granulitization. In spite, however, of considerable recrystallization the characteristic structure of the original rock is seldom wholly destroyed, and the manner of occurrence in the field, with their definite fine-textured edges (S22238) [NM 4788 6444], leaves no doubt as to their original nature. The cone-sheets and basalt lavas near the gabbro margin, as also the included granulitic masses on the other side of the boundary (p.

231), frequently show traces of a more or less intense crushing that must be regarded as an early effect of the gabbro intrusion. The crushing was usually followed by contact metamorphism that in a measure repaired the damage by partial recrystallization, more particularly in those portions of the rock which had been more or less completely comminuted (S22246) [NM 4787 6435], (S22247) [NM 4793 6434]. The usual changes attributable to contact-action in these rocks are a general development of biotite from chlorite, a granulitic recrystallization of augite, local recrystallization of felspar with a somewhat general albitization of the larger individuals, and a migration and general distribution of recrystallized iron-ore. H.H.T.

(B) Old Gabbro of Lochan an Aodainn

Of this intrusion, remnants only are left, which are cut by all the adjacent ring-dykes. Towards an inner original margin against agglomerate and basalt lavas, the rock becomes finer grained, and resembles a quartz-dolerite (S21570) [NM 4564 6542]. There is no doubt as to its intrusive relation to these older rocks, for an intrusive tongue of gabbro extends into the agglomerate east of the N.–S. stream that runs northwards towards Aodann.

The Old Gabbro must have been intruded in relation to the Earlier Ring-dyke Centre (2). Sufficient of the original inner wall is preserved to demonstrate a curvature about Aodann. On its outer side, however, it is in contact with at least three separate later intrusions. Whether this outer edge is near to the original outer margin or not there are no means of knowing. At any rate, it marks a fracture, or fractures, the result of which is a curve conforming to the inner margin and to the Aodann Centre (2). On a hillside north-east of Garbh-dhail, the junction of the Quartz-gabbro (c) with the Old Gabbro is apparently steep. For this reason, and also on account of the ring-dyke pattern of the Old Gabbro, it seems certain that the Old Gabbro extends in depth like a ring-dyke, and is not merely capping the Quartz-gabbros (c) and (d) with which it is mainly in contact.

The Old Gabbro is certainly of early date. Though it is only known to be traversed by a single porphyritic cone-sheet, it is definitely proved earlier than the Inner Cone-sheets generally, since it is intruded by the Grigadale Granophyre (c′) and Garbh-dhail Quartz-gabbro (c), both of which are profusely cut by the sheets. Its antiquity might also be inferred from its highly altered condition. In the hand-specimen it is a similar rock to the Hypersthene-gabbro (a), being moderately coarse grained, and pyroxene-rich. It differs however in not containing hypersthene, so far as is known, and also in the cloudy appearance of its felspars under the microscope. This cloudiness has been also noticed by Dr. Thomas in other gabbros that have been contact altered, but in no other mass is it developed to such an extent, as a general characteristic of the rock. It is to be correlated with the remarkable black or bluish-black hue of the gabbro, characteristic of weathered surfaces in the field.

In the vicinity of Lochan an Aodainn (or Lily Loch), the normal coarse-grained augite-rich type is most usually met with, but frequently allivalitic olivine-rich patches occur, in which the olivine weathers with a reddish-brown colour. Sometimes the rock is dappled over with coarsely crystalline acid spots. Though these seem to be original, because they appear to be completely isolated in the dark gabbro, it is possible that acid magma has inserted itself and hybridized with the Old Gabbro in a spotty manner (*see* p. 240). Epidote is of frequent occurrence, more especially in the acid spots. In the coarse type, large ophitic augite-plates are often seen, which glint in mirror fashion when viewed from certain angles. A coarser type than usual, with blade-shaped pyroxenes, occurs on a rocky bluff fringed with trees on the south-west side of the Allt Garbh-dhalach.

A fine-grained type is also met with, smooth-weathering and therefore easy to distinguish from the coarse type which has highly roughened, knobby surfaces. Sometimes these two types may be seen in sharp contact. Both, however, seem equally metamorphosed, and they are too closely associated to be considered other than parts of one intrusive mass.

It is possible that the fine-grained portions above referred to are of xenolithic origin. Only one specimen was collected, which occurs as a sheet-like band. It is suggestive that this rock is granulitized and, according to Dr. Thomas, resembles the nonporphyritic quartz-dolerite type characteristic of the majority of the Outer Cone-sheets. It shows in its cloudy felspars that it has been altered in the same way as the Old Gabbro itself (S24429) [NM 4376 6622]. J.E.R.

