Chapter 30 Gravitational differentiation

Introduction

A gradual uphill change from gabbro (of the quartz-gabbro type, but often carrying olivine in its more basic portions) to granophyre<ref>Granophyre is used in a rather broad sense in the present chapter and includes, in some instances, acid craignurites (Chapter 19),with rather less than 70 per cent. SiO_2.</ref> is sufficiently often encountered in Mull to leave no doubt as to the potency of gravitational differentiation. The subject is systematically treated in this chapter under three headings:

a) A series of examples is enumerated with a few critical remarks. It is hoped that this enumeration will convince the reader that he is faced with a recurrent phenomenon and not a mere local coincidence.

b) The most conveniently situated example is illustrated with special reference to specific gravity determinations. The object in this case is to show how definitely the field appearance of upward transitions from basic to acid can be confirmed by recourse to simple quantitative examination.

c) The petrology of the transition is discussed in the light of microscopical and chemical analyses.

As a general remark, it may be added that, in every case, the instances of gravitational differentiation, here considered, come from massive, slowly cooled, more or less vertical intrusions. The basic portions do not show chilling where they come into contact with country-rock, and the same remark often applies to the acid. No similar stratification of acid, intermediate, and basic material has been met with among the numberless relatively thin and quickly cooled sheets of Mull, almost all of which show clearly chilled margins. (C.T.C), E.B.B.

Localities

Eleven examples, cited below under eight localities, furnish good evidence of density-stratification one of them (Locality 6) is admittedly ambiguous; and two (Localities 7 and 8) are somewhat obscured by later intrusions. Only in one noteworthy case, where gabbro and granophyre occur linked by transitional types, is there any marked failure of density-stratification (Locality 9). It is interesting to note that the discontinuous Glen More Ring-Dyke (Chapter 29) supplies a series of examples considered separately under Localities 1, 2, 6, and 9, and perhaps also 7.

Locality 1—one example

The more northerly of the two western terminations of the main outcrop of the Glen More Ring-Dyke furnishes the type-example discussed below. With the help of (Figure 54), and (Plate 6) (p. 307), one can easily fix the locality on the one-inch Map, Sheet 44. The Ring-Dyke crosses Glen More road rather more than a mile east of Craig Cottage, and the branch that concerns us strikes north-east to the summit of Cruach Choireadail. The upward transition from gabbro to granophyre is very gradual and complete. There are practically no later intrusions to complicate the exposures. The vertical range is about 1500 ft.

Locality 2—two examples

Both the south-easterly terminations of the Coir' an t-Sailean mass reaching up into Corra-bheinn yield good examples of upward gradual passage from gabbro to granophyre. The locality is easily recognized with reference to Corra-bheinn on (Plate 6) and the one-inch Map. There are a few later intrusions, but they do not lead to any confusion. The vertical range is about 1000 ft. (C.T.C.)

Locality 3—three examples

Similar uphill passage from gabbro to granophyre can be traced in both limbs of a forking ring-dyke which runs up Monadh Beag from Allt Molach. Comparison with (Figure 52) (p. 308), where the unbranched gabbro stein is shown numbered 9, will enable the reader to identify the intrusion on the one-inch Map. A very pretty complication is introduced by the horizontal faulting of this ring-dyke (p. 312). As one mounts the hill from the south, one finds that gabbro has given rise to granophyre in both arms of the intrusion before a fault, shown on (Plate 6), is reached. On crossing the fault, one finds both branches displaced somewhat to the south-east. - This happens to be the direction in which the hill-face slopes, so that the severed arms are more deeply eroded north-east of the fault than south-west of the same. The result of this more searching erosion has been, in the case of the easterly branch of the ring-dyke, to re-expose its basic (or rather its sub-basic) lower part. Very soon, this sub-basic rock traced uphill northwards, away from the fault, gives place once more to acid. As in previous instances, later intrusions are very subordinate and do not trouble the observer. The vertical range is about 800 ft.

Locality 4—one example

Immediately west of the last-described gabbro ring-dyke in Allt Molach, is another ring-dyke numbered 10 in (Figure 52). It can be seen to grade upwards into granophyre. The exposures of this ring-dyke are intermittent. The vertical range is about 300 ft.

Locality 5—one example

A very definite and well-exposed case of upward passage from gabbro to granophyre is furnished by a ring-dyke (numbered 3 in (Figure 53)) at the head of the Doir' a Mhàim corrie, 1 mile south-south-east of Beinn Talaidh. The locality is shown in the south-west corner of Fig 53, and is easily found on the one-inch Map. There are several thin cone-sheets in the western (granophyric) part of the exposures, but these do not confuse the issue, and the transition can be followed step by step. The gabbro portion of the ring-dyke continues southwards past the bridge across Allt Molach (3 in (Figure 52)). The vertical range is about 1000 ft.

Locality 6—one ambiguous example

Merging of gabbro into granophyre is clearly demonstrable at the northern end of the Glen More Ring-Dyke, numbered 1 in (Figure 53). It takes place in the hollow connecting Glen More with Glen Forsa, at the east edge of (Figure 53). The locality is easily fixed on (Plate 6), and also on the one-inch Map, for there is no confusion due to outcrops of later intrusions. What renders the evidence ambiguous is the fact that the transition takes place in such flat ground that it can scarcely be trusted as evidence of gravitational stratification. All that is clear is that the ring-dyke, as exposed for three miles along the hollow of Glen More, southwards from the transition zone, consists of gabbro, whereas, in the high ground rising in the reverse direction through Coire Gaibhre towards the summit of Beinn Talaidh, it consists of granophyre. The vertical range is about 800 ft.

Locality 7—one example

East of Beinn Fhada and just outside the fault which has guided the Loch Bà Felsite Ring-Dyke; one can recognize a mass of quartz-gabbro shown on (Plate 6) as running north and south. Reference to the one-inch Map brings out the fact that this mass spans the summit of a ridge connecting Beinn Fhada with An Cruachan. At the summit of the ridge, the intrusion is much more acid than on the slopes on either side. A multitude of cone-sheets renders the evidence difficult to read. The vertical range is about 500 ft.

Locality 8—one example

The augite-diorite of An Cruachan ((Plate 5), p. 165) is a variable mass passing at the top of the hill into granophyre and felsite, while on the slopes leading down to the River Clachaig it becomes gradually more basic. Again, there are too many cone-sheets present to allow an observer to trace the variation in detail. The vertical range is about 1500 ft. J.E.R.

Locality 9—irregular association, one example

Granophyre enters into the constitution of the main outcrop of the Glen More Ring-Dyke in three exposures. Two of these have already been mentioned (Localities 1 and 6). The third is in the southernmost extension of the mass west of Loch an Ellen. Here, while transitional types again occur, and the various types clearly form part of a single intrusion, there are marked departures from density-stratification. In fact, gabbro, in a marginal strip, actually occurs in the highest exposures; while, south-eastward, granophyre extends into the lowest. If, as one naturally supposes in the light of the other occurrences, the granophyre has resulted through gravitational differentiation, it would seem to have moved somewhat after it formed, and thus upset the regular stratification of the reservoir. The vertical range is 1000 ft., so that the anomalies are developed on a considerable scale. (C.T.C.), E.B.B., G.V.W.

