Chapter 8 General petrology

In the Memoir dealing with the Tertiary igneous rocks of Mull an attempt was made to give some account of the composition and variation of the Tertiary Magma at successive stages in its history. We were able to recognize, as represented by the rocks, definite compositional characteristics which further enabled us to select average compositions around which individual rocks of the Tertiary Province seemed to group themselves. These average compositions, representative of widespread rock-types and based upon a great number of trustworthy analyses, we assumed to mark certain stages in the evolutionary history of the magma, and thus might logically be regarded as indicative of definite magma-types. The recognition and establishment of such types appeared to be the natural preliminary to any discussion of the probable course of differentiation, for such types will of necessity stand in either lineal or collateral relationship to each other. Magma-types that appear to have a direct lineal relationship may collectively be regarded as constituting what may be termed a magma-series, while divergent types may constitute collateral series.

The study of the Tertiary centres of Arran,<ref>G. W. Tyrrell, The Geology of Arran, *Mem. Geol. Surv.,* 1928.</ref> the Mourne Mountains<ref>J. E. Richey, The Structural Relations of the Mourne Granites, Quart, *Journ, Geol. Soc., vol, lxxxiii.,* 1928, p. 653.</ref> and, more particularly, of Ardnamurchan has enabled us to confirm, expand and, in some instances, to modify our previous conceptions.

In Ardnamurchan the plateau basalts are feebly represented, but they are of the usual type and composition and may be considered, as in other districts, to have had a much greater extent than they now exhibit. Our main concern is with the intrusive masses that occur as ring-dykes, cone-sheets, and sills.

The major intrusions of the Ardnamurchan centres are mostly of gabbro and quartz-gabbro with quite subordinate masses of granophyre. At the latest of these centres, however, following upon the Great Eucrite Ring-dyke, in point of time, we encounter an important development of tonalitic and quartz-monzonitic types that are practically unrepresented amongst the intrusive masses of the other Tertiary centres, with the exception, perhaps, of Slieve Gullion in Ireland.

A chemical and microscopical study of the plutonic intrusions of Ardnamurchan indicates that the bulk of the quartz-gabbros belong to the Porphyritic Central Magma-Type as established in Mull, but that the tonalitic and quartz-monzonitic types, together with certain more acid plutonic masses of other Tertiary centres, suggest the existence of an independent collateral magma-series with entirely distinct end-products of differentiation.

The Normal Magma-Series

The Normal Magma-Series (Figure 6) as established in Mull and as described in the Memoir<ref>H. H. Thomas and E. B. Bailey *in* Tertiary Mull Memoir, 1924, p. 14.</ref> on that island was based primarily on the chemical and petrographical characters of a very large suite of rocks. It appears as a typical lineal series and has a wide range of composition from basic to acid. At its basic end stands the Plateau Type, and this is followed by the Non-porphyritic Central Type, and through several intermediate and sub-acid stages reaches the Acid Magma-Type (Figure 6).

This magma-series is responsible for most of the igneous rocks of Mull. Many of these have an immature or hypabyssal type of crystallization. Where such is the case, it is more or less certain that each rock is a faithful expression of the magma which gave rise to it, and has not been compositionally modified to any extent during its intrusion or solidification.

In Northern Mull and Ardnamurchan most of the lavas and minor intrusions, as well as granophyres such as those of Grigadale, are representatives of this series, and we have reproduced the Mull variation diagram for comparative purposes. A recent analysis of the granite of the north of Arran ((Table 3), C) enables this diagram to be extended slightly in the acid direction, and analyses of rocks from other areas suggest that this magma-series may be regarded as generally applicable to the Tertiary Province.

Almost all the various magma-types embraced by the Mull Series have their representatives within the Ardnamurchan centres, although there is, perhaps, much less variety in their solid expression. In many cases rocks encountered in

Ardnamurchan, such as plateau lavas, basalt and dolerite dykes, etc., proved on microscopic examination to be so similar to types represented in Mull or some other Tertiary centre that further chemical analyses were deemed unnecessary. For comparative purposes, however, analyses of important Ardnamurchan rock-types, representative of this magma-series, were undertaken, and these are given in (Table 2) and (Table 3), pp. 82 and 84.

The compositional characters of the magma-series as a whole are set out in (Figure 6). The main features are the fairly constant Al_2O_3 with falling Iron, CaO and MgO towards the acid end, and the concentration of TiO_2 towards the basic end where the falling CaO with rising MgO, and the high Iron and Al_2O_3, indicate the concentration of olivine, augite, and iron-ores at the expense of basic plagioclase felspar. There is a general tendency throughout a large part of the series for Na_2O predominate over K_2O, but close to the acid end there is a rapid relative concentration of K_2O causing the two alkali curves to cross and diverge at a silica percentage of about 68. The series is one throughout which the plagioclase felspars play an important part, as is indicated by the flat curve representing a more or less constant content of Na_2O.

The Plateau Magma-Type

The Plateau Type in the north of Mull is represented by a great development of basalt lavas and a great number of basic dykes. In the Ardnamurchan peninsula it is clearly demonstrated by a small development of plateau lavas and by a considerable number of dykes that have basaltic or doleritic types of crystallization. The lavas of Ardnamurchan, however, are possibly referable to the Mull centre (p. 107), and the dykes, which are of all periods of intrusion, belong in part to the Mull Swarm (p. 343). The great group of Early Basic Cone-sheets, an early expression of this magma-type in South-central Mull, is not met with in Ardnamurchan. As pointed out in the Tertiary Mull Memoir the essential minerals of this magma-type are olivine, augite, basic plagioclase and iron-ore, with a certain amount of interstitial matter, which in certain cases can be demonstrated to yield analcite, natrolite, and possibly nepheline on crystallization. A purple tint indicative of the presence of titanium is usually exhibited by the augite, which does not occur either as phenocrysts or small idiomorphic crystals but exhibits an ophitic structure.

The nature of the residual matter left over on the solidification of this magma-type is noteworthy in connexion with the alkaline segregations encountered by the Survey in certain of the plateau lavas of Mull and more recently by Dr. Walker in a thick Tertiary Sill of plateau basalt composition occurring in the Shiant Isles. In the lavas the segregations consist of titaniferous augite, labradorite and ilmenite with a residuum of alkali-felspar, aegirineaugite and analcite, the presence of nepheline being expected but not proved. In the Shiant sill Dr. Walker finds that the segregations are of the nature of an alkali-syenite similar to the Carsaig Syenite in Mull but with the addition of large crystals of nepheline.

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

	QUARTZ-DOLERITE.				
	I.	II.	III.	IV.	A.
SiO_2	50.10	50.67	50.79	52.06	52.16
Al_2O_3	12.08	11.89	12.10	11.79	1.95
Fe_2O_3	4.35	8.61	4.10	3.41	4.86
FeO	11.18	7.08	11.29	11.68	9.92
MgO	3.93	3.94	4.02	4.35	3.77
CaO	8.85	7.75	8.05	7.57	7.14
Na_2O	3.06	2.94	3.50	3.36	2.36
K_2O	0.96	1.50	1.30	1.23	1.74
$H_2O > 105°$	1.01	0.77	0.23	0.92	1.95
$H_2O < 105°$	0.53	1.05	1.56	0.56	0.56
TiO_2	2.98	2.88	2.46	3.10	3.25
P_2O_5	0.17	0.55	0.22	0.23	0.24
MnO	0.25	0.20	0.26	0.20	0.18
CO_2	trace	0.21	0. 17	—	0.18
FeS_2	0.28	0.02	0.28	—	—
Fe_7S_8	0.02	—	—	—	—

SO_3	—	0.38	trace	—	—
S	—	—	—	0.11	0.18
Cr_2O_3	trace	trace	0.02	–	—
(Co,Ni)O	–	0.00	–	–	—
BaO	0.05	0.02	trace	0.00	—
LiO	—	0.00	trace	–	—
Cl	—	—	—	0.00	—
C	—		—	—	—
Organic matter	—	0.01	—	—	—
	99.80	100.47	100.39	99.57	100.44

I. ((S22819) [NM 4949 6392]; Lab. No. 788.) Quartz–dolerite, Talaidh type. Cone-sheet, Centre 2, Ardnamurchan. Quarry west of crofts at Tom a'Chrochaidh, 0.5 mile E. of Kilchoan. Anal. B. E. Dixon.

II. ((S21253) [NM 526 629]; Lab. No. 737.) Quartz-dolerite. Ben Hiant Main Intrusion, Centre 1, Ardnamurchan. Cliffs 700 feet above shore, Camas nan Clacha Mora, Ben Hiant. Anal. B. E. Dixon.

III. ((S23296) [NM 4928 6260]; Lab. No. 792.) Quartz-dolerite, Talaidh type. Cone-sheet, Centre 2, Ardnamurchan. Shore at Rudha Aird an Iasgaich, seven-eighth's mile S.E. of Kilchoan. Anal. B. E. Dixon.

IV. Quartz-dolerite, Talaidh type. Cone-sheet. Same intrusion and locality as preceding. Anal. H. S. Washington.

A. ((S18467) [NM 5684 3313]; Lab. No. 444.) Quartz-dolerite, Talaidh type. Cone-sheet. 70 yds. S. of summit, Cruachan Dearg, Mull. Quoted from The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban, Mem. Geol. Surv., 1924, p. 17. Anal. F. R. Ennos.

The Non-porphyritic Central Magma-Type

This type, which in Mull accounted for a thick series of lavas, many of the sills, most of the Late Basic Cone-sheets, and many dykes, in Ardnamurchan is responsible for most of the cone-sheets, the relatively large intrusion of Ben Hiant, and many dykes; but it is practically only the more acid representatives of the type that here find expression. The essential minerals are augite, plagioclase felspar and magnetite, the rocks being either olivine-free or having olivine as a minor constituent. There is usually an acid residuum which on crystallization yields alkali-felspar and quartz. The kind of solidification or crystallization which the type affects is very variable and may be largely glassy, variolitic, basaltic or doleritic.