Petrology

The gabbro of Lochan an Aodainn, as might be expected from its position and relative antiquity, has suffered considerably at the hands of later intrusions by which it is hedged in and intersected. It has had impressed upon it widespread textural and mineralogical changes of both dynamic and thermal character, and in these changes lies its chief petrological interest.

The gabbro in its original condition was a somewhat variable olivine-bearing doleritic type, and many of the variations, which have been described above, are clearly related to original textural and mineralogical features of the mass, and are such as can be paralleled in most of the Tertiary gabbros.

The rock almost invariably shows evidence of crushing, shattering, and granulitization. In its coarser variety (S21568) [NM 4419 6644] it is an olivine-gabbro in which the pseudomorphs after olivine have been replaced by a fine aggregate of biotite, magnetite, and granular pyroxene. The felspars are schillerized and turbid, as a result of reheating, and granulitization has taken place along lines of crush and along cleavage planes in the felspars. In some varieties olivine had a definitely porphyritic habit (S22283) [NM 4436 6649], but in other instances the rock appears to have been olivine-free. In the latter cases (S21516) [NM 4483 6561], (S21277) [NM 480 683] the texture assumed is that of a moderately coarse dolerite, composed of ophitic augite, labradorite, and iron-ore. The felspars are turbid and the augite exhibits local schillerization, both the results of subsequent thermal alteration. The augites and felspars are traversed by narrow zones of crush which have been granulitized, and it would appear that the granulitization followed immediately after, or was attendant upon, the crushing. Although the production of hypersthene is a common result of the process of granulitization (S22283) [NM 4436 6649], especially in areas that were once occupied by olivine (S21278) [NM 441 665], hypersthene does not appear to have been an original constituent of the gabbro, and thus the mass seems to be essentially different from the Hypersthene-gabbro (a) described above (p. 223). In one instance only has hypersthene that may be an original constituent been encountered (S21252) [NM 447 658]. In this case hypersthene occupies areas comparable in size to those of olivine, but the mass has been crushed, and contact altered, and there has been a considerable amount of recrystallization.

The olivine of this gabbro is usually pseudomorphed, and the pseudomorphs, originally chloritic, serpentinous, or hornblendic, have passed over as the result of thermal alteration to aggregates of biotite, and monoclinic and rhombic pyroxenes. In some instances where original decomposition was delayed fresh olivine is still met with (S22283) [NM 4436 6649], but this is the exception.

The original augite has developed schiller structure, and in the more completely granulitized rocks has been replaced by granular pyroxene-aggregates (S24426) [NM 4588 6555]. The amount of shattering to which the mass has been subjected varies from place to place. In some instances there is scarcely a crystal that has not suffered rupture and some displacement (S22286) [NM 4440 6661]. Hand in hand with the shattering and granulitization of the mass goes a segregation and migration of acid material that locally assumes the more or less definite character of an augite-granophyre (S22331) [NM 4581 6621]. Such acid rocks generally contain a good deal of basic plagioclase and old granulitized augites, which probably belong to the surrounding gabbro, while a certain amount of pyroxene appears to have separated out in the form of enstatite-augite. More generally the gabbro is locally impregnatedwith acid matter after the manner of the quartz-gabbros, and it is most difficult to conclude whether we should regard this acid material as representing an acid residuum of the gabbro magma or as a separate and subsequent injection.

There has been a general acidification of the gabbro (S22332) [NM 4581 6621], which takes the form of albitization and deschillerization of the felspars (S21561) [NM 4574 6611], the formation of rhombic pyroxene, separation of biotite, and the formation of definite lakes of micrographic quartz and orthoclase. Granophyre veins are also frequently met with (S21571) [NM 4571 6538], (S22313) [NM 4546 6540].