Type-Example: one mile west of Craig, Glen More

A geologist, ascending the slopes of Cruach Choireadail (Locality 1, p. 320), from the Glen More road by way of the outcrop of the Glen More Ring-dyke, realizes very readily the upward transition from gabbro through rocks of augite-diorite affinities to granophyre (with sometimes felsitic margins). The gabbro is a dark rock with stumpy crystals of felspar bound together by ophitic augite. The diorite has a considerable proportion of pink felspathic base, in which early-formed grey felspar and dark augite-crystals abound, both characterized by a needle-habit. The granophyre is essentially a pink felspathic rock with subordinate quartz. The change of colour, of mineral-content, and of crystal-habit, all manifest themselves quite gradually during the ascent. Above the 750 ft. contour, the hill-slope is free of drift; and, though much of the surface is covered by blocks loosened by frost, these have travelled so little that they do not obscure the issue.

The only important divergence from gradual upward transition from basic to acid is in the case of several horizontal acid veins which intersect the more basic lower portion of the mass. These veins are sometimes 3 or 4 ft. thick, and their edges are unchilled, though their margins are well-defined. They are clearly the in-filling of fissures which developed in the almost completely consolidated gabbro.

To be able to portray on a map the general gradual upward passage from gabbro to granophyre, a suite of specimens was collected, and their specific gravities measured. The result is shown in (Figure 54). The same data have been employed in the construction of (Figure 55). It is obvious that an observer supplied with either of these two diagrams could, if he so chose, determine his height on the slope of Cruach Choireadail by taking specific gravity determinations of the rocks, and could attain something of the same degree of accuracy as by taking barometric readings of atmospheric pressure. (C.T.C)

Petrology

Type-locality: One mile west of Craig, Glen More

(Anals. I-IV; (Table 8), p. 29)

The almost complete exposure of the Glen More Ring-Dyke on the slopes of Cruach Choireadail (Figure 54) presents features of great petrological interest. At the summit, we have a pale buff granophyric rock, and, in the valley, some 1500 ft. below, a moderately coarse gabbro or dolerite. Between these extremes, there is a wide zone of rock, which, with evident transition, connects the acid and basic types. The lower position of the gabbro, considered in conjunction with the general and gradual increase in density as we pass downward, as well as the practical absence of any sudden changes in texture or composition, invitingly suggests the differentiation of a magma aided, or controlled, by the action of gravity. Concomitant with the gradual change in composition there is a gradual variation in the type of crystallization of the rock-mass, clearly discernible in the field. Thus the augite, as it becomes increasingly plentiful, exchanges an acicular form for a columnar to sub-ophitic habit. It was first<ref>E. B. Bailey, in Summary for Progress for 1913, Mem. Geol. Surv., 1914, p. 51.</ref> thought that this adjustment of crystal-habit to the bulk-composition of the rock supported the view of gravitational differentiation of an emulsion of two liquids, but more mature consideration has convinced us that such is not the ease. Moreover, the chemical instability of the early crystal-elements, which microscopic study reveals as a striking feature of the intermediate portions of the intrusion, strongly supports the view that crystallization was the chief agent in preparing the way for the separation of acid from basic material While the granophyre above, and the gabbro below, are both normal rocks, the transitional zone has a decidedly mixed aspect, as 'viewed under the microscope, and exhibits on a small scale many of the properties of hybrid s.<ref>A. Harker, Natural History of Igneous Rocks, p 333.</ref> The observed characters are in keeping with the idea that there has been pronounced relative migration of early-formed crystals and residual magma within the limits of the differentiating intrusion (p. 355).

Only one alternative to some type of gravitational differentiation of the mass seems worthy of mention, and that is the injection and gradual assimilation of a basic rock by an acid magma. Dr. Harker<ref>A. Harker, Tertiary Igneous Rocks of Skye, Mem. Geol. Surv., 1904, pp. 169 *et seq.*</ref> has found instances in the Island of Skye where acid magma, intruded into, or alongside, hot newly-consolidated basic rock, has developed a hybrid zone by reason of a partial dissolution of the basic material. Hybridization is a common phenomenon in Mull (Chapter 33), but does not seem to us to have operated in the development of the variable mass of Crunch Choireadail (Figure 54). The form of the intrusion, as determined in the field, renders it practically impossible for the granophyre to occupy the position it does if it be a separate injection; and it must be remembered that the Cruach Choireadail example is but one of eleven of like character. Further, in contradistinction to the occurrences in Skye, there is a complete absence of all traces of xenolithic, as opposed to xenocrystal, structure; in this and other respects, such as the absence of rhombic pyroxene, of biotite, and of pyrogenetic hornblende, the intermediate zone of the present intrusion differs from the undoubted hybrid zones described in Chapter 33. We, therefore, feel that the true explanation of the observed variation of the mass must be differentiation in *situ.* As stated above, we have good reason to attribute the differentiation to progressive crystallization that allowed of a partial separation of solid and liquid phases, rather than to the immiscibility of two liquids. One's deductions in this respect are strongly reinforced by the fact that all recent investigations as to the behaviour of silicate-melts go to prove that such fluids are miscible with each other in every proportion.

Serial Micro-sections

A series of specimens (S17625) [NM 5956 3048], (S17626) [NM 5952 3042], (S17627) [NM 5953 3034], (S17628) [NM 5965 3046], (S17629) [NM 5966 3041], (S17630) [NM 5968 3036], (S17631) [NM 5981 3021], (S17632) [NM 5965 3014], (S17633) [NM 5969 3004], (S17634) [NM 5983 2992], (S17635) [NM 5989 2979], (S17636) [NM 5968 2968] was taken in sequence by Dr. Clough to illustrate the increase in acidity of the Glen More Ring-Dyke when followed from the bottom of Glen More to the summit of Cruach Choireadail.

The gabbro or dolerite of the Glen More Mass (S17636) [NM 5968 2968], as exposed on the lower slopes, is a rock of moderately coarse grain and black and white aspect. The dark ferromagnesian component stands out in striking contrast to the white felspathic constituents which show distinct signs of unequal distribution.

Under the microscope the rock (Figure 56)A, is seen to be composed essentially of augite, labradorite, and titaniferous iron-ore. The augite in section shows a pale greenish-brown coloration and has a sub-ophitic habit. It occurs in moderately large individuals, that are ophitic towards the more basic felspars, but frequently exhibit crystal-boundaries and sub-idiomorphic habit when in contact with more acid material. Occasionally, the augite betrays signs of movement in the strongly curved form of its cleavage-traces. This bending of augite-crystals is frequently noticeable in other examples of these rocks, and was referred to by Dr. Falconer as a feature of the columnar augites of the quartz-dolerites of West-Lothian (p. 303).

The felspars are essentially labrodorite of normal composition, and have a tabular development. They are usually twinned and, unless completely enveloped by ophitic augite, show marked zoning, corrosion, and replacement by less basic plagioclase, culminating in a peripheral development of albite. This alteration of the first-formed basic felspars is clearly attributable to the action of acid material of later consolidation, and has taken place on all exposed surfaces of the basic felspar, and along all cracks, junctions of crystals, and other lines of weakness that rendered passage possible to the acidifying medium. In addition, narrow anastomosing veins of albite traverse the early-formed crystals of plagioclase in all directions. This veining with albite is probably part of the general albitization to which most rocks within the central region of Mull have been subjected, and is often clearly distinguishable from the albitizing effect produced by the acid residual magma.

The acid residuum shows a tendency to collect into ill-defined areas practically devoid of ferromagnesian minerals, and consists of a fine-grained turbid aggregate of alkali-felspar and quartz.

