Chapter 17 Rocks of Lower Old Red Sandstone age petrology of igneous rocks

Classification and chemistry

In the 1916 edition of this memoir a rather full discussion is provided of the origins of the petrographical classifications adopted in it for descriptive purposes. This discussion is still available in libraries for consultation, and is not here repeated.

The following SiO_2 percentages have been chosen as separating rocks of different degrees of basicity and acidity:

Ultrabasic. 45. Basic. 55. Intermediate. 65. Acid. 75. Ultra-acid

Within each of these compositional divisions a three-fold textural grouping is found convenient, namely plutonic, hypabyssal and volcanic. The same three terms can, of course, quite properly be employed in reference to field-relations, rather than texture. Accordingly the meaning of each of them depends upon the context in which it is used. Thus all the dykes of the Ben Nevis and Etive Swarms are hypabyssal intrusions; but not quite all of them are of hypabyssal texture: some few, especially narrow examples, are of volcanic texture throughout; while all have chilled selvages, which also are volcanic in the textural sense. Similarly the chilled edges of the plutonic Inner "Granite" of Ben Nevis and of the An t-Sròn "Granite" of Glen Coe are rhyolites or andesites of volcanic textural type.

An important point emphasised by Nockolds and Mitchell is that, over a wide range of composition, the Devonian (that is Old Red Sandstone) plutons, dykes and lavas of Scotland show very similar chemical variety (1948, p. 533). As yet, however, no ultrabasic lava has been collected, nor any with an olivine-augite concentration equal to that of the kentallenites (Anal. 2, (Table 2)). Still, the Taynuilt [NN 004 311] basalt lava (Anal. 3) is very close in composition to the Ardsheal basalt intrusion (Anal. 4), which latter Walker found to be a variety of adjoining kentallenite.

(Table 2) and (Table 3) record 33 analyses from Sheet 53 and its natural extensions (Anals. 3, 6, 9, 17, 31 are from Sheet 45 to the south, and 23 from Sheet 54 to the east). Strontian analyses (4, (Figure 18), p. 129) from Sheet 52 to the west are not included, since a memoir on that district is in preparation; and many others, especially from the Garabal Complex well to the south-east (9, (Figure 18)), are also omitted, because it has been thought advisable to present a chemical discussion of the whole South-West Highland suite as a separate publication (Bailey 1958).

One aim of this separate publication has been a comparison of average analyses of Devonian igneous rocks from the South-West Highlands with their Carboniferous and Tertiary counterparts taken from elsewhere in Scotland. The average analyses employed have been arrived at by averaging all suitable analyses between silica-percentage limits of 40–45, 45–50, and so on. A sample set of the values obtained by this arithmetical averaging is marked by crosses on (Figure 37). It is obvious at once that in the ultrabasic and basic divisions there is great scatter of individual composition; but the fact that the averages lie along a comparatively simple curve encourages the belief that they have considerable significance. Compositional scatter is a well-known feature in analyses of ultrabasic and basic igneous rocks all the world over.

The comparisons illustrated in (Figure 38) reproduce for the most part features noted years ago by Elder (1935). He summarised his conclusions as follows: "As might have been expected, this renewed study has brought out very clearly the well-known calc-alkali character of the Devonian and Tertiary as compared with the Carboniferous magma. It has also indicated a distinctly magnesian tendency in the Devonian magma, and a ferriferous tendency in the Tertiary magma ".

(Table 2) Analyses of Devonian Igneous Rocks of Sheet 53, 45 and 62 (Geol.)