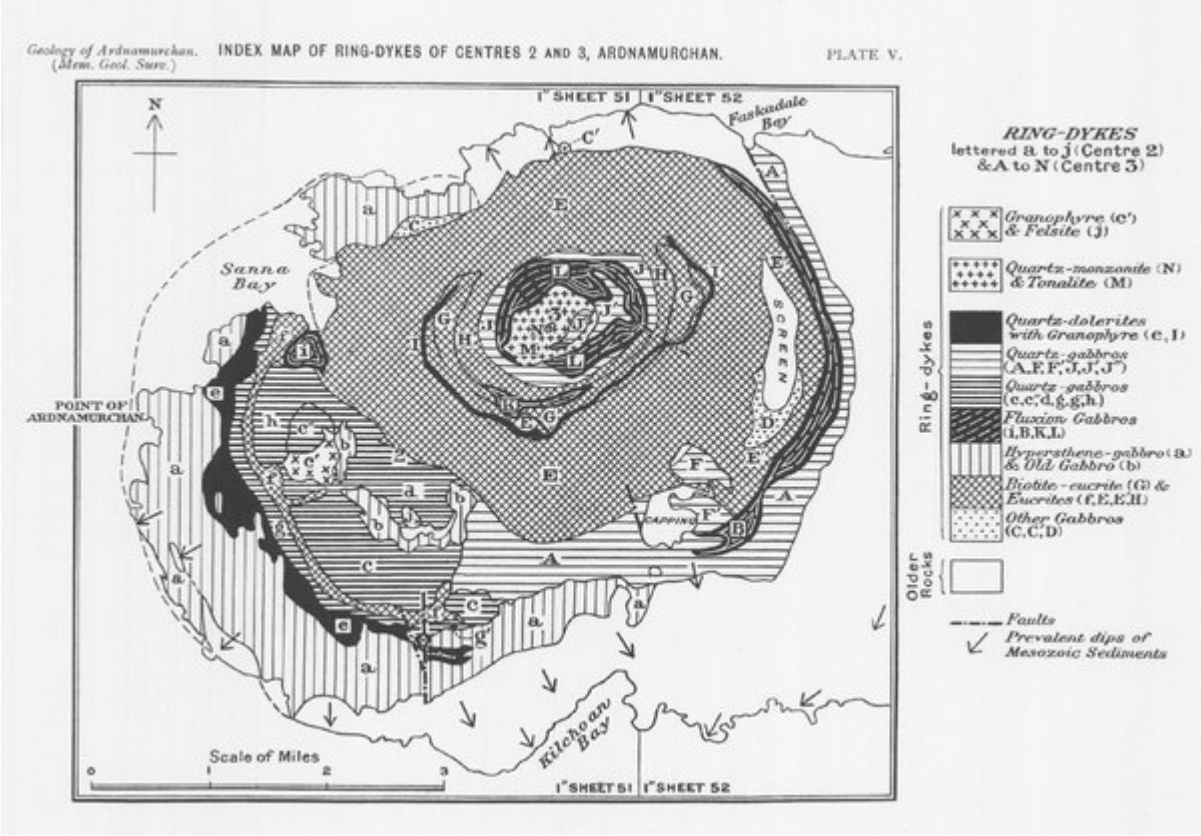
This migration of acid material through the body of the gabbro in all cases follows the shattering that the mass has undergone, but it is quite possible that it is contemporaneous with at any rate one stage of the granulitization.

Occasionally within the gabbro are encountered basic masses that from microscopic examination suggest cone-sheet material. Such a quartz-dolerite (S22461) [NM 4453 6617], with, of course, all the original augite converted into granular pyroxenic aggregates, was collected from the gabbro near its western extremity.

The basalt lavas and agglomerates that form the inner margin of the gabbro to the south of Lochan an Aodainn are in a severely metamorphosed condition. Not only have they suffered at the hands of the gabbro itself, but they have come under the same set of metamorphosing conditions as affected the gabbro after its consolidation. The fragments in the agglomerate are similar to those met with in the agglomerates of the vents of Centre 1 and consist of basalt lavas (S21813) [NM 4549 6555], and trachytic rocks with perthite phenocrysts (S21814) [NM 4569 6545]. Tuffs in a metamorphosed condition are also represented (S22310) [NM 4576 6564].

The basalt lavas, while retaining their major structures, have passed over to beautiful pyroxene-granulites, in which the development of hypersthene is particularly well marked in the neighbourhood of siliceous strings and patches (S22309) [NM 4579 6574].

A somewhat rare occurrence in the agglomerates of Lochan an Aodainn is of a quartz-dolerite of Talaidh type (S21815) [NM 4569 6545] which, like the basalts, has suffered a granulitization of its ferromagnesian constituents; also of a rock which suggests the granulitized chilled edge of a quartz-dolerite of the same type (S21566) [NM 4528 6558]. It would therefore seem probable that cone-sheets were involved in the agglomerates before the intrusion of the Aodainn gabbro (*see* p. 131). H.H.T.