The analyses given in (Table 2) are of Ardnamurchan occurrences, with examples taken from Mull for comparison. We have been able to include a hitherto unpublished analysis (IV) of an Ardnamurchan cone-sheet by Dr. H. S. Washington. It will be seen that the Ardnamurchan rocks compare closely with the Talaidh type of quartz-dolerite as established in Mull, and although somewhat richer in CaO and Al_{203} fall naturally into their place in the Normal Magma-Series.

Intermediate, Sub-acid, and Acid Magma-Types

Of the remaining magma-types of the Normal Magma-Series the few representatives in Ardnamurchan are craignuritic cone-sheets and sills, the pitch-stone lavas of Ben Hiant, and certain granophyres (*see* (Table 3), Anal. I, II, III). The pitchstone lavas are especially interesting as furnishing an effusive example of a magma that as far as Mull is concerned is only represented as an intrusive phase. Their compositional and mineralogical identity with the Inninmorite pitch-stone of the Mull sills, marks them out as representing a very definite stage in the magma-series. Their essential minerals are enstatiteaugite, augite, plagioclase and magnetite with a very considerable residuum of glass that on devitrification yields mainly alkali-felspar and quartz.

The Acid Magma-Type in Ardnamurchan demonstrated itself at an early stage, and as in Mull and most other Tertiary centres was responsible for the explosion phenomena connected with the vents, the shattering and injection of some of the ring-dykes of Centre 2, and certain important intrusions of augite-granophyre.

(Table 3) Sub-acid and acid magma-types (*see* (Figure 6))

	Inninmorite	Inninmorite	Inninmorite	Granite and granophyre	Granite and granophyre	Granite and granophyre
	A.	I.	II.	III.	B.	C.
SiO_2	64.13	64.30	66.06	68.42	71.60	74.87
Al_2O_3	13.15	14.18	13.14	13.54	13.60	11.24
Fe2O3	1.08	1.09	2.27	2.53	2.40	0.34
FeO	6.31	4.44	2.84	2.02		1.22
MgO	1.08	1.47	0.77	0.22	0.21	0.22
CaO	3.62	2.87	2.75	2.13	2.30	1.30
Na_2O	3.64	4.30	4.28	5.12	5.55	3.31
K_2O	2.32	2.83	1.54	4.08	3.53	5.68
H_2O > 105°	2.71	3.02	3.38	0.15	0.70	0.49
H_2O < 105°	0.36		10.74	0.25		0.29
TiO_2	1.19	0.75	1.08	0.81	—	0.26
P2O_5	0.31	0.17	0.09	0.38	—	0.09
MnO	0.27	0.26	0.31	0.10	—	0.05
CO_2	—	0.00	0.37	0.06	—	0.49
FeS_2	0.00	—	trace	0.05	—	0.33
SO_3	—	0.00	0.16	trace	—	–
Cr_2O_3	—	0.00	trace	trace	—	0.02
(Co,Ni)O	0.00	—	0.00	—	—	—
BaO	0.09	0.16	trace	0.03	—	0.04
Li_2O	0.00	–	trace	trace	—	0.00
F	—	—	—	—	—	0.00
C	—	traces	–	—	—	—
Organic matter	—	—	0.02	—	—	—
	100.26	99.84	99.80	99.89	99.89	100.24

A. (S15990) [NM 5176 2404]; Lab. No. 387.) Fairly glassy Inninmorite or Inninmorite-Pitchstone. Sheet. 3/16th mile S.W. of Trigonometrical Station on Beinn an Lochain, Mull. Quoted from E. M. Anderson and E. G. Radley, *Quart. Journ. Geol. Soc., vol.* lxxi., 1915, p, 212. *Anal.* E. G. Radley.

I. Inninmorite-Pitchstone. Lava. E. slope of Ben Hiant, Ardnamurchan. *Anal.* Harcourt Phillips.<ref>Supplied by Dr. A. Harker,<\ref>

II. (S21255) [NM 540 622]; Lab. No. 739.) Inninmorite-Pitchstone. Lava. In stream bank 5/8th mile S. 12° E. of Trigonometrical Station at 1729 ft., Ben Hiant, and 0.5 mile W. 3° S. of Bourblaige, Ardnamurchan. *Anal.* B.E. Dixon.

III. (S22820) [NM 437 664]; Lab. No. 789.) Augite-granophyre. Major intrusion, Centre 2, Ardnamurchan. 800 yds. S. 30° E. of Grigadale. *Anal.* B. E. Dixon.

B. Augite-granophyre. 100 yds. E. of summit, Carrock Fell, Cumberland. Quoted from A. Harker, *Quart. Journ. Geol. Soc., vol.* li., 1895, p. 129. *Anal.* G. Barrow.

C. (S24380) [NR 981 394]; Lab. No. 820.) Biotite-granite. Northern granite mass, Arran. Glen Rosa, 0.5 mile above confluence with Garbh Allt. Quoted from G. W. Tyrrell, The Geology of Arran, *Mem. Geol. Surv.,* 1928, pp. 155–156. *Anal.* B. E. Dixon.

The texture of the rocks to which it has given rise varies from glassy to coarsely granophyric, while the rocks themselves are rhyolites, dacites, felsites, and coarse and fine granophyres, in which the dominant minerals are alkali-felspar and quartz. Augite is the most usual ferromagnesian constituent. Hornblende and biotite are exceptions and where present are demonstrably products of interaction between the acid magma and basic xenolithic or xenocrystal matter.

It is interesting to note that the Grigadale granophyre compares somewhat closely as regards composition with the Carrock Fell granophyre of presumed Tertiary age.

(Table 4) Porphyritic Central Magma-Type (see (Figure 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
Al_2O_3	22.80	21.11	19.46	20.38	20.10	15.06	18.82	15.98
Fe_2O_3	2.21	3.52	2.31	1.78	197	5–29	5.58	4.91
FeO	5.41	391	6.28	6.70	6.62	5.00	4.85	6.31
MgO	7.76	8.06	7.50	7.93	5.49	4.44	4.15	4.43
CaO	10.93	13.42	11.32	11.80	13.16	9.69	10.40	10.86
Na_2O	172	1.52	2.46	1.75	1.66	2.62	3.04	3.60
K_2O	0.29	0.29	0.24	0.4	0.98	070	0.56	0.70
H_2O > 105°	0.90	0.53	0.50	076	0.44	1.29	1.35	0.53
H_2O < 105°	0.11	0.13	0.18	0.09	0.02	2.65		0.46
TiO_2	0.38	0.28	0.43	0.23	0.95	2.38	1.34	1.76
$P2O_5$	0.06	trace	0.62	0.02	0.04	0.29	trace	0.08
MnO	0.31	0.15	0.17	0.28	0.32	0.19	0.28	0.18
CO_2	0.10	—	trace	0.03	0.11	0.44	—	0.21
FeS_2	0.00	—	0.16	0.04	0.00	0.00	0.00	0.05
Fe_7S_8	0.00	—	trace	0–00	—	—	—	—
SO_3	—	—	trace	—	—	0.40	0.00	trace
Cr_2O_3	—	—	0.05	—	—	0.02	0.00	0.04
(Co,Ni)O	0.00	—	–	0.00	0.00	0.00	—	—
BaO	0.00	—	–	0.00	0.10	trace	0.03	0.04
Li_2O	0.00	—	trace	0.00	0.00	trace	–	trace
C	—	—	—	—	—	—	traces	—
Organic matter	—	—	—	—	—	trace	—	—
	100.24	100.20	99.83	100.21	100.30	100.06	100.18	100.26

I. (S21250) [NM 4766 6739]; 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. (S8194) [NG 449 242]; 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 (S22821) [NM 450 638]; Lab. No. 790.) Hypersthene-gabbro. Ring-dyke, Centre 2, Ardnamurchan. In side of hollow 0.25 mile W. 33° S. of Trigonometrical Station at 1123 ft., Beinn na Seilg, and 1000 yds. E. 27° N. of Trigonometrical Station at 742 ft., Beinn nan Codhan. Anal. B. E. Dixon.

III. (S21251) [NM 4754 6665]; Lab. No. 736.) Gabbro-variant of Great Eucrite Ring-dyke, Centre 3, Ardnamurchan. W. side of Creag an Airgid, if miles S. 40° E. of Achnaha. Anal. E. G. Radley.

B. (S14846) [NM 5959 3684]; Lab. No. 373.) Olivine-gabbro. Major Intrusion, Beinn na Duatharach. 5/8th mile N.N.W. of summit of Beinn na Duatharach, Mull. Quoted from 'The Tertiary and Post-Tertiary Geology of Mull, etc.', Mem. Geol. Surv., 1924, p. 24. Anal. E. G. Radley.

IV. (S21254) [NM 540 626]; Lab. No. 738.) Porphyritic Dolerite. Major Intrusion in vent, Centre 1, Ardnamurchan. In stream bank 700 yards S. 19˚ E. of Trigonometrical Station at 1729 ft., Ben Hiant, and 0.5 mile W. 24° N. of Bourblaige.

Anal. B. E. Dixon.

V. Porphyritic Dolerite. Major Intrusion (same as preceding). E. slope of Ben Hiant. Anal. Harcourt Phillips.<ref>Supplied by Dr. A. Harker.</ref>

(S22827) [NM 4825 6514]; Lab. No. 791.) Quartz-gabbro. Ring-dyke, Centre 3, Ardnamurchan. In gorge of Amhainn Chrò Bheinn, 700 yds. E. 30° N. of where Kilchoan–Achnaha road crosses the stream. Anal. B. E. Dixon.

The Porphyritic Central Magma-Type

This magma-type in Mull<ref>H. H. Thomas and E. B. Bailey in Tertiary Mull Memoir, 1924, p. 23.</ref> was mainly responsible for a large series of porphyritic lavas and minor intrusions, but found expression in relatively few major intrusive masses. In Ardnamurchan, however, the reverse is the case. This magma is there dominant and is responsible for all the gabbros of Centres r and 2 and for much of the great eucritic mass that is the most important intrusion of Centre 3 (*see also* p. 92). Minor intrusions and lavas belonging to this type are, however, poorly represented, the most noteworthy being the porphyritic basic cone-sheets of Centres 2 and 3.