Ultrabasic	Intermediate

	1	2	3	4	5	6	7	8	9	10 (see 13)	11	12	13 (see 10)	14	15	16	17	18
SiO_2	40.26	48.00	49.86	50.60	50.73	53.05	53.22	56.25	56.50	59.11	59.25	59.43	60.05	60.45	60.80	61.49	61.50	62.21
Al_2O_3	15.74	12.52	16.33	14.67	17.08	16.96	17.20	16.30	21.15	17.85	17.30	17.24	18.55	19.89	16.25	14.98	17.35	14.43
Fe_2O_3	3.44	8.74	3.62	2.81	4.59	2.95	2.64	1.60	1.55	1.78	1.15	2.58	0.93	1.76	1.70	1.51	1.27	1.77
FeO	7.95		4.34	6.47	4.06	5.40	4.84	5.05	3.70	3.24	4.07	3.24	3.41	2.27	3.38	3.84	3.87	3.65
MgO	12.09	15.26	7.80	7.04	6.12	6.15	6.33	5.12	2.55	3.85	3.60	2.92	3.46	1.54	3.72	3.22	4.22	5.66
CaO	12.03	7.94	6.47	10.05	7.32	7.45	6.79	6.55	6.15	5.05	4.95	5.14	5.44	4.04	4.75	4.56	3.80	4.43
Na,O	2.25	3.11	3.42	3.13	3.55	3.36	2.38	4.13	4.37	4.10	4.45	4.11	3.84	4.77	4.05	3.59	2.38	2.65
K_2O	1.36	2.68	2.10	2.65	1.18	1.45	4.12	2.02	2.56	3.06	2.50	2.53	2.72	3.53	3.05	2.80	2.94	2.75
H_2O+	1.75	{1.36}	2.77	0.50	2.00	1.10	0.61	0.95	0.65	0.73	0.50	0.84	0.35	0.70	0.60	1.68	1.00	0.66
H_2O-	0.48		1.25	0.30	0.33	0.60	0.19	0.10	0.15	0.11	1.00	0.33	0.05	0.45	0.30	0.23	0.50	0.40
TiO_2	2.42	0.22	1.06	1.25	1.90	0.92	0.69	0.90	0.45	0.30	0.70	1.11	0.42	0.30	0.90	0.96	0.75	0.88
P_2O_5	0.04	—	0.54	0.24	0.35	0.54	0.28	0.40	0.22	0.14	0.21	0.26	0.29	0.23	0.28	0.32	0.17	0.20
MnO	0.03	—	0.40	0.23	0.20	0.20	0.25	0.40	tr.	0.05	0.15	0.20	0.16	tr.	0.10	0.21	0.07	0.23
CO_2	0.03	—	0.23	nil	0.82	nil	0.57	nil	nil	—	nil	0.06	—	nil	nil	0.92	nil	0.06
Cl	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.03	—	—
S	nil	—	—	nil	—	—	—	—	0.08	0.19	—	—	—	tr.	—	—	—	—
(Ni,Co)O	—	—	nt. fd.	—	nt. fd.	—	nt. fd.	-	—	—	—	nt. fd.	—	—	—	nt. fd.	—	nt. fd.
BaO	—	—	0.10	—	0.07	—	0.08	—	—	0.23	-	0.13	—	—	—	0.11	—	0.07
ZnO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Li_2O	—	—	tr.	—	nt. fd.	—	tr.	—	—	—	—	nt. fd.	—	—	—	nt. fd.	—	nt. fd.
Total	99.87	99.83	100.29	99.94	100.30	100.13	100.19	99.77	100.08	99.70[1]	99.83	100.12	99–94	99.93	99.88	100.45	99.82	100.05
Sp.Gr.	3.19	2.95	2.76	3.00	2.82	2.86	2.85	2.81	—	—	2.71	2.75	—	2.64	2.76	2.71	2.76	2.76

1 After subtracting 0.09 for S

1: Appinite; Ardsheal Hill [NM 995 568]. 2: Kentallenite; Kentallen. 3: Olivine-basalt with orthoclase; lava, Taynuilt [NN 004 311], Lorne. 4: Olivine-basalt with orthoclase; intrusion, Ardsheal Hill [NM 995 568]. 5: Hypersthene-basalt; lava, Glen Coe. 6: Biotite-diorite with hornblende and augite; basic phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite. 7: Monzonite; Glen Creran. 8: Banatite; Inner non-porphyritic Subzone 3 of Outer "Granite", Ben Nevis. 9: Tonalite; intermediate phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite. 10: Tonalite; Outer "Granite", Ballachulish (see 13). 11: Banatite; Outer non-porphyritic Subzone 1 of Outer "Granite", Ben Nevis. 12: Banatite-porphyrite; Fault-Intrusion, Glen Coe. 13: Tonalite; Outer "Granite", Ballachulish (see 10). 14: Hornblende-porphyrite; dyke, Ben Nevis Swarm, W. of Ballachulish Pluton. 15: Banatite; Mid nonporphyritic Subzone 2 of Outer "Granite", Ben Nevis. 16: Hornblende-andesite; lava, Glen Coe. 17: Hornblende-andesite; lava, contact-altered in Beinn a' Bhuiridh screen. 18: Kersantitic microdiorite; dyke, Etive Swarm, Glen Etive.

(Table 3) Analyses (continued), Sheets 53, 45, 54 and 62 (Geol.)

	Acid													Ultra-Acid		Norwegian Trondhjemites		
	19	20 (see 25)	21	22	23	24 (28, 30)	25	26	27	28 (24,30)	29	30 (24,28)	31	32	33	A	B	C
SiO_2	65.30	65.72	66.50	66.71	66.91	67.30	67.78	68.02	68.40	70.27	71.35	71.70	73.70	75.71	76.14	70.30	71.95	72.11
Al_2O_3	15.20	15.49	15.15	15.33	15.09	16.50	16.64	14.16	17.21	15.52	13.68		13.62	12.25	11.91	15.36	15.76	15.25
Fe_2O_3	2.49	2.35	1.34	1.46	1.70	1.20	1.07	1.82	tr.	0.90	1.75	}16.81	0.48	1.23	1.26	0.56	0.76	0.64
FeO	2.41	2.07	2.39	2.26	1.95	1.98	1.74	1.95	0.92	0.94	0.97		1.28	0.31	0.25	2.37	0.03	0.84
MgO	1.80	1.23	1.88	1.53	2.02	1.27	1.19	1.91	1.03	0.67	0.84	0.47	0.32	0.20	0.13	1.03	0.31	0.38
CaO	3.05	2.69	3.15	2.72	3.27	2.85	2.38	2.81	3.05	1.60	1.85	2.42	0.94	0.61	0.47	3.52	1.65	1.98