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

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 ...	—	e, e, A, C, E.
b	oE	Old Gabbro of Lochan an Aodainn	—	e, e′, d, A.
c	qE	Quartz-gabbro of Garbh-dhail	b.	c′, f, A.
c′	G	Granophyre of Grigadale	e, 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 Sgàrr 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	e″, f.	—
i	fE	Fluxion Gabbro of Portmairk	—	? 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 Ploaig	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 Sithean Mór	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.

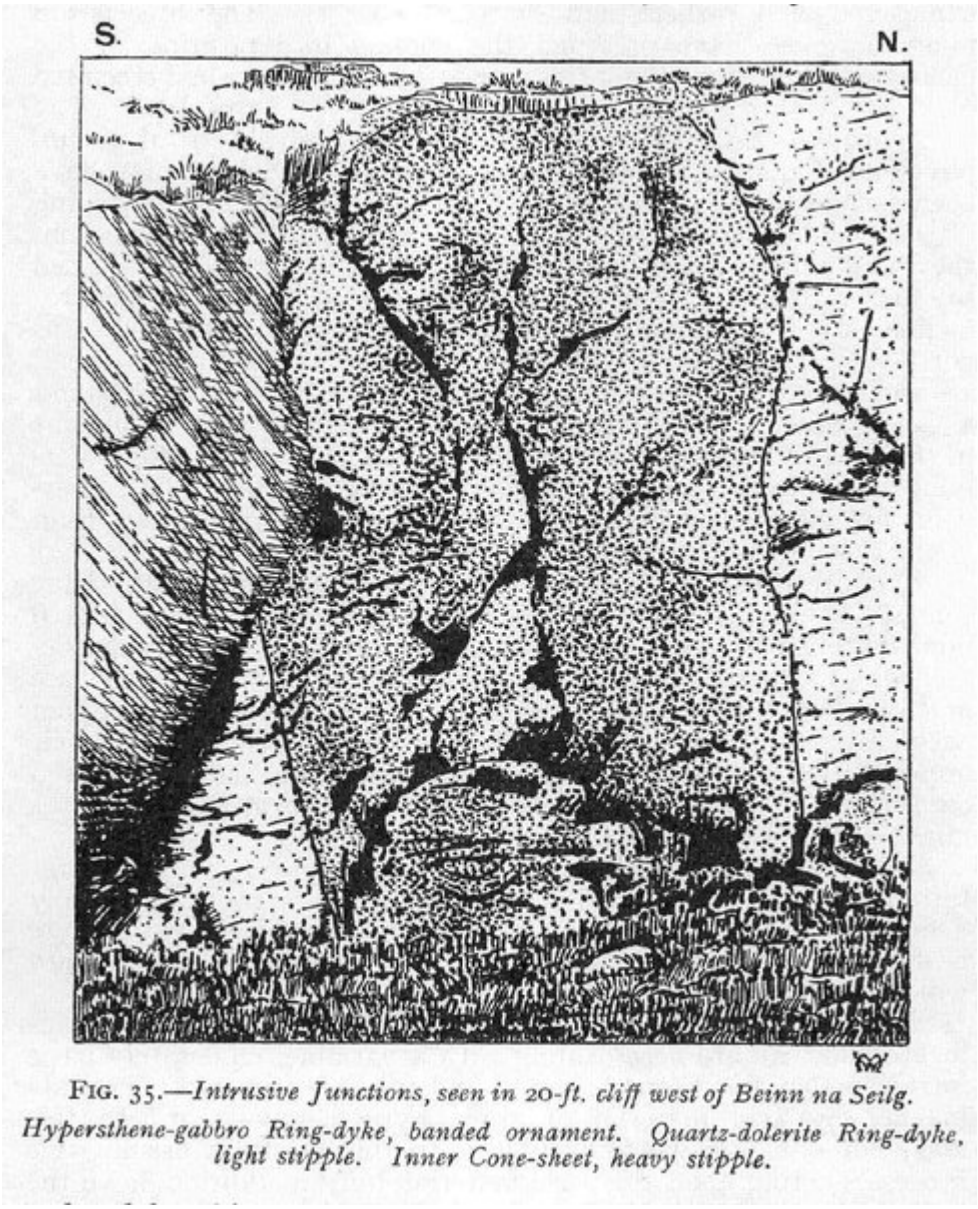


FIG. 35.—*Intrusive Junctions, seen in 20-ft. cliff west of Beinn na Seilg. Hypersthene-gabbro Ring-dyke, banded ornament. Quartz-dolerite Ring-dyke, light stipple. Inner Cone-sheet, heavy stipple.*

(Figure 35) Intrusive Junctions, seen in 20-ft. cliff west of Beinn na Seilg. Hypersthene-gabbro Ring-dyke, banded ornament. Quartz-dolerite Ring-dyke, light stipple. Inner Cone-sheet, heavy stipple.