In Mull this magma-type was associated with the Nonporphyritic Central Magma-Type on two important occasions, first as lavas and secondly as cone-sheets. Earlier lavas and earlier cone-sheets were of plateau basalt composition. It is worth noting that in Ardnamurchan the Porphyritic Central Magma-Type followed closely upon the plateau lavas, manifesting itself as one of the earliest intrusive bodies (Ben Hiant Porphyritic Basalt).

The special characteristic of this magma-type is an early separation of basic plagioclase felspar, which gives to the finer-textured rocks a marked porphyritic structure. This feature may be masked to some extent in the plutonic rocks of gabbroid texture but is always pronounced in their finer grained and presumably more quickly cooled marginal portions.

The essential minerals of the type are basic plagioclase felspar, augite and subordinate iron-ore, while olivine and rhombic pyroxene are occasionally important. As pointed out in the Tertiary Memoir on Mull, when compared with what we have called the Normal Mull Magma-Series, the outstanding feature is the relatively high percentages of Al_2O_3 and CaO in rocks of similar silica-content, which is the natural consequence of the early separation and concentration of basic plagioclase.

The suite of analyses carried out on Ardnamurchan rock-types has enabled us to demonstrate that in this magma-type the values for CaO and Al_2O_3, and the concentration of the anorthite molecule, continue to increase with a falling silica percentage. Thus, its most basic representative, as argued by Bowen,<ref>N. L. Bowen, The Problem of the Anorthosites, *Journ. Geol., vol.* xxv., 1917, p. 209; *also* The Origin of Ultrabasic and related Rocks, *Amer. Jour., Science, vol. xiv.,* 1927, p. 89.</ref> will presumably have an anorthositic composition. Such a view is supported by the occurrence of anorthositic bands and patches in the Great Eucrite of Centre 3 (pp 295–6).

Corresponding to the obviously related rise in the percentages of CaO and Al_2O_3 is a fall in all the other oxidic constituents but more particularly of MgO and FeO. It will thus be seen that the extreme basic representatives of this magma-type differ markedly from those of other collateral magmas in seldom exhibiting a concentration of either iron-ore or ferromagnesian silicates.

With the increase of SiO_2 towards a percentage of 50 the magma takes on a special type of crystallization, which results in the separation of early-formed plagioclase felspar, augite and iron-ore, and subordinate olivine, from a liquid residuum that is supersaturated as regards silica. With such a composition the magma, at a certain stage of its crystallization, is clearly capable of yielding by mechanical separation a partial magma of acid character, which will approximate closely to the acid end-members of other magma-series. Further, at or about this silica percentage the porphyritic type will of necessity lose much of its individuality, and such would possibly account for its apparently limited extension in the acid direction.

(Table 5) Tonalite and quartz-monzonite magma-series (see (Figure 8)).

	GABBRO.	TONALITE-QUARTZ-MONZONITE.				GRANITE.			
	I	II	A	B	III	C	D	E	F
SiO_2	44.50	51.59	54.00	54.20	59.16	68.15	70.48	73.09	75.65
Al_2O_3	13.00	16.76	13.09	15.73	16.50	15.95	14.24	14.15	11.89
Fe_2O_3	8.25	2.26	3.53	3.67	3.23	0.74	3.72	10.70	1.19
FeO	9.97	7.49	8.45	5.40	3.66	3.24		1.03	1.02
MgO	6.31	3.85	3.49	3.40	2.70	0.04	0.40	0.47	0.15
CaO	11.10	7.41	5.55	8.50	4.40	1.88	1.48	1.04	0.91
Na_{20}	1.88	3.04	3.27	3.07	3.66	3.40	3.66	3.76	3.44
K_{20}	0.25	1.95	1.80	4.42	3.72	5.00	4.26	4.21	4.26
H_2O> 105°	0.83	1.36	1.71	0.50	0.83	0.22	1.59	1 070	0.40
H_2O < 105°	0.29	0.30	1.26		0.44	0.65		0.60	0.41
TiO_2	2.99	2.15	2.83	0.40	1.21	0.20	—	0.22	0.28
P_2O_5	0.06	0.66	0.31	0.50	0.28	0.12	—	0.09	0.16
MnO	0.49	0.40	0.37	0.70	0.27	trace	—	0.00	0.26
CO_2	0.14	079	0.25	—	0.08	0.00	—	0.00	0.09
FeS_2	0.00	0.00	0.14	—	0.00	—	—	—	0.00
Fe_7S_8	0.00	0.00	—	—	0.00	—	—	—	—
(Co,Ni)O	000	0.00	0.00	—	0.00	—	—	—	0.02
BaO	0.00	0.00	0.02	—	0.00	—	—	—	0.03
Li_2O	0.00	0.00	trace	—	0.00	—	—	—	0.00
	100.06	100.01	100.07	100.49	100.14	99.59	99.83	100.06	100.16

I. (S21249) [NM 4744 6781]; Lab. No. 734.) Fluxion Biotite-gabbro. Glendrian Ring-dyke, Centre 3, Ardnamurchan. Ridge 0.75 mile E. 17° S. of Achnaha, Anal. E. G. Radley.

II. (S21248) [NM 4735 6873]; Lab. No. 733.) Tonalite. Ring-dyke, Centre 3, Ardnamurchan. Knoll at edge of moss 3/8th mile W. 33° S. of Glendrian. Anal. E. G. Radley

A. (S24459) [NS 019 252] Lab. No. 828.) Quartz-dolerite. Garbad sill, Arran. Gorge in Allt Dhepin, mile E.N.E. of Trigonometrical Station at 873 ft. O.D., Cnoc an Fheidh, Whiting Bay. Quoted from G. W. Tyrrell, The Geology of Arran,' Mem. Geol. Sum, 1928, pp. 147–148. Anal. E. G. Radley.

B. Monzonite. Monzoni, Tyrol. Quoted from W. C. Brögger, Die Eruptivgesteine des Kristiamagebietes. H. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Sjüdtyrol. Kristiania, 1895, p. 24. Anal. V. Schmelck.

III. (S21247) [NM 4699 6843]; Lab. No. 732.) Quartz-monzonite. Boss, Centre 3, Ardnamurchan. Small summit in low ground 0.5 mile E. of Achnaha. Anal. E. G. Radley.

C. Homblende-granite. Granite 1, Mourne Mountains. Eagle Rock, N.N.W. of Slieve Donard. Quoted from J. E. Richey, Quart. Journ. Geol. Soc., vol. lxxxiii., 1928, p. 660. Anal. W. H. Herdsman.

D. Biotite-granite. Base of Slieve na Glogh, Carlingford. Quoted from S. Haughton, Proc. Geol. Soc. London, vol. xii., 1856, p. 194.

E. Biotite-granite. Granite 4, Mourne Mountains. Spur east of Finlieve, about 5 miles E. by N. of Rostrevor. Quoted from J. E. Richey, op. cit. Anal. W. H. Herdsman.

F. (S24454) [NR 931 336]; Lab. No. 824.) Granophyric granite. Central Ring Complex, Arran. Quarry in Allt nan Dris, 1000 ft. north of Derenenach. Quoted from G. W. Tyrrell, op. cit., pp. 192–193. Anal. E. G. Radley.

The Ardnamurchan Tonalite and Quartz-Monzonite Magma-Series

Certain plutonic intrusions that occur as inner members of the Ring-dyke Complex of Centre 3 exhibit mineralogical characters that distinguish them from all the other plutonic rocks of Ardnamurchan. Their chief peculiarity is the development of hornblende, biotite and pyroxene, with plagioclase, alkali-felspar and quartz, a mineral assemblage that gives rise to biotite-gabbro and rocks of tonalitic and monzonitic affinities. These rocks we regard as having been produced from a special magma-type that we have designated Tonalite and Quartz-monzonite<ref>The names applied to the various magma-types, and as used here and in the Tertiary Mull Memoir, always carry an implicit geographical significance. When we speak, for instance, of the Tonalite and Quartz-monzonite Magma-Series, such appellation is intended to refer merely to the Ardnamurchan, or at any rate to the British, Tertiary suite.</ref> The biotite- and hornblende-granites of Carlingford and the Mourne Mountains may be representative of its acid development.

Compared with other magma-series the Tonalite and quartz-monzonite Series shows a marked difference in the relative concentrations of the oxidic constituents, more especially of Al_2O_3, Iron, and the Alkalis. It has a wide silica range but, as might be expected, exhibits the most definite characteristics in its basic development.

Compared with the Normal Magma-Series (Figure 6) the Al_2O_3 is higher over most of its range, though never reaching the altitudes attained by this constituent in the Porphyritic Central Type, and falls rapidly towards the basic end of the series. The Total Iron although mainly comparable to that held by the more acid members of the Normal Series becomes strongly concentrated towards the basic end, a concentration that is shared by MgO and TiO_2. The Alkalis exhibit a tendency, as is in accord with monzonitic and tonalitic rocks in general, to show a continued preponderance of K_2O over Na_2O from the acid well towards the basic end. Thus, whereas the ratio Na_2O: K_2O=1 is reached in the Normal Series at a silica percentage of 68, the same ratio is attained in the case of the magma-type under discussion at a silica percentage of about 58.

At the basic end of the series the high content of Iron and TiO_2, considered in connexion with falling CaO and Al_{203}, points to the concentration of magnetite, ilmenite, and non-aluminous ferromagnesian minerals rich in the enstatite and fayalite molecules. Such curves as are based upon the analyses of Ardnamurchan and other Tertiary rocks point to the extreme basic end of this series being represented by rock-types comparable with ilmenite-gabbros or ilmenite-norites,<ref>A. Harker, Natural History of Igneous Rocks, 1909, p. 142 Ekersund Soggendal).</ref>towards which the percentages of TiO_2, MgO and Iron continue to rise while those of Al_2O_3, CaO and the Alkalis continue to fall (Figure 8). Such a magma-series with such variation may be claimed to account for a not inconsiderable proportion of the major plutonic phases of the Tertiary magma.