Na_2O	4.13	4.49	3.90	3.67	4.16	4.70	4.27	3.90	4.48	4.45	3.75	}9.00	4.05	3.79	3.37	4.30	6.63	5.43
K_2O	3.37	4.38	3.68	3.96	3.16	2.75	3.48	3.92	2.88	4.16	4.36	{	4.85	4.73	5.30	1.45	2.22	2.04
H_2O+	0.81	0.49	0.90	0.28	0.56	0.50	0.48	0.56	0.30	—	0.51	—	Nil	0.52	0.30	0.79	}0.42{	0.66
H_2O-	0.19	0.12	0.20	0.88	0.14	0.20	0.30	0.20	0.12	—	0.19	—	0.55	0.08	0.36	0.05		0.03
TiO_2	0.83	0.61	0.55	0.69	0.67	0.30	0.36	0.63	0.28	0.31	0.47	—	0.36	0.21	0.15	0.35	0.08	0.17
P_2O_5	0.23	0.43	0.18	0.19	0.17	0.16	0.12	0.16	0.14	0.17	0.11	—	tr.	0.06	0.05	0.12	—	0.06
MnO	0.12	0.04	0.10	0.18	0.18	nil	—	0.22	—	0.04	0.18	—	nil	0.10	0.19	0.04	—	0.02
CO_2	tr.	—	nil	0.15	nt. fd.	nil	—	nt. fd.	—	—	nt. fd.	—	nil	0.19	0.26	0.13	—	0.22
S	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.03	—	0.06
FeS_2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
(Ni,Co)O	nt. fd.	—	—	nt. fd.	nt. fd.	—	—	nt. fd.	-	—	nt. fd.	—	—	nt. fd.	nt. fd.	—	—	—
BaO	0.11	0.19	—	0.10	0.05	—	—	0.06	-	—	0.05	—	—	0.08	0–01	tr.	—	0.03
Li_2O	nt. fd.	—	—	?	nt. fd.	—	—	nt. fd.	-	—	tr.	—	—	?	nt. fd.	-	—	—
Total	100.04	100.30	99.92	100.11	100.03	99.71	99.81	100.32	99.89	99.03	100.06	100.40	100.15	100.07	100.15	100.40	99.81	99.92
Sp. Gr.	2.70	—	2.68	2.69	2.69	2.67	-	2.69	—	—	2.65	-	2.62	-	-	2.71	2.64	2.68

19: Biotite-hornblende-porphyrite; Early Fault-Intrusion, Glen Coe. 20: Granite; Inner Granite, Ballachulish (see 25). 21: Granite; porphyritic subzone of Ben Nevis Outer "Granite". 22: Hornblende-porphyrite; dyke, Etive Swarm, Glen Etive. 23: Trondhjemite; Moor of Rannoch "Granite". 24: Trondhjemite; Inner "Granite", Ben Nevis (see 28, 30). 25: Granite; Inner Granite, Ballachulish (see 20). 26: Adamellite; Northern Lobe, Cruachan "Granite". 27: Trondhjemite; "White Granite", Ballachulish. 28: Granite; Inner "Granite", Ben Nevis (see 24, 30). 29: Granite; Starav Granite. 30: Trondhjemite; Inner "Granite", Ben Nevis (see 24, 28). 31: Binary Granite; referred to Meall Odhar Granite. 32: Rhyolite; lava, Glen Coe. 33: Quartz-porphyry; dyke, Etive Swarm, Glen Etive. A, B, C: Three Norwegian Trondhjemites to compare with 23, 24, 27, 30.

Further details regarding (Table 2) and (Table 3) are given on pp. 208–9.

List of analyses

1. APPINITE, unusually basic; Ardsheal Hill [NM 995 568], W. of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1927, p. 154). — p. 214.
2. KENTALLENITE (S7053) [NN 009 577]; Kentallen quarry, W. of Ballachulish Pluton. Anal. J. J. H. Teall. Quoted from J. J. H. Teall (Ann. Rep. 1897, p. 22). — p. 212.
3. OLIVINE-BASALT with orthoclase (S9628) [NM 989 276]; lava, N.W. side of Cruach Ard-dhuine [NM 991 272], 3 miles S.S.W. of Taynuilt [NN 004 311] (Sheet 45). Anal. E. G. Radley. Quoted from 1st edition. — p. 233.
4. OLIVINE-BASALT with orthoclase; intrusion, Ardsheal Hill [NM 995 568], W of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1927, p. 154). — p. 213.
5. HYPERSTHENE-BASALT (S14408) [NN 1403 5590]; lava, right bank of stream, ½ mile S.S.W. of Loch Achtriochtan, Glen Coe. Anal. E. G. Radley. Quoted from 1st edition. — p. 233.
6. BIOTITE-DIORITE with hornblende and augite; basic phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite, stream S. of large crag W. of Allt Cruachan (Sheet 45). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1937a, p. 518). — p. 191.
7. MONZONITE, with hornblende (S14113) [NN 0620 5109]; River Creran [NN 060 510], three-eighths mile E. of Salachail [NN 056 512], Glen Creran. Anal. E. G. Radley. Quoted from 1st edition. — p. 213.
8. BANATITE; Inner, coarse, non-porphyritic member of Ben Nevis Outer "Granite" (Sub-zone 3), at mouth of tunnel leading from hydro-electric surge-chamber. Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257). — p. 222.
9. TONALITE; intermediate phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite (Sheet 45). Anal. W. H. and F. Herdsman. Quoted from S. R. Nockolds (1934, p. 315).