The iron-ore appears to be ilmenite. It occurs in moderately large patches and crystals that are frequently skeletal in form, but often show trigonal outline. Chlorite forms somewhat indefinite patches, but occasionally it retains the form of olivine, which was undoubtedly an original constituent of the rock, though now completely replaced. Apatite is practically absent except for a few slender prisms that are more or less confined to the acid portions of the rock.

Higher in the sequence (S17635) [NM 5989 2979], although the rock shows but little change in appearance when studied in the hand-specimen, except perhaps in the more irregular distribution of the more purely felspathic matter, the microscope reveals differences of considerable importance. First we may note a distinct increase in the amount of late-consolidated acid residuum, which, as before, consists of alkali-felspar and quartz, and takes the form of orthoclase, perthite, micropegmatite, and quartz. The augite, as far as can be judged, is constitutionally similar to that in the more basic rock described above, but in sympathy with the increase of acid residual matter, it tends to adopt a columnar prismatic habit, although it retains its ophitic development locally in the more basic portions of the section. Corrosion of the original felspars (labradorite), and their replacement by plagioclase of less basic composition, are marked characters of the rock. Apatite is still a poorly represented accessory, and is confined almost entirely to the replaced portions of basic felspars and to the acid residuum. Olivine is no longer represented.

The more basic portions of the Glen More Mass are occasionally traversed by segregation-veins of more acid character, usually with ill-defined boundaries. In such veins (S17634) [NM 5983 2992], which are noticeably of a lighter colour and finer grain, the bulk of the felspar is of a variety more acid than labradorite, and is in all eases edged with albite, perthite, or orthoclase. The augite-crystals are columnar and intimately intergrown with magnetite near, or at, their surfaces. The residual material is plentiful, and consists of orthoclase, albite, perthite, and quartz, with apatite as an abundant accessory. Iron ore, which occurs plentifully as small crystals, appears to be either magnetite or titano-magnetite.

Passing upwards in the series (S17633) [NM 5969 3004], (S17632) [NM 5965 3014], (S17632) [NM 5965 3014], (S17631) [NM 5981 3021], into that portion of the mass with a specific gravity of between 2.7 and 2.8, the rock becomes more finely grained, and medium-grey in colour. Viewed with a lens, it has a finely speckled character due to the alternation of ferromagnesian and felspathic constituents. Examined microscopically (Figure 56)B, the outstanding features are the reduced basicity of the larger felspars, the almost complete suppression of ophitic structure in favour of a columnar development of augite, and the collection of acid mesostasis into better defined patches and strings (S17631) [NM 5981 3021], (S17633) [NM 5969 3004]. Further, the acid mesostasis has a pronounced acicular type of crystallization, which recalls that of the craignurites (Chapter 19). It consists of skeletal and perthitic growths of alkali-felspar with quartz, either free or in micrographic intergrowth with orthoclase, and slender needles of fibrous green hornblende, presumably psendomorphous after augite.

Apatite is moderately abundant in the acid portions and in the acidified parts of the early-formed felspars.

The augite of the basic portions of the rock, where in contact with, or surrounded by, acid material, has been converted into green fibrous hornblende.

Occasionally (S17632) [NM 5965 3014], the grain becomes somewhat coarser, and the acicular type of crystallization of the rock as a whole more pronounced. We here may notice the marked columnar and elongated character of the augite crystals with their peripheral intergrowths of magnetite, and also a cervicorn development of this mineral in crystals of plagioclase. This cervicorn growth of augite is a feature characteristic of certain examples of the Talaidh Type of quartz-dolerites described in Chapter 28 (p. 303), and also to some extent of the augite-diorites (Chapter 18).

Another somewhat coarser variety (S17630) [NM 5968 3036] of the rocks forming the intermediate zone shows well the genetic relation of the columnar augites to the acid mesostatic material which now forms a considerable portion of the mass. Also, it is interesting to note the incoming of a rudimentary salitic striation in the columnar augites and the passage of this mineral into green hornblende as the result of interaction with the acid mesostasis.

From here upwards the mass (S17629) [NM 5966 3041], (S17628) [NM 5965 3046], (S17627) [NM 5953 3034], although slightly variable ingrain, becomes gradually paler in colour. The change is due primarily to the increased proportion of acid material and the more complete isolation of the early-formed and more basic constitutents. It is particularly interesting that this acid rock sometimes clearly chills against its containing-walls as a microporphyritic epherulitic felsite (S17627) [NM 5953 3034]. The more basin rocks at lower level do not exhibit chilled margins.

The more acid rocks of the series are compact, pale-grey to buff in colour, and are best described as soda granophyre. Their more basic representatives (S17626) [NM 5952 3042] have craignurite-affinities, and are characterized by a finely acicular crystallization of their constituent felspar and augite, and a feathery base composed largely of alkali-felspar and quartz, frequently in micrographic relationship to each other (Figure 56)C. The early-formed felspar and augite, abundantly represented in the more basic portions of the transitional zone, are reduced to a minimum, and have suffered marked alteration.

Coir' an t-Sailean

(Anals. V. and VI.; (Table 8), p. 29)

The neighbouring exposures of Coir' an t-Sailean (Locality 2, p. 321) have also furnished interesting material of similar character (S16530) [NM 5788 3113], (S16531) [NM 5660 3233], (S16532) [NM 5647 3239], (S16533) [NM 5676 3233], (S16534) [NM 5672 3227], (S16535) [NM 5677 3224], (S16536) [NM 5687 3214], (S16537) [NM 5685 3212], (S16538) [NM 5683 3209], (S18455) [NM 5654 3251], (S18456) [NM 5687 3206], (S18457) [NM 5687 3206], (S18458) [NM 5669 3219], (S18459) [NM 5669 3219], which shows the same gradual transition from basic to acid types.

Discussion of analyses (Table 8, p. 29).

For a more complete realization of the compositional changes that have taken place in these masses, five analyses of the various grades exposed have been made (p. 29). Of these, two from Glen More (S18463) [NM 6027 2939], (S18462) [NM 5990 2974] and one from Coir an t-Sailean (S18455) [NM 5654 3251], are of moderately basic character. These rocks are best described as olivine-bearing quartz-gabbro or quartz-dolerite. They contain only a small amount of residual acid material, and compare closely with the basic rock already described (S17636) [NM 5968 2968]. The granophyric part (S18460) [NM 5959 3044] of the Glen More Ring-Dyke, as exposed at the summit of Cruach Choireadail, is a fine-grained soda-rich rock, poor in ferro-magnesian constitutents, with an orthoclase to albite ratio of 1 to 2. It is composed of albite, orthoclase, microperthite, and quartz, with a little fibrous green hornblende after acicular augite. It is perhaps best classed as an acid eraignurite unusually rich in soda.

The analysed rocks of the transitional zone of the Glen More Ring-Dyke (S18461) [NM 5967 3006] and the Coir' an t-Sailean Mass (S18456) [NM 5687 3206] may be regarded as representative.

Examined microscopically, these rocks present characters similar to those already described in connexion with Dr. Clough's specimens. They show the same collection of varying amounts of acid material into lakes and strings, the corrosion and replacement of early formed plagioclase by felspar of more acid character, the columnar and cervicorn development of augite, and a distinct concentration of apatite when compared with the basic and acid extreme types. They are fairly representative coarse craignurites, and differ little from some of the augite-diorites (Chapter 18), except in their less mature type of crystallization.