TABLE IV

PORPHYRITIC CENTRAL MAGMA-TYPE (*see* Fig. 7)

	EUCRITE, GABBRO, AND BASALT.								
	I.	A.	II.	III.	B.	IV.	V.	VI.	
SiO_2 ..	47·26	47·28	47·75	48·28	48·34	49·60	49·78	50·12	SiO_2
Al_2O_3 ..	22·80	21·11	19·46	20·38	20·10	15·06	18·82	15·98	Al_2O_3
Fe_2O_3 ..	2·21	3·52	2·31	1·78	1·97	5·29	5·58	4·91	Fe_2O_3
FeO ..	5·41	3·91	6·28	6·70	6·62	5·00	4·85	6·31	FeO
MgO ..	7·76	8·06	7·50	7·93	5·49	4·44	4·15	4·43	MgO
CaO ..	10·93	13·42	11·32	11·80	13·16	9·69	10·40	10·86	CaO
Na_2O ..	1·72	1·52	2·46	1·75	1·66	2·62	3·04	3·60	Na_2O
K_2O ..	0·29	0·29	0·24	0·14	0·98	0·70	0·56	0·70	K_2O
$H_2O > 105°$	0·90	0·53	0·50	0·76	0·44	1·29	1·35	0·53	$H_2O > 105°$
$H_2O < 105°$	0·11	0·13	0·18	0·09	0·02	2·65		0·46	$H_2O < 105°$
TiO_2 ..	0·38	0·28	0·43	0·23	0·95	2·38	1·34	1·76	TiO_2
P_2O_5 ..	0·06	trace	0·62	0·02	0·04	0·29	trace	0·08	P_2O_5
MnO ..	0·31	0·15	0·17	0·28	0·32	0·19	0·28	0·18	MnO
CO_2 ..	0·10	—	trace	0·03	0·11	0·44	—	0·21	CO_2
FeS_2 ..	0·00	—	0·16	0·04	0·00	0·00	0·00	0·05	FeS_2
Fe_7S_8 ..	0·00	—	trace	0·00	—	—	—	—	Fe_7S_8
SO_3 ..	—	—	trace	—	—	0·40	0·00	trace	SO_3
Cr_2O_3 ..	—	—	0·05	—	—	0·02	0·00	0·04	Cr_2O_3
(Co, Ni)O ..	0·00	—	—	0·00	0·00	0·00	—	—	(Co, Ni)O
BaO ..	0·00	—	—	0·00	0·10	trace	0·03	0·04	BaO
Li_2O ..	0·00	—	trace	0·00	0·00	trace	—	trace	Li_2O
C	—	—	—	—	—	—	traces	—	C
Organic matter ..	—	—	—	—	—	trace	—	—	Organic matter
	100·24	100·20	99·83	100·21	100·30	100·06	100·18	100·26	

I. (21250; Lab. No. 735.) Biotite-eucrite. Ring-dyke, Centre 3, Ardnamurchan. Bank of stream, 1 mile E. 33° S. of Achnaha. *Anal.* E. G. Radley.

A. (8194; Lab. No. 19.) Olivine-gabbro. Major Intrusion. Coir' a' Mhadaidh, Cuillins, Skye. Quoted from A. Harker, 'Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 103. *Anal.* W. Pollard.

II. (22821; Lab. No. 790.) Hypersthene-gabbro. Ring-dyke, Centre 2, Ardnamurchan. In side of hollow ¼ mile W. 33° S. of Trigonometrical Station at 1123 ft., Beinn na Seilg, and 1000 yds. E. 27° N. of

(Table 4) Porphyritic Central Magma-Type (see (Figure 7)).