10. TONALITE; Outer "Granite", Ballachulish Pluton (see 13). Anal. I. D. Muir. Quoted from I. D. Muir (1953a, p. 184). — p. 225.
11. BANATITE; Outer, fine, non-porphyritic member of Ben Nevis Outer "Granite" (Subzone 1), 150 yd below light-railway bridge, Allt na Caillich (Sheet 62). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257). — p. 222.
12. BANATITE-PORPHYRITE (S14117) [NN 2081 5748]; Fault-Intrusion of Glen Coe, Stob Mhic Mhartuin [NN 207 575], 1¼ mile N.W. of Altnafeadh, Anal. E. G. Radley. Quoted from 1st edition. — p. 218.
13. TONALITE; Outer "Granite", Ballachulish Pluton (see 10). Anal. W. H. Herdsman. Quoted from F. Walker (1924, p. 554). — p. 225.
14. HORNBLENDE-PORPHYRITE; N.E. dyke, Ben Nevis Swarm, Ardsheal Hill [NM 995 568], W. of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1927, p. 154). — p. 230.
15. BANATITE; Mid non-porphyritic member of Outer "Granite" of Ben Nevis (Subzone 2), beside light railway between Allt a' Mhuilinn [NN 161 730] and Allt na Creige Duibhe (Sheet 62). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257). — p. 222.
16. HORNBLENDE-ANDESITE (S14576) [NN 146 545]; lava, corrie between Stob Coire nan Lochan and Bidean nam Bian [NN 140 543], Glen Coe. Anal. E. G. Radley. Quoted from 1st edition. — p. 234.
17. HORNBLENDE-ANDESTTE; lava, contact-altered in Beinn a' Bhuiridh Screen, Allt Coire Ghlais, a little above junction with Allt Coire Chreacha inn (Sheet 45). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1937a, p. 521). — p. 176.
18. KERSANTITIC MICRODIORITE (S14406) [NN 2058 5130]; N.B. dyke, Etive Swarm, roadside E.N.E. of Alltchaorunn [NN 196 509], Glen Etive. Anal. E. G. Radley. Quoted from 1st edition. — p. 229.
19. BIOTITE-HORNBLENDE-PORPHYRITE (S14109) [NN 1928 5876]; Early Fault-Intrusion of Glen Coe, 2½ miles N.W. of Altnafeadh. Anal. E. G. Radley. Quoted from 1st edition. — p. 215.
20. GRANITE; Inner Granite, Ballachulish Pluton (see 25). Anal. I. D. Muir. Quoted from I. D. Muir (1953a, p. 184). — p. 225.
21. GRANITE Porphyritic member of Ben Nevis Outer "Granite", just outside tunnel intake Allt an t-Sneachda [NN 180 763] (Sheet 62). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257). — p. 223.
22. HORNBLENDE-PORPHYRITE (S14398) [NN 1717 5113]; N.E. dyke, Etive Swarm, River Etive above falls, ¼ mile E. of Dalness. Anal. E. G. Radley. Quoted from 1st edition. — p. 230.
23. TRONDHJEMITE (S14110) [NN 260 550]; Moor of Rannoch "Granite", road-cutting to shooting lodge ½ mile from Kinghouse Hotel (Sheet 54). Anal. E. G. Radley. Quoted from 1st edition. — p. 225.
24. TRONDHJEMITE; Inner "Granite", Ben Nevis (see 28, 30) tourist path. Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1935b, p. 257). — p. 223.
25. GRANITE; Inner Granite, Ballachulish Pluton (see 20). Anal. W. H. Herdsman. T. R. M. Lawrie (unpublished). — p. 225.
26. ADAMELLITE (S14112) [NN 2252 5237]; Northern lobe, Cruachan "Granite", River Etive where Allt Fionn Ghlinne enters. Anal. E. G. Radley. Quoted from 1st edition. — p. 221.
27. TRONDHJEMITE; White Granite", W. margin of Ballachulish Pluton. Anal. W. H. Herdsman. Quoted from F. Walker (1924, p. 554). — p. 225.
28. GRANITE; Inner "Granite", Ben Nevis (see 24, 30). Anal. Geochem. Labs. Quoted from S. R. Nockolds and & L. Mitchell (1948, p. 574). — p. 223.
29. GRANITE (S14111) [NN 1429 4662]; Starav Granite, streamlet, ¼ mile a little N. of E. of Coileiter, Glen Etive, Anal. E. G. Radley. Quoted from 1st edition. — p. 222.
30. TRONDHJEMITE; Inner "Granite", Ben Nevis (see 24, 28). Allt a' Mhuilinn [NN 161 730], mile N. of Ben Nevis summit. Anal. B. Lightfoot. Quoted from 1st edition — p. 223.
31. BINARY GRANITE; referred to Meall Odhar Granite, summit of Taynuilt [NN 004 311] peak, 3611 ft, Ben Cruachan (Sheet 45). Anal. W. H. Herdsman. Quoted from J. G. C. Anderson (1937a, p. 518). — p. 221.
32. RHYOLITE (S14100) [NN 1638 5518]; lava, Allt Coire Gabhail [NN 162 550], at S. end of alluvial flat, 1 mile S.S.W. of River Coe [NN 155 569]. Anal. E. G. Radley. Quoted from 1st edition. — p. 235.