It has already been pointed out (p. 28) that the differentiation series of Glen More corresponds remarkably closely in composition with the variation-diagram for the Normal Mull Magma-Series, illustrated in (Figure 2) (p. 14). Between the limits set by 50 and 70 per cent. SiO_2, this variation-diagram is approximately of straight-line character. The following table demonstrates the predominant linear tendency met with in the variable complex of Glen More.<ref>Straight-line variation is a characteristic of differentiation of quartz-dolerite magma in West Lothian, as is shown by curves drawn by E. B. Bailey in Geology of the Glasgow District, *Mem. Geol. Surv.,* 1911, p. 147 to illustrate analyses by G. S. Blake, quoted by J. D. Falconer in Igneous Geology of the Bathgate and Linlithgow Hills, Trans. Roy. Soc.Edin., vol. xlv., 1906, p. 147.</ref>

	SiO_2	MgO	CaO	Alkalies	P_2O_5
Gabbro (S18463) [NM 6027 2939]	49.90	5.88	10.39	3.81	0.20
Granophyre (S18460) [NM 5959 3044]	68.12	0.71	1.81	8.62	0.22
Mixture 1: 1 of above	58.5	3.1	6.1	6.2	0.21
Average of transition-zone (S18456) [NM 5687 3206] and (S18461) [NM 5967 3006]	56.7	2.5	5.8	6.9	0.48

Viewed from the standpoint of the differentiation theory outlined above, linear variation bespeaks an approximate constancy of composition of the acid residuum during its miarations. This emphasizes, once again, the comparative pause that occurred in the crystallization-history of the magma after the separation of its gabroic elements. Of course, the pause was not absolute. For instance, the microscope shows that a relative richness in apatite, to some extent, distinguishes the acid residuum, entangled in the basic and intermediate portions of the ring-dyke, from the fairly pure acid concentrate encountered at higher levels; so that it is clear that much of the crystallization of the apatite occurred during the migration of the acid residuum. Apatite is a very minor constituent of the Glen More series; but its content of phcsphorus allows us to follow its distribution, even in bulk-analyses: here, the findings of the microscope are confirmed by a marked relative concentration of P_2O_3 in rocks that are otherwise of intermediate composition.

Conclusions

In these differentiated masses, we have as extreme types an olivine-bearing quartz-gabbro, or quartz-dolerite, and a soda-granophyre. The wide transitional zone between these types gradually varies in composition, but retains a fine-grained texture throughout, and shows no trace of xenolithic structure on a macroscopic scale. The basic rock, after the manner of quartz-gabbros, invariably contains a small, but inconstant, proportion of acid material in the form of strings and patches of alkali-felspar and quartz. Upwards in the succession, the ratio of light to dark-coloured constituents undergoes a progressive change. Under the microscope, we encounter increasingly frequent patches and strings, composed of albite, perthite, and micropegmatite, with little or no ferro-magnesian minerals; and these patches and strings separate earlier-formed crystals of augite and zoned labradorite (S17872) [NM 6064 3079]. The acid material has, wherever favourable opportunity offered itself, produced corrosion and substitution of the more basic felspars (S18462) [NM 5990 2974], and, at its contacts with augite, has effected a change of this mineral into fibrous green hornblende. Further, there is the tendency, as the amount of acid matter increases, for the ophitic augite of the basic rock to assume a sub-idiomorphic columnar habit and to develop an incipient salitic striation. This columnar augite is highly characteristic of the augite-diorites (Chapter 18), and of the quartz-dolerites of Talaidh Type (Chapter 28), and is almost always associated and intergrown with abundant magnetite. With further increase in the amount of acid base, acidification of the basic felspars of early formation is a marked feature, and progresses to the ultimate production of oligoclase-albite which may, or may not, retain a core of more basic felspar. It is obvious in the transitional zone that, although no xenolithic structure on a large scale is to be detected, the whole fabric of the rock is composed of minute patches and crystals that are of the nature of xenocrysts, and out of equilibrium with their surroundings. As was stated previously, the change in type of crystallization noticed on passing from the basic to acid portions of these ring-dykes is one primarily controlled by composition. The increase in acidity is accompanied by a greater tendency to acicular crystallization of the component minerals, a feature noticed in the craignurites (Chapter 19), which in their acid representatives are structurally similar to the acid mesostasis of the transitional zone; the same feature is also characteristic of the acid differentiates of the quartz-dolerites of West Lothian.

There is little doubt that we have, in this transitional zone, a commingling and interaction of a fluid magma with solid material; but exactly similar phenomena can be studied in the quartz-dolerite sills of West Lothian, where it can be demonstrated that acid residual fluid, that originally existed more or less evenly distributed throughout a basic rock, has been squeezed out and segregated in certain portions of the mass in variable quantity. In connexion with this assumed application of external force, attention may be directed to the sharply flexed condition of many of the augite-crystals (Figure 56)A, both in the differentiated ring-dykes of Mull and in the quartz-dolerites of West Lothian. In the case of the Mull ring-dykes, the force responsible for the squeezing out of the acid mesostasis and the deformation of crystals appears in the main to have been gravity, for otherwise it is difficult to account for the almost universal and gradual downward increase in density.

The upward passage of the acid residual material, and its progressive concentration in higher portions of the intrusions, are naturally accompanied by a new set of physical and chemical conditions, whereby previously existing equilibria are disturbed. This accounts for the reproduction on a microscopic scale in these rocks of some of the characters of hybrids as discussed in Chapter 33; but, as there indicated, other characteristic features of hybrid rocks are unrepresented. There is all through the transitional zone of these differentiated ring-dykes abundant evidence of crystals, and groups of crystals, being out of sympathy with their environment, and of efforts made to stabilize the conditions through resorption, recrystallization, and replacement of earlier-formed crystalline phases. Absolutely analogous disturbances and readjustments are to be seen in the partially differentiated quartz-dolerites of West Lothian, where a migration of acid reiduum has locally modified the bulk-composition of the rock.

Our conclusions regarding the conditions, that in certain Mull Ring-Dykes favoured the migration of a partial magma, and its ultimate more or less complete separation from the early crystalline phases, are as follows. After crystallization had proceeded for some time, and had practically exhausted the magma as regards lime and magnesia, there still remained a residuum which retained its fluidity over a considerable range of temperature, so that there was, at this stage, a marked pause in the process of crystallization. Under such conditions, ample opportunity was afforded for migration of the fluid residuum under stress during the extended period that elapsed before crystallization was completed. In such a high column of magma as these ring-dykes represent, the gravitational pressure of the early crystalline phases on the still-liquid residuum would be considerable, and would in our opinion be quite sufficient to cause an upward filtration of the still-fluid portion of the mass, and its ultimate intrusion as an entity into the uppermost part of the dyke-fissure, where it chilled marginally against the country-rock. H.H.T., E.B.B.