A similar magma-series, subject to similar variation, it will be remembered, is responsible for the bulk of the plutonic intrusions of Lower Old Red Sandstone age in Scotland.<ref>A. Harker, Natural History of Igneous Rocks, 1909. pp. 127–131.</ref>

The Eucrite–Allivalite Magma-Series

This series in Mull, Skye, and especially Rum was responsible for important plutonic intrusions. In Ardnamurchan it is represented by parts of the. Great Eucrite, Outer Eucrite, and the less important Inner Eucrite of Centre 3, and by the Beinn nan Ord Eucrite of Centre 2.

The variation in composition exhibited by some of the larger gabbroid intrusions, such as the Great Eucrite of Centre 3 and the Hypersthene-gabbro of Centre 2, makes it quite clear that the Eucrite–Allivalite and Porphyritic Central Magma -Types are closely related. For example, it is usual for the normal facies of the Great Eucrite to be associated with, or pass into, rocks much richer in olivine and anorthite on the one hand, and, on the other, into less basic types that carry augite as the dominant ferromagnesian mineral and a less basic plagioclase. It would appear, therefore, that a gabbro-magma of Porphyritic Central Type is capable of giving rise to two sets of basic differentiates, one set passing through eucrite to allivalite, and the other having anorthosite as its end-member. Such a divergence would be effected chiefly by the impoverishment or enrichment of the magma by early-formed olivine and basic plagioclase felspar.

The two divergent branches are respectively characterized by a concentration of CaO and Al_2O_3 in the case of the anorthosites, and of MgO in the case of the more peridotitic and allivalitic types.

The Alkaline Magma-Series

The Alkaline Magma-Series of Mull, which there was responsible for mugearites, alkali-syenite, trachytes, and bostonites, is only represented in Ardnamurchan by a certain early development of trachytic rocks (pp. 133, 137) that occur in the vent-agglomerates of Centre 1, and by a few occasional dykes of bostonitic composition (p. 355). The outstanding feature of this magma-type is the relatively great concentration of the Alkalis, which is responsible for an abundance of alkali-felspar and, in extreme cases not developed in Ardnamurchan, for the presence of soda-rich amphiboles and pyroxenes, and the occurrence of nepheline. The view that this magma is descended from the plateau magma is supported by the already-mentioned alkaline segregations encountered in certain of the plateau basalts, and will be discussed more fully in the following remarks on the probable cause of differentiation (p. 100).

The magma-sequence and course of differentiation

The magma-sequence of Ardnamurchan subsequent to the extrusion of the plateau lavas presents many points in common with that observed in Mull, and a similar course of magmatic differentiation is indicated. The sequence for Ardnamurchan, exclusive of dykes, is set out below in tabular form:-

Centre	Intrusion-Type	Rock-Type	Magma-Type Or -Series
Centre 1	Volcanic vents	Trachytic and more acid types	Alkaline and Normal Acid Types
Centre 1	Volcanic vents	Inninmorite-Pitch-stone	Normal Sub-acid and Porphyritic Central Types
Centre 1	Volcanic vents	Big-felspar Basalt	Normal Sub-acid and Porphyritic Central Types
Centre 1	Major Intrusions partly as Ring- dykes	Olivine-gabbro	Non-Porphyritic and Porphyritic Central with subordinate Normal Acid Types,
Centre 1	Major Intrusions partly as Ring- dykes	Ouartz-gabbro	Non-Porphyritic and Porphyritic Central with subordinate Normal Acid Types,
Centre 1	Major Intrusions partly as Ring- dykes	Porphyntic Dolerite	Non-Porphyritic and Porphyritic Central with subordinate Normal Acid Types,
Centre 1	Major Intrusions partly as Ring- dykes	Subsidiary Granophyre	Non-Porphyritic and Porphyritic Central with subordinate Normal Acid Types,
Centre 1	Cone-sheets and Ben Hiant Intrusion	Quartz-dolerite with quite subsidiary acid rocks	Non-porphyritic Central and Normal Acid Types
Centre 2	Cone sheets	Non-porphyritic Quartz-dolerite with quite subsidiary acid types	Non-porphyritic Central and Porphyritic Types
Centre 2	Cone sheets	Porphyritic quartz-dolerite at end of phase	Non-porphyritic Central and Porphyritic Types
Centre 2	Ring-dykes	Hypersthene-gabbro	Porphyritic Central with subordinate Normal Acid Types

Centre 2	Ring-dykes	Quartz-gabbro	Porphyritic Central with subordinate Normal Acid Types
Centre 2	Ring-dykes	Subsidiary Granophyre	Porphyritic Central with subordinate Normal Acid Types
Centre 2	Cone-sheets	Porphyritic Quartz dolerite and Basalt	Porphyritic Central Types
Centre 2	Ring dykes	Eucrite	Porphyritic Central Type
Centre 3	Ring dykes	Quartz-gabbro	Mainly Porphyritic Central Type
Centre 3	Cone-sheets	Porphyritic Quartz dolerite and Basalt	Mainly Porphyritic Central Type
Centre 3	Ring-dykes	Eucrite	Mainly Porphyritic Central Type
Centre 3	Ring-dykes of Interior Complex	Quartz-biotite-gabbro	Tonalite and Quartz-monzonite Series
Centre 3	Ring-dykes of Interior Complex	Fluxion Biotite-gabbro	Tonalite and Quartz-monzonite Series
Centre 3	Ring-dykes of Interior Complex	Tonalite	Tonalite and Quartz-monzonite Series
Centre 3	Ring-dykes of Interior Complex	Quartz-monzonite	Tonalite and Quartz-monzonite Series

It will be seen from the above that there has been a recurrence and repetition of magmatic types at various periods in the igneous history of Ardnamurchan and that there is evidence of three cycles of igneous intrusion. At the outset we have the clearest indication of the uprise of centrally disposed magma to within a relatively short distance from the surface, where the magmatic pressure, was sufficient to break through the remaining crust with the formation of vents and vent-agglomerates. That the magma responsible was in an advanced state of differentiation is proved by the nature of the material entering into the composition of the agglomerates and by the composition of the lavas and intrusions associated with the vents. There is reason for assuming that the magma occupied a cupola-like upward extension of the main basaltic magma-reservoir, situated in a cool portion of the crust, in which differentiation by crystallization was progressing. There is, further, indication that the main body of the magma filling this subsidiary reservoir had been reduced to complementary layers corresponding to the Nonporphyritic and Porphyritic Central Types of composition. An acid differentiate, probably of subordinate amount and charged with volatile constituents, occupied the upper part of the cupola. During the vent-period the more basic differentiated magmas found means of expressing themselves as the Pitchstone lavas and Big-felspar Basalt of Ben Hiant.

The dissipation of excessive magmatic pressure responsible for the vents of Centre 1 was presumably followed by a period of crustal subsidence that allowed the Central Type of magma to be intruded as ring-dykes, and other centrally disposed masses, from lower regions of the subsidiary magma-reservoir.

There is little doubt that the bulk of the magma available towards the end of the period represented by Centre 1 was of nonporphyritic quartz-dolente composition, and this was responsible for the early massive cone-sheets and the big intrusion of Ben Hiant. Magmatic pressure at this stage within the reservoir had increased considerably and there was an effort on the part of the magma to raise its roof. This effort was in part successful, for we notice definite doming of the country rock and the intrusion of a second series of cone-sheets referable to Centre 2, which are indications of the yielding of the crust to upward pressures.

It is during such a period of upward stress that the adjustment of crustal stability to magmatic pressure is most critical, and during which the locus of the summit of the intercrustal reservoir is most likely to shift its position. We thus find the locus moving in a west-south-westerly direction for a distance of no less than three miles, and taking up its position at Centre 2. From the calculated depth of the cone-sheet foci in the respective centres it would appear that the summit of the cupola marked by Centre 2 stood at a slightly lower intercrustal level than that previously reached in Centre 1.

The igneous activity connected with Centre.2 divides itself into two cycles both commencing with the intrusion of a suite of cone-sheets, and followed by ring-dyke intrusions of Central Magma-Types (Gabbros and Eucrite). The effect of differentiation is obvious also in the cone-sheets themselves, for starting as quartz-dolerites of the Normal Magma-Series they gradually develop in their later representatives characters that link them with the Porphyritic Central Types.

The last intrusive cycle is heralded by another, but smaller, displacement of activity to Centre 3, and the available magma appears to be of Porphyritic Central Type accompanied by an acid differentiate that by admixture and reaction in the later stages of intrusion was responsible for the tonalite and quartz-monzonite masses that occupy the centre of the complex.

The main difficulties that have to be overcome in presenting any scheme of differentiation applicable to a petrographical province are twofold. First, the recognition of a parent magma and the production of the magmatic variation necessary for the formation of the observed rock-types, and secondly of explaining the observed order of extrusion or intrusion of the respective igneous masses. If we allow, as I think we must from the evidence of crystallized melts, that magmatic variation is primarily brought about by fractional crystallization and the removal or concentration of certain less soluble constituents, we are frequently confronted by opposing evidence offered by the order of magmatic expression. It has been proved that the two great magmatic cycles recognized in Mull commenced with a manifestation of the Plateau Magma-Type, which gave place to increasingly acid types as the presumed differentiation progressed; and the same order of decreasing basicity appears to be generally applicable to every other Tertiary centre where complete cycles are represented. Let us first turn our attention to a consideration of the development of the various magma-series and the rock-types for which they are responsible.

The Normal Magma-Series

In the Brito-Icelandic province the great bulk of rocks attributable to the Plateau Magma, its early and widespread manifestation and its reappearance at repeated intervals, cause us to regard it as the most probable common ancestor of the other magma-types and collateral magma-series. There can be no question that the Plateau Magma was responsible for the earliest and greatest expression of Tertiary igneous activity and that it continued to appear, and is even still appearing, within the limits of the province.

The course of variation of the main magma-series of Ardnamurchan is expressed graphically by the three figures given above, and these may be supplemented by those given in the Tertiary Mull Memoir to illustrate respectively the alkaline and eucrite-allivalite magma-types.