33. QUARTZ-PORPHYRY (S14114) [NN 248 546]; N.E. dyke running parallel with River Etive, 2 miles E.S.E. of Altnafeadh, Glen Coe. Anal. E. G. Radley. Quoted from 1st edition. — p. 232.

A, B, C. Three Norwegian Trondhjemites: A from Mastravarde, Anal. Röer; B from Frenstad, Anal. Damm; C from Skavlien, Anal. Röer, to compare with 23, 24, 27, 30. Quoted from A. Johannsen (1932, pp. 383, 385).

The main additional point made in (Figure 38) is that, among acid and intermediate rocks, the average Devonian product tends to be richer in Al_2O_3 than the average Tertiary product; whereas among thoroughly basic rocks the reverse holds good. The high alumina among the acid and intermediate Devonian rocks corresponds with a tendency to develop porphyries and porphyrites in rocks of hypabyssal crystallisation. The drop in Al_2O_3 on the basic side of 57 per cent. SiO_2 occurs in spite of rising CaO; so that it is clear that rapid increase in MgO in this direction takes more and more of the CaO into the ferromagnesian camp, either in augite or hornblende — a lamprophyric feature.

It is well to realise that the Tertiary hump for Al_2O_3 at 47 per cent. SiO_2, corresponding as it does with a high for CaO, is an average rather than a universal feature. It depends upon a strong representation of the anorthite molecule in rocks such as allivalite, eucrite, highly felspathic olivine-gabbro and the Mull Porphyritic Central Type of dolerite and basalt. These rocks have no close analogues in the Devonian of the South-West Highlands — but the contrast is reduced in emphasis when we recall that the Mull Normal Series, among Tertiary products, does not carry felspar phenocrysts and does not show a hump in its Al_2O_3 curve.

The relatively high K_2O in Devonian basic rocks as compared with Tertiary corresponds with the monzonitic tendency of the former, illustrated by prevalence of biotite.

Elder's use of the word magma in the passage quoted may perhaps be criticised, since many of the analyses concerned probably represent rocks with compositions largely determined by crystal concentration. On the other hand the features to which he draws attention, such as high MgO, characterise rocks through a wide range of Si02 percentages, so that it seems justifiable to regard them as in some measure of magmatic character.

In the paper (Bailey 1958), already referred to, a rather complex set of comparisons leads to the suggestion that the basic plutonic rocks of our Devonian suite have crystallised in an augitic facies (*cf.* kentallenite, augite-diorite) or a hornblendic facies (*cf.* appinite) according to the relative dryness or wetness of the parent magma. One supporting circumstance is that all the basic lavas of the district are augitic. It is true that hornblende-andesites are typical among the intermediate lavas; but their hornblende has obviously been out of equilibrium under near-surface conditions, for it has suffered greatly from resorption. It is further suggested in this paper that the South-West Highland Devonian magma was on the whole wetter than the Hebridean Tertiary magma; but readers must consult the original if they want to pursue the argument further.

Meanwhile it may be pointed out that Walker (1927, p. 152) and Nockolds (1941, p. 498) had both come to much the same conclusion regarding the augitic and hornblendic plutonic rocks of our district. Also, after this view had been developed by the writer, it received, quite independently, strong experimental support from Yoder and Tilley (1956).

One of the most important petrological contributions furnished by the district is evidence which J. G. C. Anderson has described in relation to gravitational differentiation in intermediate to acid plutons in the Ben Nevis and Etive Complexes. Kynaston and Grabham had already put forward a claim in this direction in the 1916 edition of the memoir; but Kynaston's observations were confused owing to an important mistake, later corrected by Anderson (pp. 168, 184).