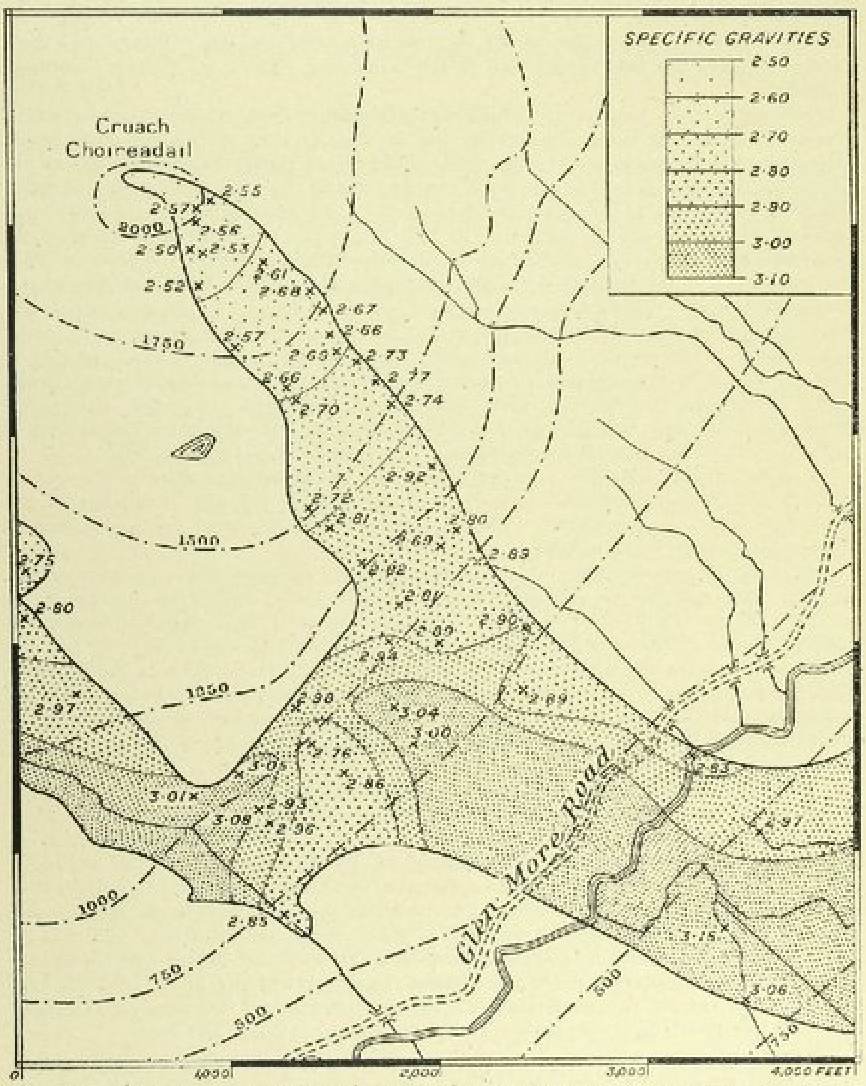
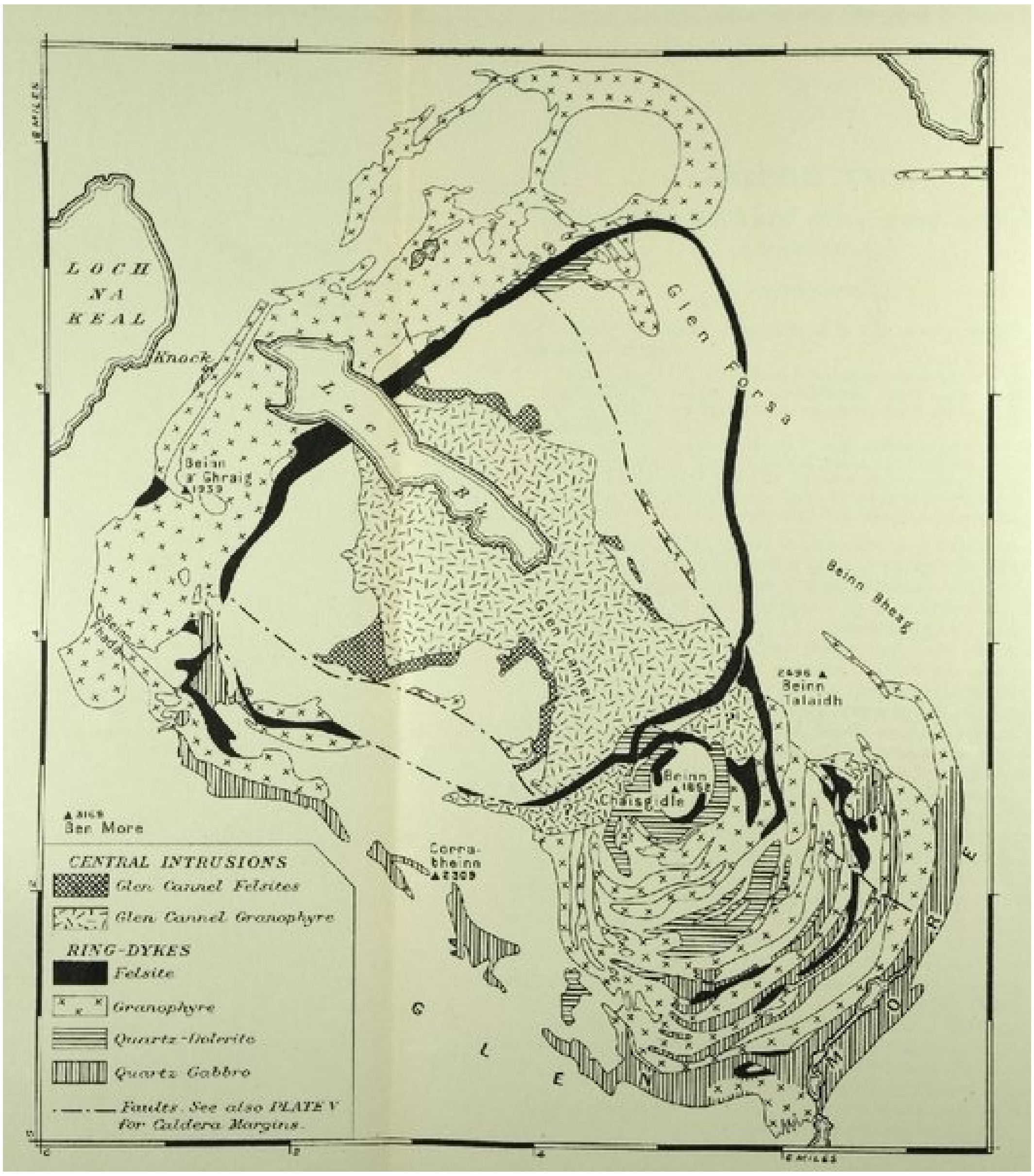
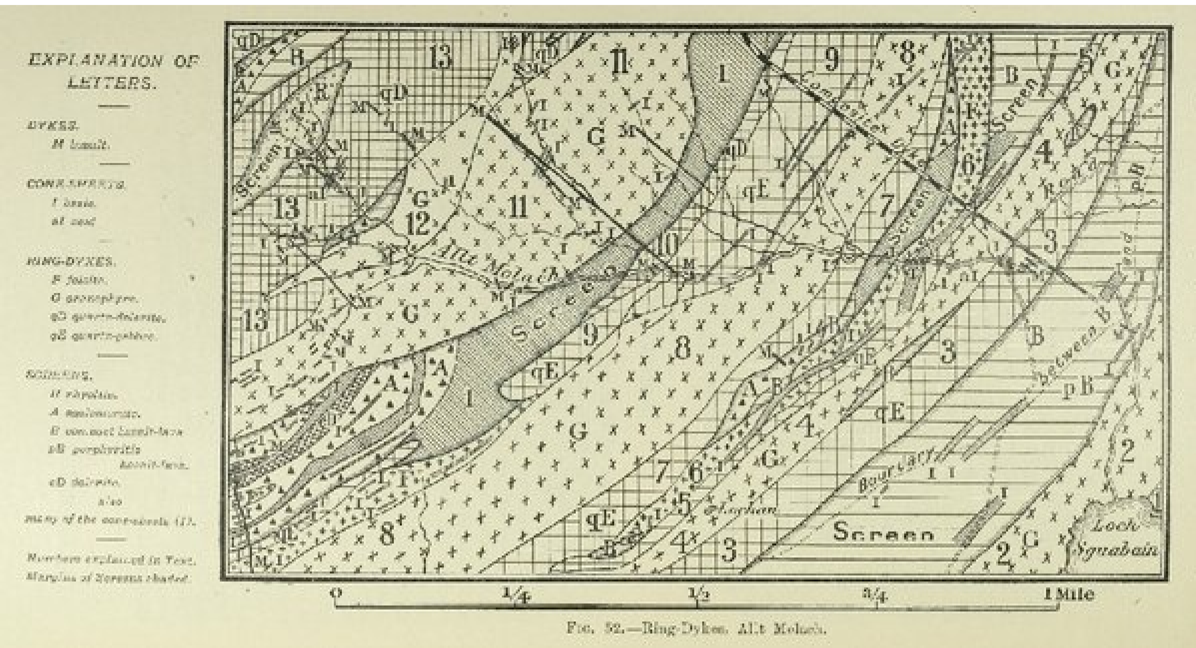