From an examination of rapidly cooled rocks with porphyritic or phenocrystal structure, the order of solubility of different minerals as proved by heterogeneous holocrystalline masses, and the evidence supplied by crystallized artificial melts, we have been able to equip ourselves with much information that has a direct bearing upon the question of magmatic variation. Such information as is furnished by those rocks with low silica percentages from the Tertiary province may be summarized. by the statement that olivine, iron-ores, and basic plagioclases are often the least soluble magmatic constituents, and that with falling temperature they begin to crystallize at a very early stage. We have therefore in this fact alone, provided the early crystalline phases can be mechanically transferred from one part of the magma to another, ample means of accounting for at any rate the preliminary stages of magmatic variation.

Viewed in this light and assuming that the Plateau Magma is the parent stock, the Normal Mull Magma-Series presents no great difficulties. It is obvious that if we initially abstract iron-ores, olivine, and basic plagioclase, and follow this by the abstraction of other crystalline phases such as augite and less basic plagioclase, we can produce just such a progressive variation in magmatic composition as is represented by the sequence of increasingly siliceous magma-types. The partial extraction of such crystalline phases from a magma of plateau type, on account of the silica being generally more than is necessary for the formation of the basic ferromagnesian silicates and basic plagioclase, produces a rapid relative, concentration of silica and alkalis; and a composition would soon be reached which would find expression as quartz-doleritic rocks with an acid mesostasis capable of mechanical separation and a separate existence as acid lavas or intrusions.

Since the publication of the memoir on Mull many references have been made to the evidence that this region has been able to contribute to the general problems of petrogenesis. Quite recently, in fact after much of the present Memoir had been written, a most valuable contribution has been made to petrographical literature by Dr. N. L. Bowen<ref>N. L. Bowen, The Evolution of the Igneous Rocks, Princeton and Oxford, 1928.</ref> of the Geophysical Laboratory in Washington, in a volume entitled 'The Evolution of the Igneous Rocks'. Making full use of experimental data and coupling these with a careful study of natural occurrences of igneous rocks, he has given us well-reasoned theories of magmatic descent and petrogenesis. His references to Mull and the British Tertiary Province as a whole are numerous, and he has considered in detail the origin and mutual relationships of the Mull magma-types. In dealing with the crystallization of a basaltic magma he, like ourselves, lays great stress upon the importance of the early separation of plagioclase and pyroxene, and at a still earlier stage of olivine, as petrogenetic factors<ref>H. H. Thomas, Pres. Address, Sec. C., *Bop. Brit. Assoc.* (Leeds), 1927, p. 56.</ref> In the early separation of olivine and its removal from the sphere of influence of the magma in which it was formed and with which it would continuously react, he sees a magmatic source of free silica. When critically discussing the development of the Non-porphyritic Central Magma-Type from the Plateau Type he has perhaps taken too seriously the suggestion made in the Mull Memoir that such may have been brought about in part by assimilation. He has, however, shown by calculation that the Non-porphyritic Central Magma-Type would arise from the Plateau Type on the separation from it of crystals of olivine and basic plagioclase, and that there is no need for the assimilation of extraneous material.

Hesums up the situation by saying that the determining factor is the continuance of crystallization of olivine until the composition of the liquid is such that it can only be expressed as metasilicate with free quartz. Further, he agrees with us in regarding the procession of magma-types from the Non-porphyritic Central Type, through the Intermediate Types, to the Acid Types of the Normal Magma-Series, as being the direct result of fractional crystallization, mainly connected with the simultaneous crystallization of augite and basic plagioclase.

The Porphyritic Central Magma-Type

The Porphyritic Central Type of magma is directly deducible from the Plateau Type. It is clear both on microscopic and chemical evidence that the concentration of early-formed crystals of basic plagioclase felspar is the determining factor of the type. It will be readily understood that as the Plateau Magma has a silica percentage of approximately 45, and theoretically pure anorthite 43.2, a large amount of anorthite could be concentrated in the magma without seriously affecting its silica content. It is, however, almost unknown for the porphyritic felspar to have the composition of pure anorthite, for it always contains small but varying amounts of the albite-molecule. The addition of such a basic member of the plagioclases will therefore either leave unchanged the magmatic silica percentage or effect a slight concentration of silica together with that of soda. A still further concentration of silica and alkalis would be the normal result of the removal from the magma, either before or after its enrichment in anorthite, of any of the less siliceous ferromagnesian minerals and iron-ores.

Compared with the original Plateau Magma this enriched magma would show a great concentration of CaO and Al_2O_3, a less obvious but still definite concentration of Na_2O, and, through dilution, a fall in the percentages of MgO, Total Iron, and TiO_2. In order to produce this concentration of CaO and Al_2O_3 and the related falling off of other constituents, the original magma would have to be enriched by some 30–40 per cent. of basic plagioclase.

We have seen that the probable course of variation in the Normal Magma-Series was outlined mainly by the withdrawal of olivine and basic plagioclase. Such crystalline phases could only be removed to greater depths in the magma by the gravitational process of sinking, giving rise to an enriched magma of Porphyritic Central composition. It must be understood that the precipitation of olivines and basic plagioclase need not have been simultaneous throughout the whole early period of magmatic crystallization, nor may these minerals have been separated or resorbed in like proportion, but it will be quite evident that the establishment of a Porphyritic Central Type is the logical sequel to the variation of the Plateau Type towards the other types of the Normal Series.

Such an enriched magma as has been developed, if erupted, would give rise to a quickly cooled rock that would represent the undifferentiated Porphyritic Central Magma, and of such rocks we have many examples in the Porphyritic Central lavas of Mull. These have an average silica percentage of about 47.5, and the composition as indicated for this silica value in (Figure 7) may be taken as being that of the initial magma of Porphyritic Central Type.

If such a magma were intruded into a separate reservoir situated within the temperature limits that permit of crystallization it would differentiate in two directions, towards a basic end by the concentration, and towards an acid end by the withdrawal, of its more basic constituents. Differentiation in the basic direction would, quite reasonably, take place along two lines, both dependent upon the separation of olivine, basic plagioclase, and iron-ore. The accumulation of all these solid phases would give rise to an increasingly basic series that would proceed by way of the eucrites to the allivalites and other peridotitic rocks, while the concentration of felspar, with the withdrawal to depth of olivine and iron-ores, would give rise to a subordinate magmatic branch, responsible, in its most extreme development, for the anorthosites.

Such a type of differentiation is rendered most probable, if not proved, by the constant occurrence of allivalitic, eucritic, and anorthositic patches and veins in the body of gabbro-intrusions of Porphyritic Central Type. That the early differentiates have sometimes solidified is suggested by their occasional occurrence as xenolithic masses and schlieren, but quite frequently the types grade into each other in a manner suggestive of the incomplete admixture of liquid, or partially liquid, magmas. In the acid direction the rapid extraction of basic plagioclase and the basic iron-magnesian silicates allows the crystallization of augite and also soon supersaturates the residual magma as regards silica. This, together with the consequent concentration of alkalis, gives rise to rocks of non-porphyritic quartz-dolerite composition with a mesostasis of alkali-felspar and quartz. The acid mesostasis, the last product of the more acid differentiates to solidify, may under normal conditions be retained in the rock to which it belongs; it may, however, if under stress, migrate and penetrate as veins the already solid rocks in its neighbourhood. Such a process of segregation and migration of acid residual matter is a feature constantly to be observed in connexion with the major intrusions of Porphyritic<ref>N. L. Bowen, The Evolution of the Igneous Rocks, Princeton and Oxford, 1928, p. 134, *et seq.* Dr. Bowen does not altogether exclude the possibility of re-solution of early crystals but considers that he has found limits to its significance: 'Solution of calcic plagioclase never occurs beyond an amount sufficient to endow the liquid with normative plagioclase more calcic than Ab_1An_2' (*op. cit.,* p. 276). This happens to be the normative composition of felspar in two out of the three analyses of lavas of Porphyritic Central Magma-Type published in the Tertiary Mull Memoir (III and V of (Table 6), p. 24)</ref> has carefully considered the position of the Porphyritic Central Magma-Type in the scheme of magmatic differentiation, and regards the essential characters of the type as being directly attributable to the process of crystal-sorting, that is to say, to the concentration by mechanical means of one or more early formed solid phases. He will not allow, however, that the various rock-types embraced by the Porphyritic Central Magma-Type are lineally related, for he holds that there were no liquids corresponding in composition to the Magma-Type. His reason for this view is primarily that representatives of the Type are always porphyritic even in their finer crystallizations. Perhaps the statement in the Tertiary Mull Memoir, that a porphyritic structure is 'always' to be observed in the more quickly cooled rocks of the Porphyritic Central Type, is a little too general. At any rate, the proportion of porphyritic individuals is by no means constant and there is frequently a marked increase in the number and size of the crystals as the interior of a mass is approached. On Dr. Bowen's own showing there is nothing inherently impossible in the re-solution of accumulated early formed plagioclase, and that this condition was approximated to, even if not completely attained, is suggested by the great textural differences exhibited by marginal and internal portions of the same rock-mass, and existing between plutonic and hypabyssal representatives of the Porphyritic Central Type.

Therefore, while admitting the possibility of the Porphyritic Central Magma never having been quite free from solid phases, there appears to be evidence that these, in certain cases, have been reduced to mere nuclei, and that the liquid, in which they later became regrown without serious modification of their composition, was capable of yielding its own suite of differentiates. Towards the basic end these differentiates would be distinct from those of the Normal Magma-Series, but in the other direction the respective descendants of the two magmas would be similar.

It is, however, evident that in many noteworthy cases, such as the fluxion gabbros, representatives of the Porphyritic Central Type were intruded in a partly solid condition, and also that a partly solid magma of this type was necessary for the production of certain plutonic masses of abnormal composition (*e.g.* Tonalite and Quartz-monzonite Series).