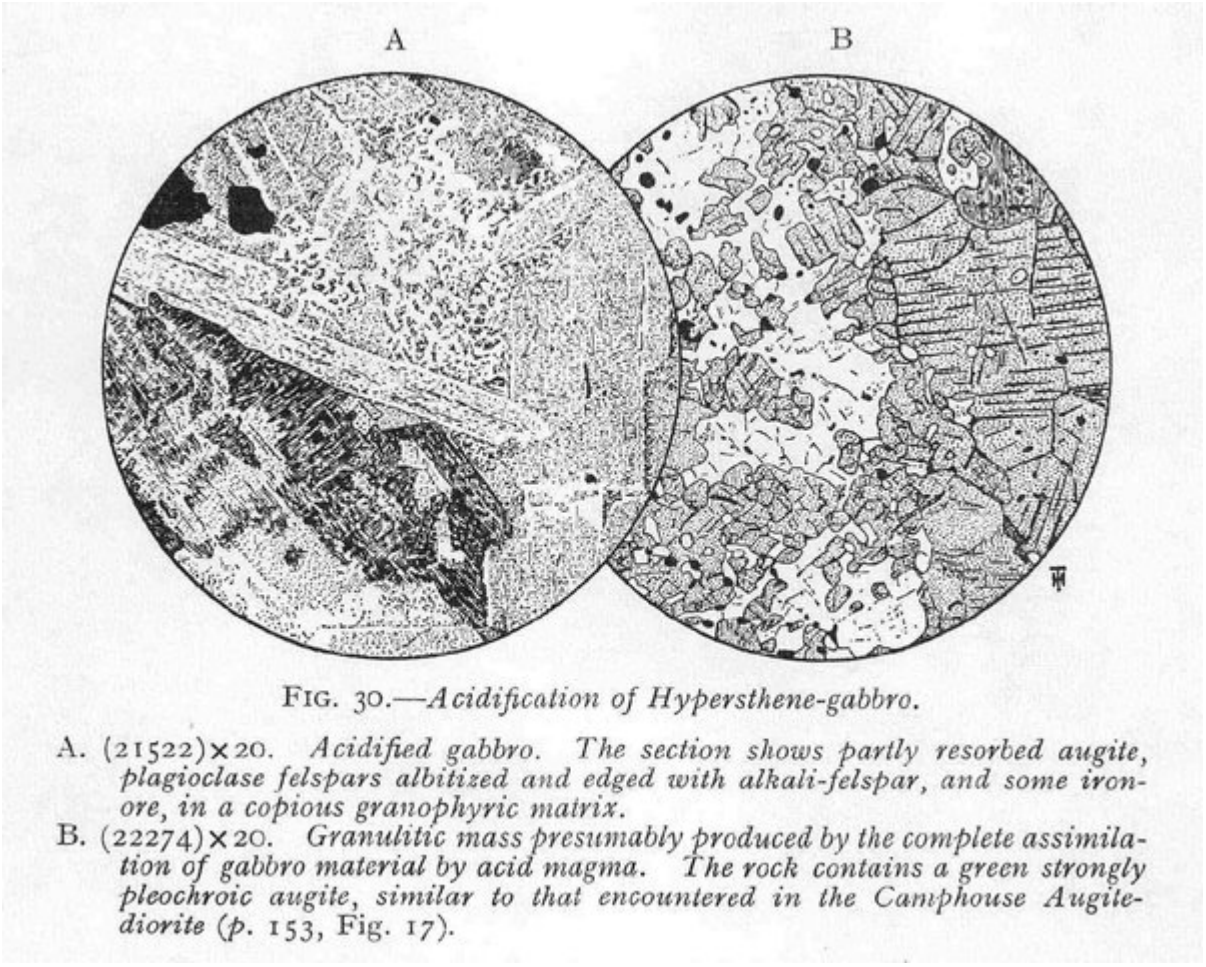


FIG. 30.—*Acidification of Hypersthene-gabbro.*

A. (21522)×20. *Acidified gabbro. The section shows partly resorbed augite, plagioclase felspars albitized and edged with alkali-felspar, and some iron-ore, in a copious granophyric matrix.*

B. (22274)×20. *Granulitic mass presumably produced by the complete assimilation of gabbro material by acid magma. The rock contains a green strongly pleochroic augite, similar to that encountered in the Camphouse Augite-diorite (p. 153, Fig. 17).*

(Figure 30) Acidification of Hypersthene-gabbro. A. (S21522) [NM 4716 6440] × 20. Acidified gabbro. The section shows partly resorbed augite, plagioclase felspars albitized and edged with alkali-felspar, and some iron-ore, in a copious granophyric matrix. B. (S22274) [NM 4416 6942] × 20. Granulitic mass presumably produced by the complete assimilation of gabbro material by acid magma. The rock contains a green strongly pleochroic augite, similar to that encountered in the Camphouse Augitediorite (p. 153, (Figure 17)).