FIG. 54.—Map showing Density-Stratification in differentiated Ring-Dyke, Cruach Choireadail, Glen More (Locality 1). The extreme products exposed are olivine-bearing quartz-gabbro and granophyre.

(Figure 54) Map showing Density-Stratification in differentiated Ring-Dyke, Cruach Choireadail, Glen More (Locality 1). The extreme products exposed are olivine-bearing quartz-gabbro and granophyre.



(Plate 6) Map showing ring-dykes



(Figure 52) Ring Dykes, Allt Melach.

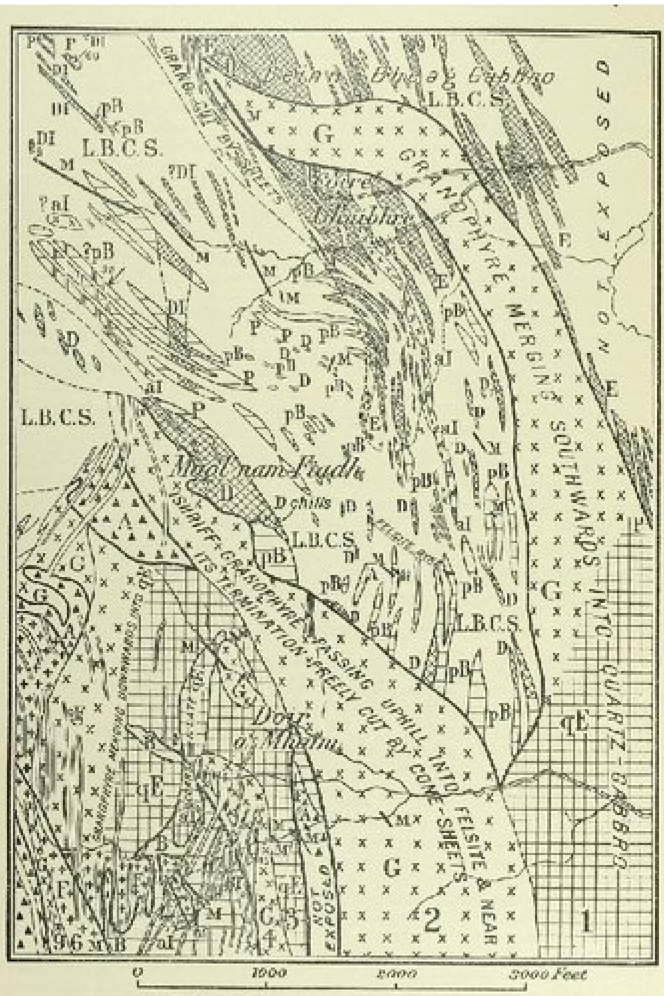


Fig. 53.—Ring-Dykes, Maol nam Fiadh.

Dykes: M basalt,

Cone-Sheets: DI dolerite; aI acid; L.B.C.S. Late Basic Cone-Sheets (shown without ornament).

Ring-Dykes: F felsite; G granophyre; qE quartz gabbro.

Screens: A agglomerate; B compact basalt lava; pB porphyritic basalt-lava; P pillow-lava; D dolerite; E gabbro; also many of the cone-sheets.

Numbers as in Fig. 52, see Text.

(Figure 53) Ring-Dykes, Maol nam. Fiadh. Dykes: M basalt, Cone-Sheets: DI dolerite; aI acid; L.B.C.S. Late Basic Cone-Sheets (shown without ornament). Ring-Dykes: F felsite; G granophyre; qE quartz-gabbro. Screens: A agglomerate; B compact basalt-lava; pB porphyritic basalt-lava; P pillow-lava; D dolerite; E gabbro; also many of the cone-sheets. Numbers as in Figure 52, see Text.