The Tonalite and Quartz-Monzonite Magma Series

When we come to consider the Tonalite and Quartz-monzonite Series as represented in Ardnamurchan we find a certain amount of evidence that militates against its being a normal collateral series produced by the ordinary direct processes of differentiation. A comparison of the variation diagrams set out above shows clearly that the series under discussion is related to the Porphyritic Central Series in its relatively high alumina. At the acid end of the series, however, the compositional characters are similar in a general way to those of the Normal Series. The curves for Total Iron, CaO and MgO are approximately parallel to those for the same constituents in the Normal Series. At its basic end there is a superficial resemblance to the basic end of the Normal Series, especially if the latter were enriched in iron oxides, TiO_2 and MgO by the addition of titaniferous iron-ores and magnesian olivine.

Certain ferromagnesian minerals characteristically appear in rocks of this series and they may either replace or be supplementary to those met with in representatives of the other magma-series; such minerals as exemplified in the Fluxion Biotite-gabbro, the Tonalite, and Quartz-monzonite, of Centre 3, are hypersthene, hornblende, and biotite, the last-named becoming increasingly abundant as the percentages of silica and potash rise. A review of these analysed rocks, and others to which they are allied, coupled with an examination of certain granophyric masses and veins that have clearly been modified by the assimilation of basic material, strongly suggests that the various members of the Tonalite and Quartz-monzonite Series are due to magmatic admixture or hybridization before intrusion.

It has been found that in the granophyre-veined Quartz-dolerite Ring-dyke of Centre 3, biotite and hornblende are developed, giving rise to tonalitic and monzonitic types as the result of assimilation of basic material. The Biotite-eucrite, which locally is a good eucrite or gabbro, where acidified, develops biotite and hornblende with the formation of more siliceous veins of tonalitic character. Certain portions of the Fluxion Biotite-gabbro of Sìthean Mòr contain much xenolithic basic matter of eucritic nature, and there is ample evidence of acidification of the xenoliths. The Fluxion Biotite-gabbro of Glendrian (analysed) shows the effects of the acidification of a basic rock in all stages. The quartz-biotite-gabbros, too, are occasionally dioritic, with much hornblende, and locally become monzonitic by modification. The same mineralogical peculiarities have been noted over and over again, throughout the whole ring-dyke complex, in the case of acid veins that have penetrated and assimilated basic material. The fact that amongst the larger gabbro masses of the Tonalitic and Quartz-monzonitic suite we have small areas of normal eucrite, olivinegabbro, and basic rocks either rich or poor in iron-ore, makes it probable that basic representatives of the Porphyritic Central Magma-Type were involved in the production of these rocks.

The general presence of hornblende and biotite in representatives of this series, and the preponderance of K_2O over Na_2O above a silica percentage of 58, point to the influence of an acid differentiate or end-member of a series, in which there had been a considerable concentration of volatile constituents and a somewhat high concentration of potash.<ref>See N. L. Bowen, The Later Stages of the Evolution of the Igneous Rocks, Journ. Geol., vol. xxiii., Supplement, 1915, p. 41; J. H. L. Vogt, The Physical Chemistry of Crystallization and Magmatic Differentiation of Igneous Rocks, Journ. Geol., 9122, vol. xxx., p. 659; P. Niggli, Die gasförmigen Mineralisatoren im Magma, Geol. Rundschau, III, 1912, p. 473.</ref>

Although of necessity the acid end-product of the Normal Series would be the richer in volatile constituents and would thus most readily fulfil the conditions demanded, it does not appear likely that such a partial magma could be available throughout the intrusive period represented by the Porphyritic Central Types. The evidence of reaction between basic types and what must clearly be regarded as an acid differentiate of the same magma is furnished by the acid veins in most of the basic intrusions, and by certain hybrid masses such as that of Beinn an Leathaid (p. 158).

It therefore seems probable that the tonalitic and quartz-monzonitic rocks are due to the acidification of Porphyritic Central Magma-Types or, conversely, the basification of some acid magma, such magma being the end-member of the Porphyritic Central Magma-Series. It must, however, be pointed out that this conclusion is based wholly upon petrological considerations. The field evidence is summarized on p. 211.

The Alkaline Magma-Series

The origin of this magma-series lies clearly in the Plateau Magma and is the normal outcome of the latter's crystallization under special conditions. The evidence for the direct connexion of the Alkaline Series and the Plateau Magma is furnished by the alkaline segregations encountered in the lavas and sills of Plateau Magma composition and may be inferred by the frequent presence in rocks of this character of a zeolitic or analcitic base. The members of the Alkaline Series are clearly not normal lineal differentiates of the Plateau Magma, for the Normal Series, so well represented in the Tertiary Province, progresses along a much less alkaline course. The difference is probably to be found in the different conditions of crystallization, and the bulk of the magma involved, whereby a great concentration of volatile constituents and alkalis is effected<ref>See N. L. Bowen, ibid.</ref> I would suggest that the Alkaline Series owes its origin to the more or less complete crystallization of the plateau basalt magma, without the interim withdrawal of solid phases, such as is assumed to account for successive stages in the Normal Series, accompanied by a strong concentration of the volatile constituents. In fact, I regard the alkaline magma as representing the normal alkaline mesostasis of such basic rocks as are formed by the more or less rapid cooling of the undifferentiated plateau magma.

Hybrids and hybridization

In his study of the igneous rocks of Skye Dr. Harker encountered a number of rock masses, both in the plutonic complex and in the composite dykes and sills, which exhibited abnormal composition and presented an unusual mineral assemblage. He recognized that such rocks were due to what might be termed a reversal of the normal processes of differentiation and might arise either from the commingling of two fluid rock magmas or from the reaction between fluid magma and solid rock. He was able to study the veining and acidification of basic rock by acid magma, the inclusion of basic xenoliths and xenocrysts that showed every stage of dissolution, and to show that there was an accompanying basification of the acid magma. To such modified and abnormal rocks he gave the name of Hybrid, and to the processes by which their abnormality was produced, Hybridization.

In Mull a number of rocks exhibited characters that appeared to be abnormal, and certain of these were undoubtedly true hybrids produced by the intrusion and partial assimilation of basic rock by an independent acid magma. In the majority of cases, however, the abnormalities presented, while being of the same general nature as those characterizing hybrids, were produced in a partially consolidated magma by the migration of its own acid differentiate. The authors of the 'Tertiary Mull Memoir 'considered that in Mull, at any rate, there was no positive evidence of the commingling of magmas prior to their arrival at the place where they consolidated.

There can be no question that the formation of an acid differentiate is the natural outcome of the fractional crystallization of a parental basic magma such as that with which we have to deal. Further, there appears from microscopic evidence to have been a considerable time and temperature interval during which this acid partial magma remained fluid and was capable of migration under stress. It will be readily appreciated that as soon as a magma has become partially solid and a crystalline mesh has formed, uniform hydrostatic pressures no longer operate. The mass, therefore, may be subjected to localized stresses that, by causing varying contraction of the crystalline mesh, may produce unequal distribution of the residual liquid. It is a process such as this that would best account for the great variability of many of those rock-masses which have an acid mesostasis, and also in extreme cases for the separate existence of acid veins and acid minor masses.

When a magma that would yield an ultimate acid differentiate has crystallized under normal conditions, without the mechanical extraction or addition of any crystalline or liquid phase, the constituent minerals show a definite harmonious relation to each other. The felspars and other minerals that form solid solution series exhibit the effects of what Dr. Bowen terms continuous reaction, and which are the results of the composition of the crystals keeping pace, as solidification progressed, with the changing composition of the liquid phase. In such cases there is no widespread exhibition of the results of disturbed equilibria and consequent resorptive processes. Where solid phases, through the migration of an acid partial magma, have found themselves in surroundings inimical to their normal development, there has been a supreme effort to restore equilibrium between them and the liquid phase. Local evidence of this action is forthcoming in the resorption of basic plagioclase, the regrowth of felspar of increasingly alkaline composition, the deschillerization and recrystallization of augite, and in the existence of clots of definitely gabbroic matter swamped by an excess of acid mesostatic material. Mechanical effects are often noticeable in the reduction of the original basic material to a xenocrystal state, the fissuring and albitization of original felspars, the obliteration of ophitic structure, and the bending of columnar augites. Dr. Bowen has considered this condition when dealing with the effects of assimilation,<ref>N. L. Bowen, The Evolution of the Igneous Rocks, Princeton and Oxford, 1928, p. 175, *et seq*.</ref> and he brings out the important fact that the mutual changes produced in solid and magma are exothermic. Such changes therefore can be accomplished without demanding that the liquid phase shall be superheated. Such appears to have been the conditions that prevailed in most of the Ardnamurchan quartz-gabbros. In discussing these and related rocks it has been found expedient to use the term hybridization to describe in a general non-committal way the evidence of disturbed and partially restored equilibria frequently furnished by rocks of this class, and it must not be assumed, in such cases, that an independent acid magma has intervened.

Certain rocks in this Memoir have been described as hybrids with the assumption that either an independent acid magma has reacted with a basic rock, or that co-existing magmas of widely different composition have commingled prior to, or during, their intrusion. Examples of the former class are furnished by composite minor intrusions, such as that of Sran Bheag, and can be studied in relation to the acid veining of basic rocks by granophyric matter. To the latter class belong the important tonalitic and monzonitic masses of Ardnamurchan. These occurrences, which in some cases can be proved, and in others inferred, to have a hybrid nature, are linked together by the presence of biotite and hornblende among their mineral constituents. Dr. Bowen<ref>N. L. Bowen, The Evolution of the Igneous Rocks, Princeton and Oxford, 1928, pp. 79–91.</ref>regards the formation of these two minerals as the natural result of slow crystallization of basaltic magma where the conditions admit of zoning or crystal-sorting of the early calcic felspars with a consequent concentration of alkalis, especially potash, in the liquid residuum. In the Tertiary rocks of the Hebrides we can cite no basic or intermediate rocks belonging to the Normal Magma-Series or of Porphyritic Central Type that carry either biotite or hornblende as unquestionably original constituents, and thus differentiation of the Hebridean Magma appears to have followed a different course.