As set out in (Figure 38) the variations with which Anderson was concerned in the intermediate to acid range follow, on the average, roughly linear courses — Anderson has indeed pointed out that Anals. 6, 26, 29 and 31 show very close linear variations, though Anal. 9 does not fit into the scheme at all (1937a, fig. 6, p. 517). If any material consisting of two substances, each itself of constant composition, is sorted out into a number of fractions in which these two substances occur in quite different proportions, the composition of the products will vary in linear fashion. Accordingly it would seem that the intermediate to acid products, here considered, consisted during consolidation of early crystals and residual magma, and that variations of bulk composition have been controlled by relative migration during which the compositions of the early crystal assemblages and of the residual magma have not altered materially. Of course the same result chemically would be attained by hybridisation in varying proportions of two originally separate magmas, that is by mixing instead of unmixing; but the unmixing explanation seems to meet the field appearances better.

Allusion has often been made to the chilling or quenching of the Fault-Intrusion of Glen Coe and of the Inner "Granite" of Ben Nevis against the cold contents of the cauldron-subsidences which they surround. Additional data are furnished in the sequel in relation to the quenching of permeation products of the former in this critical position (p. 216).

In the 1916 edition several outside analyses were published to enable comparison with those of the local rocks. With increase of local analyses foreign records have now almost been crowded out; but a place has been reserved in (Table 3) for Analyses A, B, C of three trondhjemites from Norway. The intermediate and acid plutonics of our district have commonly a fair proportion of both plagioclase and orthoclase. Where the plagioclase to orthoclase ratio is greater than 2:1, the rock is usually intermediate and can be comfortably accommodated as a tonalite. Where it is less than 2:1 and yet greater than 1:2, the rock is generally acid and can find a position among the adamellites. There are, however, a few acid plutonics in the district, which often seem to have a plagioclase to orthoclase ratio greater than 2:1. In the 1916 edition they were grouped as aplodiorite. This name serves quite well to suggest the composition of the rocks concerned; but it is apt to convey a completely wrong idea as to texture. In the present account the aplodiorites have been transferred to trondhjemite. They are represented by Anals. 23, 24, 27, 30, and among them the most important constitutes much of the Inner "Granite" of Ben Nevis. Comparison of these four analyses with Anals. A, B, C shows that the Scottish examples can only be regarded as standing on the verge of the trondhjemite group. Their CaO is sufficiently high, but their K_2O is definitely too abundant to be typical.

Just as the name aplodiorite has been abandoned, so also that of aplogranite is replaced by the more easily intelligible term binary granite. Anal. 31 may be classed as belonging to a binary granite, or at any rate to a near approach to the type. The ultra-acid Anals. 32, 33 are more definitely representative, so far as composition is concerned; but they represent hypabyssal and volcanic specimens.

Ultrabasic and basic plutonic rocks

Cortlandtite

The name cortlandtite is applied in this memoir to coarse-grained olivine-augite-hornblende rocks which many would call hornblende-picrites. Two small outcrops are shown black and lettered C in (Figure 32), p. 186; but they are included with kentallenite, K, in Sheet 53. The more easterly (S11441) [NN 0516 5294] used to be seen in Allt Eilidh [NN 067 530] surrounded by trondhjemite (S11363) [NN 0690 5309]. It is now covered by a fish-pond. The more westerly (S11442) [NN 0544 5288] lies in the tongue of basic rocks extending from the Ballachulish Pluton towards Allt Eilidh [NN 067 530], and is surrounded by appinite.

The slice (S11441) [NN 0516 5294] is on the whole beautifully fresh. It consists for the most part of irregular grains of olivine and almost colourless augite set in large poikilitic crystals of brown hornblende. There is also a little rather pale-brown biotite that may be earlier than the hornblende. The olivine is clouded with rod inclusions, similar to what we shall see in the kentallenites. Its partial decomposition has developed a network of magnetite-filled cracks in itself and corresponding sheaves of black cracks traversing adjacent minerals. The augite is almost colourless, and frequently shows lamellar twinning It rarely makes contact with the olivine, and some crystals are crowded with inclusions due to reaction. The coexistence of abundant fresh augite and primary hornblende is an unusual feature.

The other slice (S11442) [NN 0544 5288] is somewhat similar, but all its augite is reacting to give hornblende, which may be brown or green; and fresh hypersthene is an important constituent; while biotite builds a large poikilitic crystal.

Kentallenite (Plate 11), 1

The type slice (S7053) [NN 009 577] from Kentallen quarry has been described by Teall as follows (Annual Report 1897):

"The rock is composed of olivine, augite, biotite, plagioclase, orthoclase, magnetite, and apatite. The olivine is fresh, colourless, and is traversed by the usual anastomosing veins of magnetite. It is also, as a rule, crowded with extremely minute and often rod-like inclusions, which give it a cloudy aspect when viewed with low powers [the rods are now commonly thought to be exsolved magnetite]. The sections of the individuals are never bounded by straight lines meeting in sharp angles, but traces of idiomorphism are not uncommon; in other words, the mineral occurs as grains or crystals with more or less rounded angles. It is present as inclusions, both in augite and biotite, and the felspars are often moulded upon it.