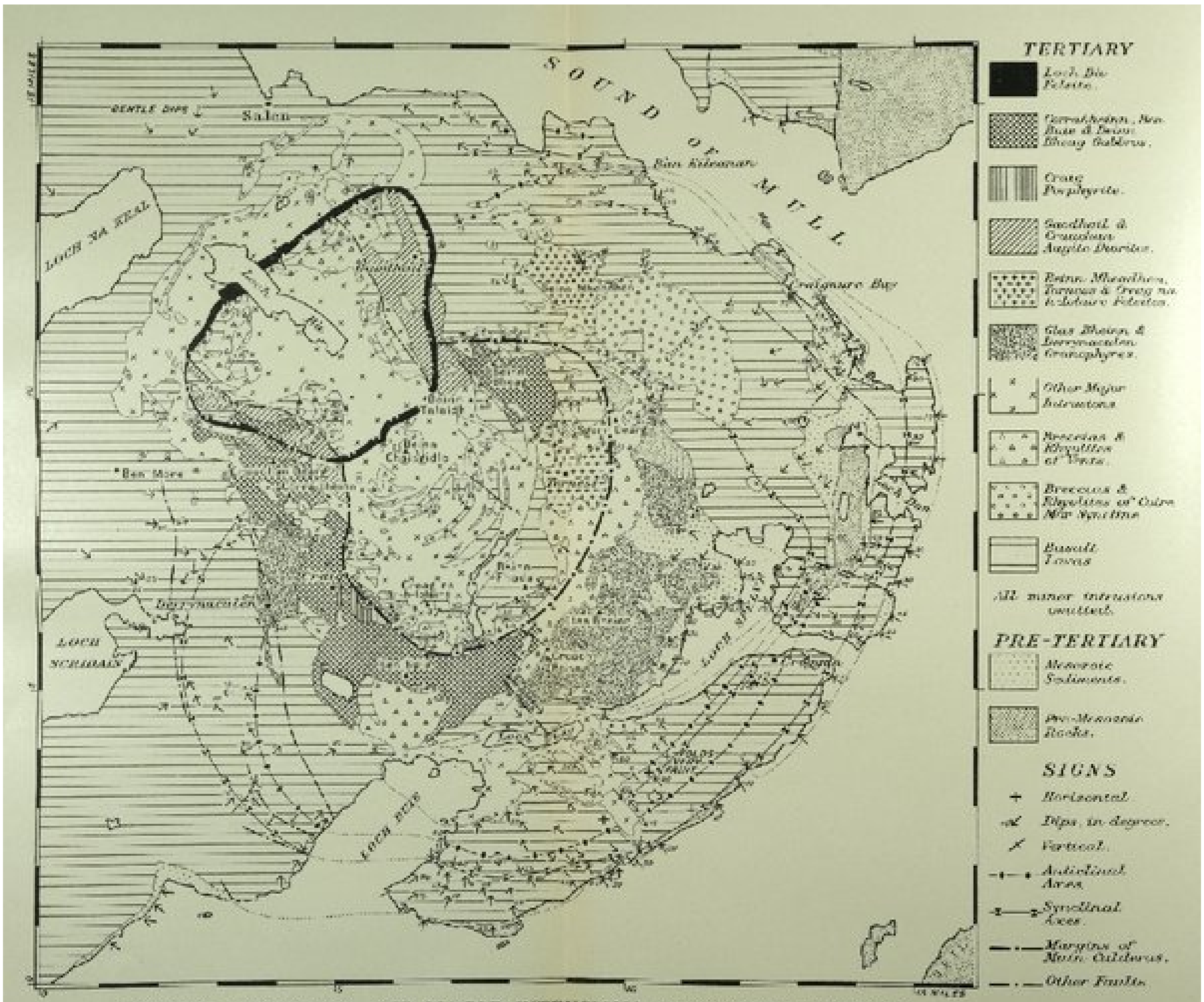


PLATE V. TECTONICS AND MAJOR INTRUSIONS ABOUT MULL CENTRES.

(Plate 5) Map showing calderas, major intrusions, and folds

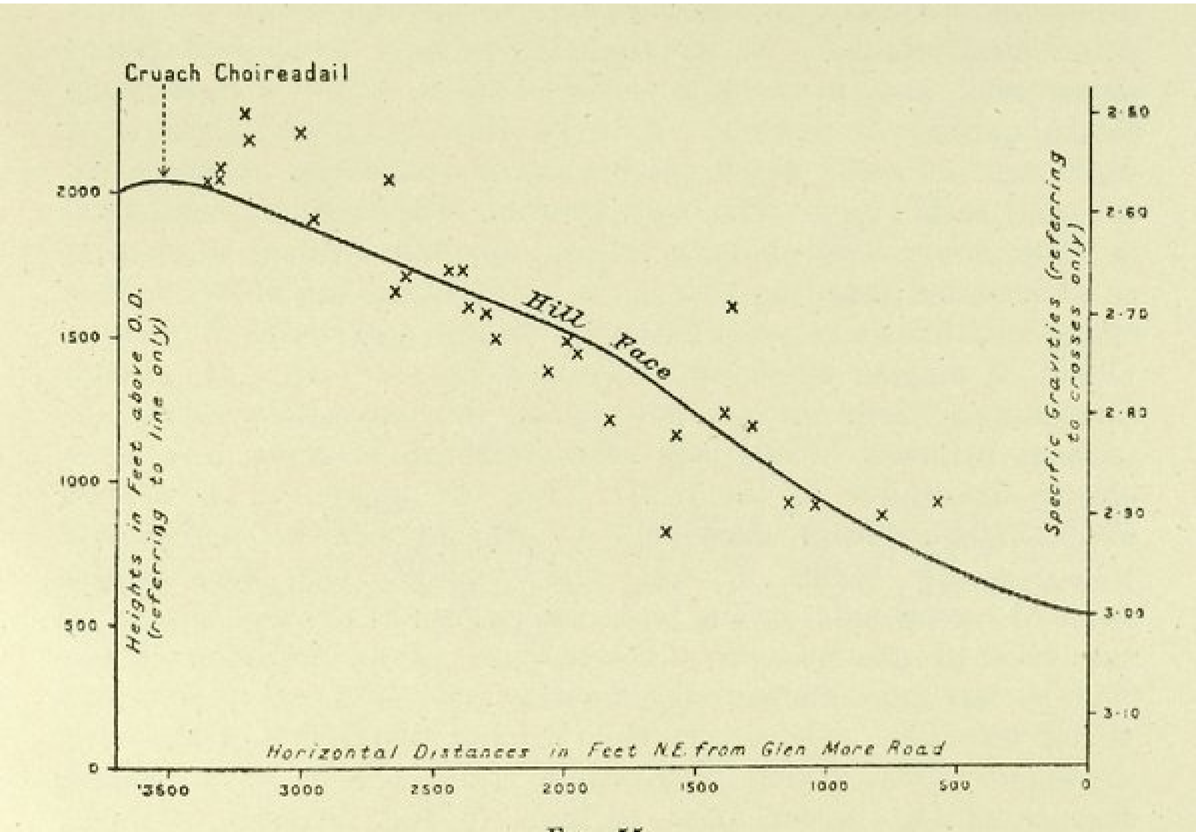


FIG. 55.

(Figure 55) Graph showing relation of Specific Gravity to Altitude in gravitationally differentiated Ring-Dyke, Cruach Choireadail, Glen More.

	Cruach Choireadail, Fig. 54, p. 322.				Coir' an t-Sailein.		
	I.	II.	III.	IV.	V.	VI.	
SiO_2	49·90	51·32	56·22	68·12	50·04	57·18	SiO_2
TiO_2	2·56	0·98	2·74	1·26	2·56	3·25	TiO_2
Al_2O_3	12·70	13·96	12·45	13·08	13·32	10·75	Al_2O_3
Fe_2O_3	4·20	2·48	3·09	1·02	4·71	4·96	Fe_2O_3
FeO	7·88	7·10	7·58	3·26	8·07	6·24	FeO
MnO	0·36	0·34	0·43	0·39	0·33	0·32	MnO
(Co, Ni)O	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	(Co, Ni)O
MgO	5·88	5·78	2·78	0·71	5·01	2·15	MgO
CaO	10·39	11·51	5·93	1·81	10·02	5·73	CaO
BaO	nt. fd,	nt. fd.	0·04	0·04	nt. fd.	0·06	BaO
Na_2O	2·86	3·50	3·82	4·15	3·28	4·62	Na_2O
K_2O	0·95	1·16	2·67	4·47	1·08	2·67	K_2O
iL_2O	nt. fd.	nt. fd.	nt. fd.	nt. fd.	tr.	tr.	Li_2O
$H_2O + 105°$	1·65	1·27	1·35	1·16	1·45	1·31	$H_2O + 105°$
H_2O at 105°	0·67	0·36	0·44	0·40	0·27	0·33	H_2O at 105°
P_2O_5	0·20	0·24	0·50	0·22	0·28	0·46	P_2O_5
CO_2	0·09	0·09	0·05	0·06	0·08	0·08	CO_2
FeS_2	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	FeS_2
	100·29	100·09	100·09	100·15	100·50	100·11	
Spec. grav.	2·95	2·91	2·77	2·55	2·97	2·71	

I.–IV. Ascending Sequence, Cruach Choireadail.