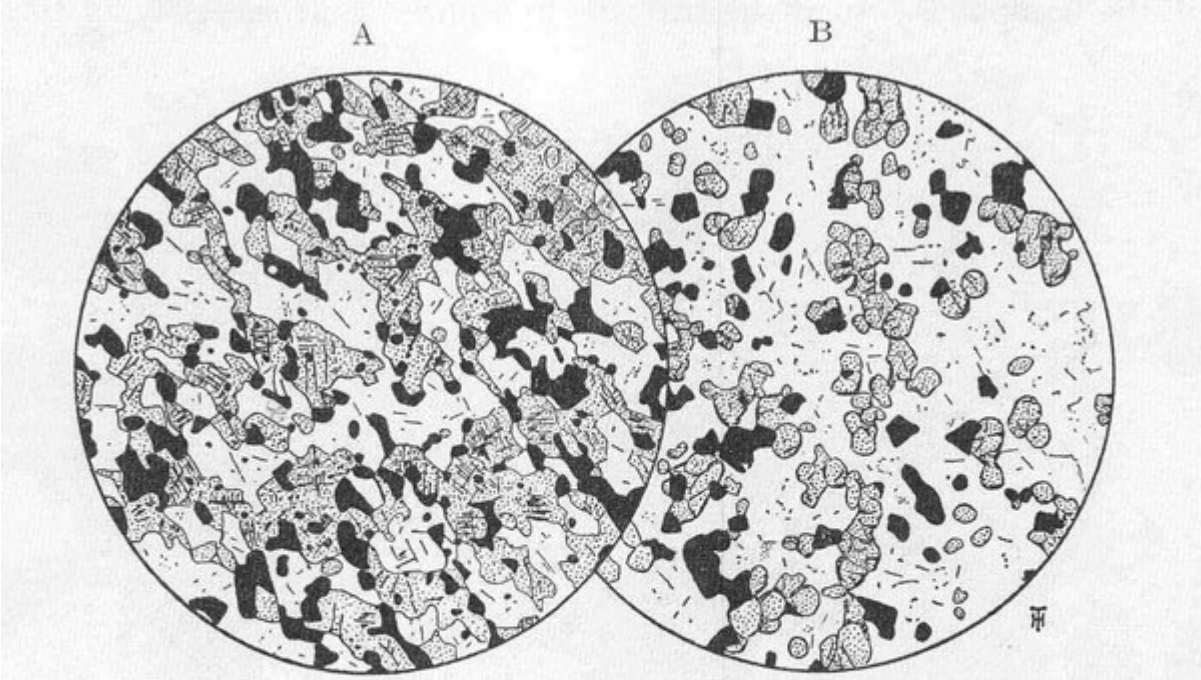


FIG. 31.—*Granulitic Masses associated with Basic Ring-dykes.*

A. (22658) ×20. *Granulitic gabbro, at margin of Great Eucrite south-west of Meall nan Con. A completely recrystallized rock composed of augite, clear plagioclase, and abundant iron-ore. All the constituents tend to have a granulitic development.*

B. (23620) ×20. *Granulitic gabbro of allivalitic composition, enclosed by Hypersthene-gabbro. It is composed of granulitic olivine, basic plagioclase felspar, and iron-ore. The rock has been completely recrystallized and has developed a faint banding.*

(Figure 31) Granulitic masses associated with basic ring-dykes.. A. (S22658) [NM 4986 6764] × 20. Granulitic gabbro, at margin of Great Eucrite south-west of Meall nan Con. A completely recrystallized rock composed of augite, clear plagioclase, and abundant iron-ore. All the constituents tend to have a granulitic development. B (S23620) [NM 4223 6631] × 20. Granulitic gabbro of allivalitic composition, enclosed by Hypersthene-gabbro. It is composed of granulitic olivine, basic plagioclase felspar, and iron-ore. The rock has been completely recrystallized and has developed a faint banding.