"The augite occurs in grains, crystals, and patches, which vary in size — the forms may frequently be recognised, and the angles are often fairly sharp. The colour in thin slices is pale green, and sections which appear homogeneous in ordinary light often show a beautiful zonal structure under crossed nicols.

"Biotite occurs in large ragged patches, which, in spite of their apparent isolation, often show uniform orientation over large areas. The mineral is of a rich brown colour, approximately uniaxial and strongly pleochroic. It is not only moulded on the augite and olivine, but also occasionally on the felspars, and was therefore one of the last minerals to form.

"The felspars, together with the small amount of biotite, make up the interstitial matter in which the olivines and augites are embedded. Both plagioclase and orthoclase are present in approximately equal quantities, and the former is markedly idiomorphic with respect to the latter. The plagioclase sometimes shows a zonal structure, and probably ranges in composition from labradorite to oligoclase, the acid type predominating. It may be readily distinguished from the orthoclase by its higher refractive index and by the albite twinning. The orthoclase occurs as interstitial matter (mesostasis). Individual patches sometimes show twinning on the Carlsbad plan. The accessory minerals are apatite and magnetite, the latter occurring almost exclusively in the veins that traverse the olivine. All the minerals are remarkably fresh".

Teall went on to comparison with Brögger's olivine-monzonite type. Later, Hill and Kynaston (1900), introducing the name kentallenite, did not insist upon any definite proportion between plagioclase and orthoclase. Teall's analysis of the type rock is given in (Table 2) (Anal. 2, p. 206).

In Kentallen quarry the kentallenite is traversed by occasional intermediate segregations. A conspicuous white patch filling a pocket contains plates of biotite set in any direction and measuring up to an inch and a half across. It is probably what Rosenbusch (1907, p. 170) has called an inclusion on the authority of K. Furbringer. Rosenbusch has noted fairly frequent pseudomorphs after nepheline, but he was almost certainly mistaken. The rock is a syenite consisting essentially of an allotriomorphic aggregate of microperthitic felspar and subordinate, fresh, rich-brown biotite (S15874) [NN 0105 5784]; (S15875) [NN 0105 5784]. Small idiomorphic apatites and fairly large sphenes are conspicuous accessories, while there is also a very little quartz. Some neighbouring olivines in the kentallenite have been replaced by serpentine with a rim of magnetite followed externally by radiating tremolite. In other cases olivine is replaced by a tremolite-magnetite aggregate often sprouting green biotite. At the same time the original brown biotite of the kentallenite has mostly changed to green with much re-crystallisation. It is not necessary to attribute all this to the acid segregation, since the kentallenite lies within the contact-aureole of the great Ballachulish Pluton. Very likely the segregation vein induced preparatory decompositions, which were later turned to advantage by the Ballachulish Pluton. It is noteworthy that the felspars of the kentallenite near the segregation show clouding of the type commonly met with in contact-altered igneous rocks. The felspars of the segregation also show this effect (in a minor degree); but the felspars of the type kentallenite slice (S7053) [NN 009 577], away from the vein, are almost free of clouding. The suggestion is that the segregation introduced some material (perhaps containing iron) that made adjoining felspars susceptible to subsequent clouding (*cf.* p. 259).

Another such segregation, occurring as a thin vein, is a biotite-diorite, mostly made of panidiomorphic much-zoned plagioclase, seldom as basic as labradorite, along with a small proportion of allotriomorphic flakes of brown biotite of about the same length as the felspars (S15873) [NN 0105 5784].

The field relations of the other little kentallenite bosses of Sheet 53 have already been detailed in chapter 15 with slices duly quoted. Beautifully fresh material is provided in a slice (S8830) [NM 9668 5222] from west of Beinn Sgluich and in others (S11357) [NN 050 504]; (S11360) [NN 0514 5009]; (S11445) [NN 0484 5030] from Glen Creran. All these slices closely resemble the type (S7053) [NN 009 577], though in two (S11357) [NN 050 504]; (S11360) [NN 0514 5009] there is very little orthoclase, while their augite tends to recur in a second generation, sprouting from olivine or moulded on plagioclase. In one also (S11357) [NN 050 504] there is a little enstatite. In another slice (S11361) [NN 0514 4998] from Glen Creran olivine is represented by tremolitic aggregates, recalling those described near the segregation vein in Kentallen quarry — see also (S11439) [NN 0519 4970]; while augite is rimmed and crossed by green secondary hornblende. The development of tremolite is perhaps due to the great Cruachan Pluton.