(Table 8) Differentiation — Column of Glen More Ring-Dyke as exposed In Cruach Choireadail and Coir' An T-Sailein, 2½ miles apart

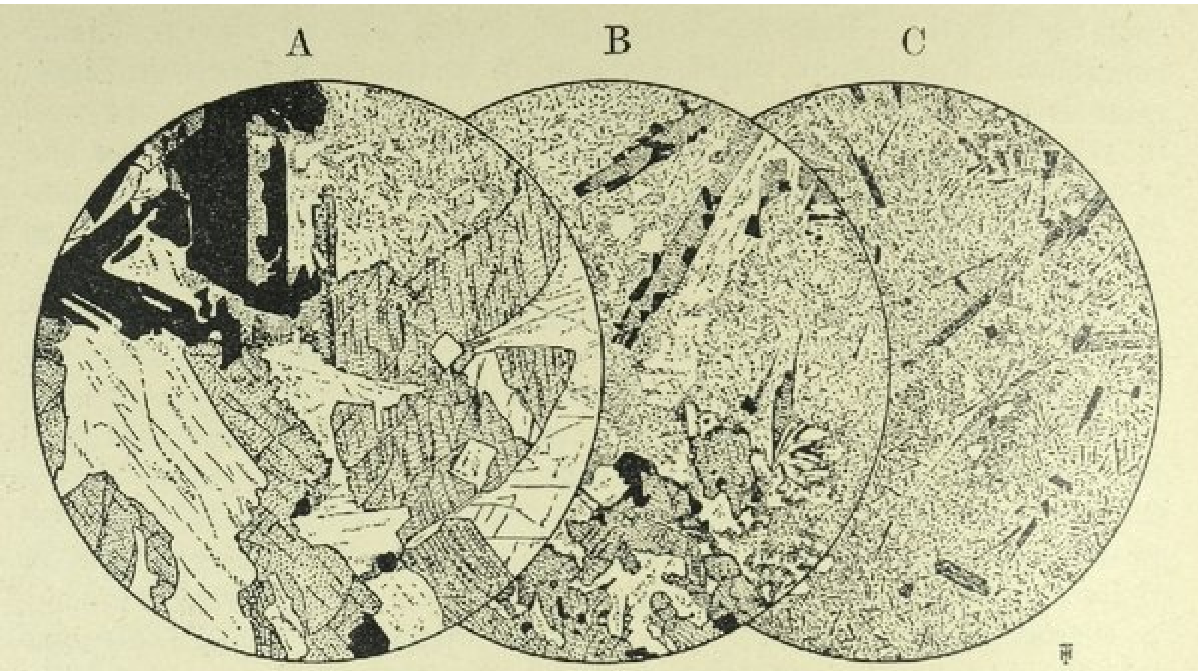
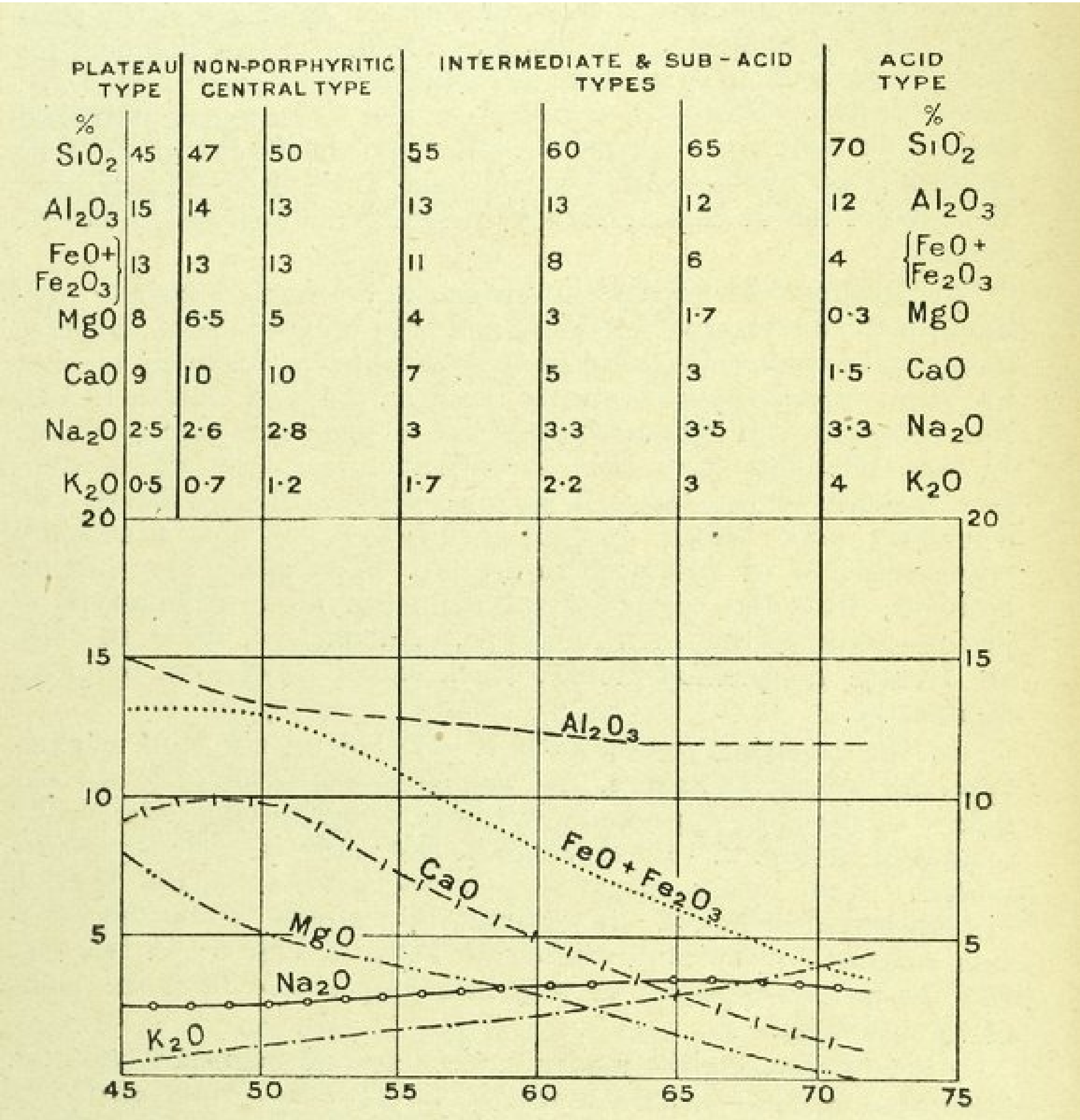


FIG. 56.—The Glen More Differentiated Ring-Dyke.

(Figure 56) The Glen More Differentiated Ring-Dyke. A. [(S17636) [NM 5968 2968]] ×15. Lower Basic Portion. Quartz-gabbro. The rock is composed of labradorite, ophitic augite and large plates of ilmenite, with a variable amount of finely crystalline acid mesostasis (top). Where in contact with the acid residuum, the augite shows signs of resorption. Movement of the mass after partial consolidation has frequently resulted in the bending and breaking of crystals—note the curved cleavage-traces in the large crystal of augite.Fig. 56 B. [(S17632) [NM 5965 3014]] ×15. Intermediate Portion. The figure shows a rock in which there is an increased proportion of acid mesostatic matter with characteristic acicular crystallization of its components. It has developed columnar crystals of augite (top) with their usual association of magnetite, and it encloses small patches of more doleritic material (bottom) which show signs of resorption and of being out of equilibrium with their surroundings. C. [(S17626) [NM 5952 3042]] x 15. Higher Acid Portion. Acicular type of crystallization is a characteristic feature. The rock is composed of elongated crystals of greenish hornblende, pseudomorphous after augite, in a feathery base of alkali-felspar and quartz, frequently in micrographic relationship to each other.



(Figure 2) Variation-diagram: Normal Mull Magma-Series.