The fact that biotite and hornblende are very sparingly developed as the result of interaction between the normal acid mesostasis of the quartz-gabbros and their pyroxenic constituents, but are prevalent where these or similar rocks are traversed by acid veins from an external source (*e.g.* Sròn Bheag Intrusion), is of considerable significance. It furnishes evidence for regarding the dominantly biotitic and hornblendic rocks of Ardnamurchan as hybrids. H.H.T.

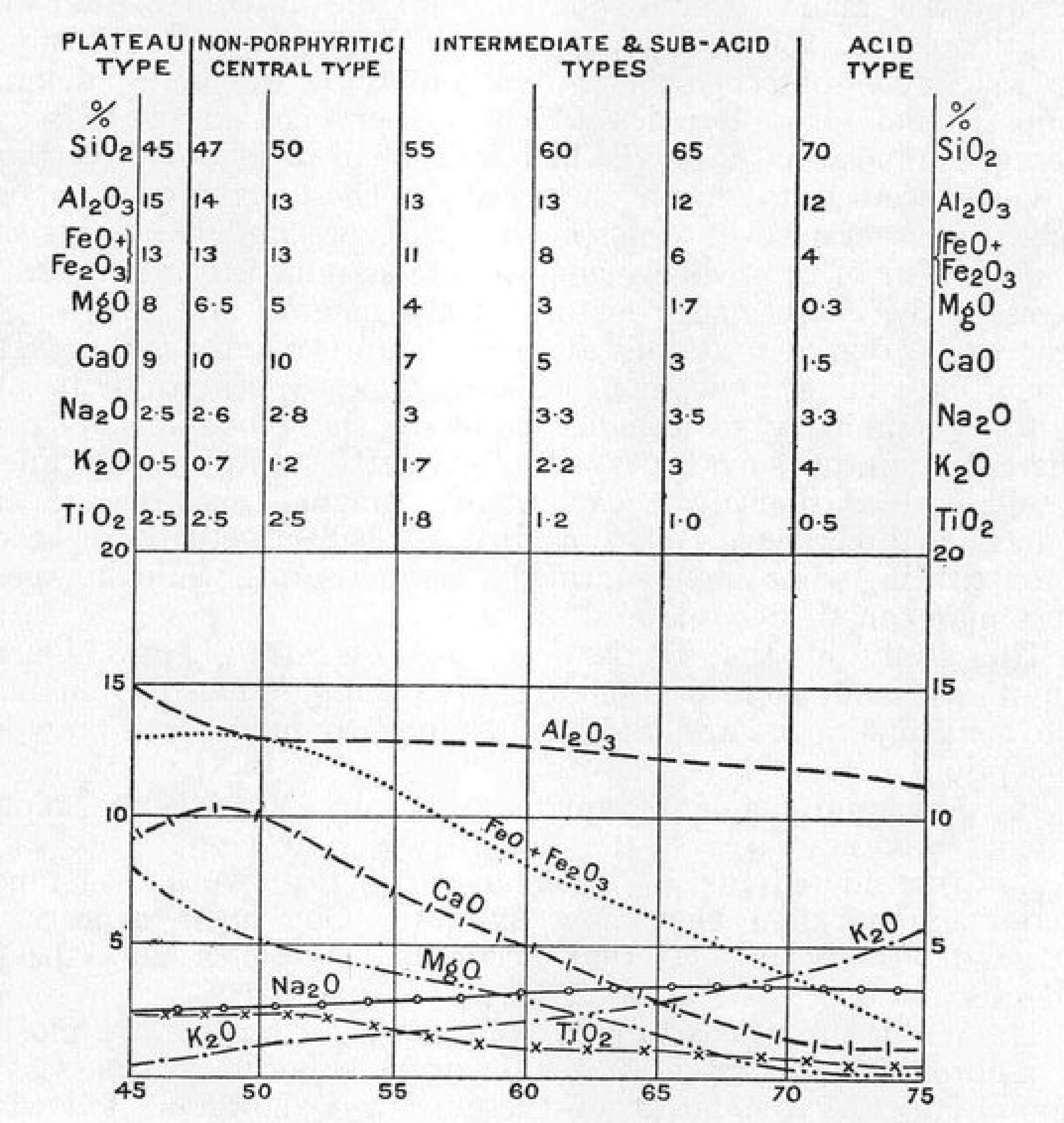

FIG. 6.—*Variation-Diagram, Normal Magma-Series.*

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

TABLE III

SUB-ACID AND ACID MAGMA-TYPES (*see* Fig. 6)

	Inninmorite.			Granite and Granophyre.			
	A.	I.	II.	III.	B.	C.	
SiO_2	64·13	64·30	66·06	68·42	71·60	74·87	SiO_2
Al_2O_3	13·15	14·18	13·14	13·54	13·60	11·24	Al_2O_3
Fe_2O_3	1·08	1·09	2·27	2·53	2·40 (with FeO)	0·34	Fe_2O_3
FeO	6·31	4·44	2·84	2·02		1·22	FeO
MgO	1·08	1·47	0·77	0·22	0·21	0·22	MgO
CaO	3·62	2·87	2·75	2·13	2·30	1·30	CaO
Na_2O	3·64	4·30	4·28	5·12	5·55	3·31	Na_2O
K_2O	2·32	2·83	1·54	4·08	3·53	5·68	K_2O
$H_2O > 105°$	2·71	3·02 (with $H_2O < 105°$)	3·38	0·15	0·70 (with $H_2O < 105°$)	0·49	$H_2O > 105°$
$H_2O < 105°$	0·36		0·74	0·25		0·29	$H_2O < 105°$
TiO_2	1·19	0·75	1·08	0·81	—	0·26	TiO_2
P_2O_5	0·31	0·17	0·09	0·38	—	0·09	P_2O_5
MnO	0·27	0·26	0·31	0·10	—	0·05	MnO
CO_2	—	0·00	0·37	0·06	—	0·49	CO_2
FeS_2	0·00	—	trace	0·05	—	0·33	FeS_2
SO_3	—	0·00	0·16	trace	—	—	SO_3
Cr_2O_3	—	0·00	trace	trace	—	0·02	Cr_2O_3
(Co, Ni)O	0·00	—	0·00	—	—	—	(Co, Ni)O
BaO	0·09	0·16	trace	0·03	—	0·04	BaO
Li_2O	0·00	—	trace	trace	—	0·00	Li_2O
F	—	—	—	—	—	0·00	F
C	—	traces	—	—	—	—	C
Organic matter	—	—	0·02	—	—	—	Organic matter
	100·26	99·84	99·80	99·89	99·89	100·24	

A. (15990; Lab. No. 387.) Fairly glassy Inninmorite or Inninmorite-Pitchstone. Sheet. $\frac{3}{16}$ mile S.W. of Trigonometrical Station on Beinn an Lochain, Mull. Quoted from E. M. Anderson and E. G. Radley, *Quart. Journ. Geol. Soc.*, vol. lxxi., 1915, p. 212. *Anal.* E. G. Radley.

I. Inninmorite-Pitchstone. Lava. E. slope of Ben Hiant, Ardnamurchan. *Anal.* Harcourt Phillips.[1]

II. (21255; Lab. No. 739.) Inninmorite-Pitchstone. Lava. In stream bank $\frac{7}{8}$ mile S. 12° E. of Trigonometrical Station at 1729 ft., Ben Hiant, and $\frac{1}{8}$ mile W. 3° S. of Bourblaige, Ardnamurchan. *Anal.* B.E. Dixon.

III. (22820; Lab. No. 789.) Augite-granophyre. Major intrusion, Centre 2, Ardnamurchan. 800 yds. S. 30° E. of Grigadale. *Anal.* B. E. Dixon.

B. Augite-granophyre. 100 yds. E. of summit, Carrock Fell, Cumberland. Quoted from A. Harker, *Quart. Journ. Geol. Soc.*, vol. li., 1895, p. 129. *Anal.* G. Barrow.

C. (24380; Lab. No. 820.) Biotite-granite. Northern granite mass, Arran. Glen Rosa, $\frac{1}{4}$ mile above confluence with Garbh Allt. Quoted from G. W. Tyrrell, 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928, pp. 155–156. *Anal.* B. E. Dixon.

[1] Supplied by Dr. A. Harker.

(Table 3) Sub-acid and Acid Magma-Types (see (Figure 6)).

TABLE II

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

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

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

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

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 (both)	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)).

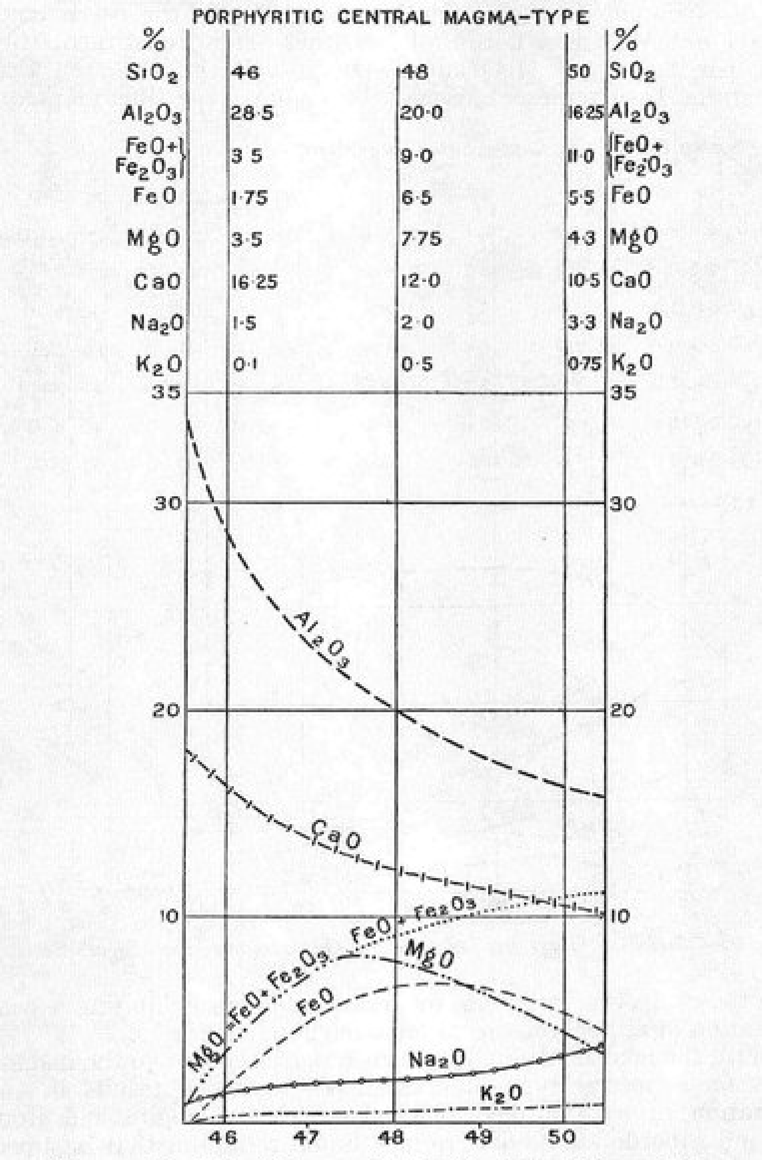

FIG. 7.—*Variation Diagram, Porphyritic Central Magma-Type.*

(Figure 7) Variation diagram, Porphyritic Central Magma-Type.