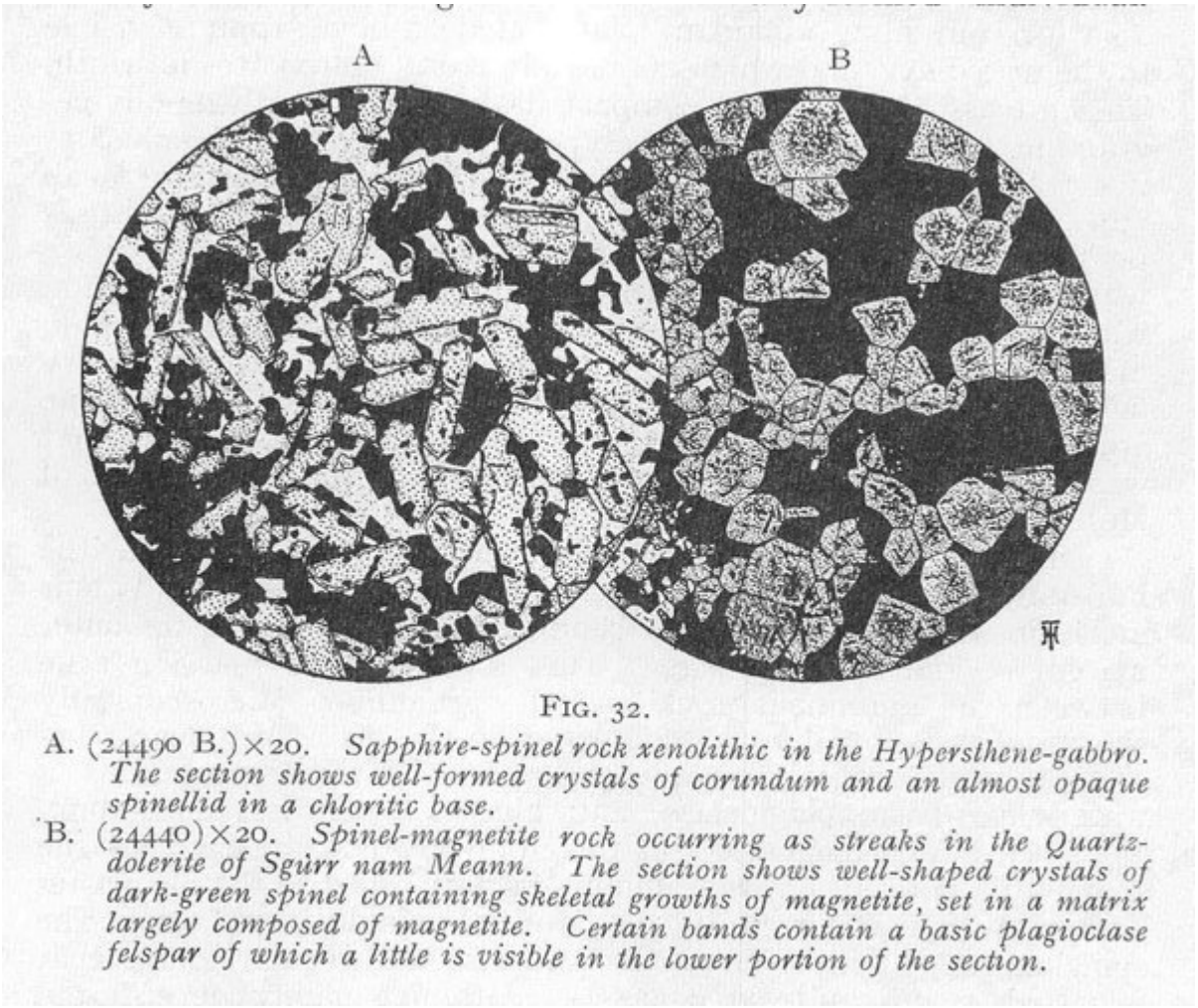


FIG. 32.

A. (24490 B.) × 20. *Sapphire-spinel rock xenolithic in the Hypersthene-gabbro. The section shows well-formed crystals of corundum and an almost opaque spinellid in a chloritic base.*

B. (24440) × 20. *Spinel-magnetite rock occurring as streaks in the Quartz-dolerite of Sgùrr nam Meann. The section shows well-shaped crystals of dark-green spinel containing skeletal growths of magnetite, set in a matrix largely composed of magnetite. Certain bands contain a basic plagioclase felspar of which a little is visible in the lower portion of the section.*

(Figure 32) A (S24490 B) [NM 4805 6478] × 20. Sapphire-spinel rock xenolithic in the Hypersthene-gabbro. The section shows well-formed crystals of corundum and an almost opaque spinellid in a chloritic base. B (S24440) [NM 4283 6815] × 20. Spinel-magnetite rock occurring as streaks in the Quartz-dolerite of Sgùrr nam Meann. The section shows well-shaped crystals of dark-green spinel containing skeletal growths of magnetite, set in a matrix largely composed of magnetite. Certain bands contain a basic plagioclase felspar of which a little is visible in the lower portion of the section.