TABLE V

TONALITE AND QUARTZ-MONZONITE MAGMA-SERIES (*see* Fig. 8).

	GABBRO.	TONALITE–QUARTZ-MONZONITE.				GRANITE.			
	I.	II.	A.	B.	III.	C.	D.	E.	F.
SiO_2 ..	44·50	51·59	54·00	54·20	59·16	68·15	70·48	73·09	75·65
Al_2O_3 ..	13·00	16·76	13·09	15·73	16·50	15·95	14·24	14·15	11·89
Fe_2O_3 ..	8·25	2·26	3·53	3·67	3·23	0·74	3·72 (Fe₂O₃ + FeO)	0·70	1·19
FeO ..	9·97	7·49	8·45	5·40	3·66	3·24		1·03	1·02
MgO ..	6·31	3·85	3·49	3·40	2·70	0·04	0·40	0·47	0·15
CaO ..	11·10	7·41	5·55	8·50	4·40	1·88	1·48	1·04	0·91
Na_2O ..	1·88	3·04	3·27	3·07	3·66	3·40	3·66	3·76	3·44
K_2O ..	0·25	1·95	1·80	4·42	3·72	5·00	4·26	4·21	4·26
$H_2O > 105°$	0·83	1·36	1·71	0·50	0·83	0·22	1·59	0·70	0·40
$H_2O < 105°$	0·29	0·30	1·26		0·44	0·65		0·60	0·41
TiO_2 ..	2·99	2·15	2·83	0·40	1·21	0·20	—	0·22	0·28
P_2O_5 ..	0·06	0·66	0·31	0·50	0·28	0·12	—	0·09	0·16
MnO ..	0·49	0·40	0·37	0·70	0·27	trace	—	0·00	0·26
CO_2 ..	0·14	0·79	0·25	—	0·08	0·00	—	0·00	0·09
FeS_2 ..	0·00	0·00	0·14	—	0·00	—	—	—	0·00
Fe_7S_8 ..	0·00	0·00	—	—	0·00	—	—	—	—
(Co, Ni)O	0·00	0·00	0·00	—	0·00	—	—	—	0·02
BaO ..	0·00	0·00	0·02	—	0·00	—	—	—	0·03
Li_2O ..	0·00	0·00	trace	—	0·00	—	—	—	0·00
	100·06	100·01	100·07	100·49	100·14	99·59	99·83	100·06	100·16

I. (21249 ; Lab. No. 734.) Fluxion Biotite-gabbro. Glendrian Ring-dyke, Centre 3, Ardnamurchan. Ridge ¾ mile E. 17° S. of Achnaha, *Anal.* E. G. Radley.

II. (21248 ; Lab. No. 733.) Tonalite. Ring-dyke, Centre 3, Ardnamurchan. Knoll at edge of moss ⅜ mile W. 33° S. of Glendrian. *Anal.* E. G. Radley.

A. (24459 ; Lab. No. 828.) Quartz-dolerite. Garbad sill, Arran. Gorge in Allt Dhepin, ¼ mile E.N.E. of Trigonometrical Station at 873 ft. O.D., Cnoc an Fheidh, Whiting Bay. Quoted from G. W. Tyrrell, 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928, pp. 147–148. *Anal.* E. G. Radley.

B. Monzonite. Monzoni, Tyrol. Quoted from W. C. Brögger, 'Die Eruptivgesteine des Kristianiagebietes. II. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol.' Kristiania, 1895, p. 24. *Anal.* V. Schmelck.

III. (21247 ; Lab. No. 732.) Quartz-monzonite. Boss, Centre 3, Ardnamurchan. Small summit in low ground ½ mile E. of Achnaha. *Anal.* E. G. Radley.

C. Hornblende-granite. Granite 1, Mourne Mountains. Eagle Rock,

(Table 5) Tonalite and Quartz-monzonite Magma Series (see (Figure 8)).

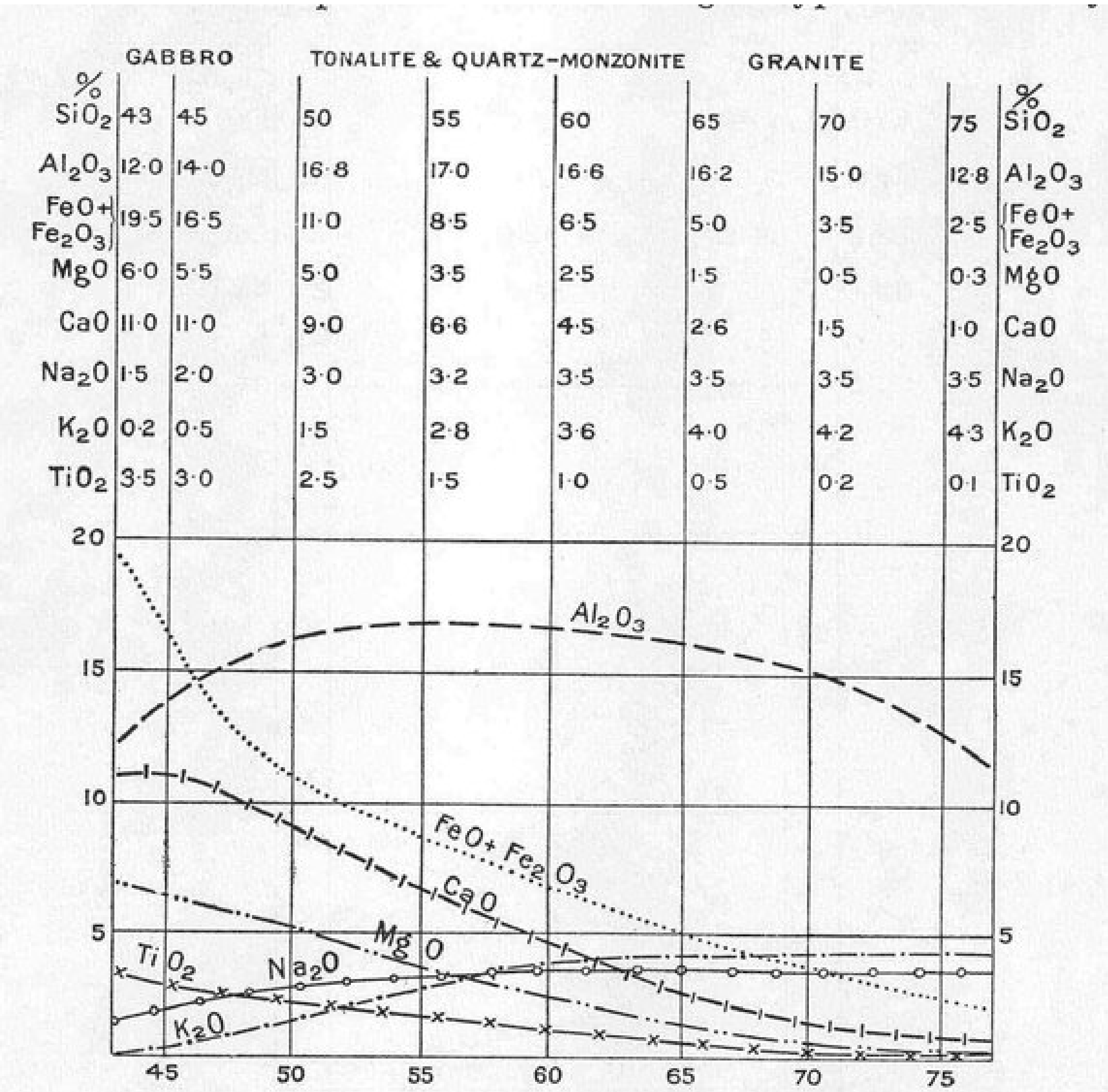

FIG. 8.—*Variation Diagram, Tonalite and Quartz-monzonite Magma-Series.*

(Figure 8) Variation diagram, Tonalite and Quartz-monzonite Magma-Series.

TABLE VI

DATA CONCERNING CONE-SHEETS, ARDNAMURCHAN

Order of Age.	Title of Set.	Angle of Inclination.	Thickness in Feet.	Age Relations with Other Intrusions.
1	Set of Centre 1	10–20°	20–50	Pene-contemporaneous with Ben Hiant Intrusion, and later than Ben Hiant and Northern Vents.
2	Outer Set of Centre 2	35–45°	5–20	Later than the Major Intrusions of Centre 1, generally. Almost all earlier than all ring-dykes.
3	Inner Set of Centre 2	70°	5–30	Later than most ring-dykes of Centre 2. Earlier than all ring-dykes of Centre 3.
4	Partial Set of Centre 3	50°	3–5	Later than earliest of the ring-dykes of Centre 3, and earlier than Great Eucrite Ring-dyke.

(Table 6) Data concerning cone-sheets, Ardnamurchan.