The fine-grained marginal types associated with the Glen Creran outcrops just noticea are particularly interesting, since they prove that the large olivines and augites of the kentallenites were carried in a liquid matrix. Of four slices, only one (S11438) [NN 0523 5057] retains most of its olivine fresh — in crystals bordered externally by a narrow halo of serpentine that separates olivine and matrix. In another (S11358) [NN 050 504] some olivine is preserved, but most has gone to serpentine with a concentration of magnetite at the margin (as well as along cracks). Here too there is a serpentine halo. In still another (S11435) [NN 0521 5056], which shows a kentallenitic dyke with very fine groundmass cutting a coarser kentallenite, all olivines are replaced by tremolite-magnetite aggregates, with tremolite extending into a serpentinous halo. Similar aggregates of tremolite, or related amphibole, representing olivine (S11440) [NN 0519 4970], may also extend into manifest cracks crossing the felspathic base. Augite as big crystals in these four slices is relatively fresh. It tends to show internal skeletal perforation such as is generally ascribed to corrosion. It recurs in the groundmass as small prisms or grains. Biotite is almost wanting, while little grains of magnetite are abundant. Here again the tremolite developments may perhaps be referred to contact-action by the Cruachan Pluton.

Turning back to west of the Ballachulish Pluton, we may recall Walker's description of the orthoclase-bearing olivine-basalt intrusion of Ardsheal Hill [NM 995 568] (Anal. 4, (Table 2)), which passes laterally into a kentallenite with rather fine matrix. This basalt has large augites; but its olivines, though darkened with exsolved magnetite, are fewer and smaller than those commonly found in kentallenites. Correspondingly there is a comparative poverty in MgO. Biotite is absent from the groundmass, where instead we find plenty of minute crystals of magnetite. The alkali content agrees with what is found in kentallenites.

We have already followed Walker in comparing the Ardsheal [NM 995 574] basalt intrusion with the Taynuilt [NN 004 311] basalt lava (Anal. 3, (Table 2); (S9628) [NM 989 276]. In this latter, olivine phenocrysts (serpentinised) are big and numerous enough to match those of the kentallenites; but augite phenocrysts are wanting. In keeping, the analysis shows but little more MgO than is found at Ardsheal [NM 995 574]. That augite has not developed as phenocrysts is connected with relatively low CaO accentuated by high Al_2O_3, which last shows that a considerable proportion of the CaO has gone to felspar.

Two slices (S11573) [NN 1169 5239]; (S11574) [NN 1184 5233] represent the unusually basic kentallenite north-east of Sgòr na Ulaidh [NN 111 518]. Both show tremolite-magnetite pseudomorphs after olivine along with some development of irregular green hornblende after augite. The alteration is particularly marked in the relatively fine slice (S11574) [NN 1184 5233], which is from a marginal specimen. It may be attributable either to the Cruachan or the An t-Sròn pluton, since these two are about equidistant from the occurrence.

Biotite-augite-diorite and monzonite

The biotite-augite-diorites of Sheet 53 had perhaps better be called monzonitic gabbros. They may be described as augite-felspar-biotite-rocks. Their main differences from kentallenite are that olivine is much less important or actually absent, whereas biotite is more abundant and tends to occur in stout flakes of moderate extent, seldom poikilitic, while quartz may be present with granophyric tendency. Apatite remains a conspicuous accessory. The abundance of biotite associated with augite gives the rocks a strongly marked monzonitic character, and in some cases (S14113) [NN 0620 5109], Anal. 7, (Table 2) there is enough orthoclase present to warrant the name monzonite without any qualification. Secondary hornblende has been widely developed, and there is occasionally a little brown primary hornblende.

All the six slices in the collection agree closely with the general description given above. For the most part only special features will be referred to below. The occurrences are taken in the order in which they are mentioned in chapter 15 dealing with field relations. Grant Wilson recorded chilling in the field, but there is no corresponding specimen.

- Rudha Mor (S7055) [NM 968 563]. Tremolitic pseudomorphs after olivine. Interstitial quartz.
- Ardsheal [NM 995 574] Hill (S7054) [NM 995 569]. Some brown hornblende intergrown with biotite. Also green hornblende, probably juvenile.
- S. W. of Salachail (S11362) [NN 0584 5094]. Some tremolitic aggregates after olivine. Occasional primary hornblende growths about augite. Biotite as always.
- E. of Salachail (S14113) [NN 0620 5109]; Anal. 7, (Table 2)). Augite largely replaced by pale hornblende which may be juvenile. Biotite abundant. Felspars dirty, but orthoclase appears to serve as base to plagioclases.
- W. of Corbhainn (S11431) [NN 0757 5147]. Augite largely replaced by pale hornblende. Much micropegmatite.
- Glen Ure (S10125) [NN 060 475]. Undoubted contact-alteration by Cruachan "Granite". Augite replaced by aggregates of stout prisms of green hornblende. Some aggregate crystallisation of brown biotite. Some clouding of felspars.

Appinite (Plate 11), 2

On pp. 167–8 of the 1916 edition of this memoir the following definition was offered of appinite. (The name was based upon the parish of Appin that stretches south from the entrance to Loch Leven; and it was pointed out that the type appears to be widely distributed in the Highlands.)

"Appinites are the plutonic equivalents of hornblende vogesites and spessartites: they are dark rocks of medium to coarse texture, and mainly composed of green or brown idiomorphic hornblende (either stumpy or acicular) in a groundmass which contains plagioclase, orthoclase, and quartz in variable proportions; granophyric growths of quartz and orthoclase are common; where plagioclase is the dominant felspar, quartz may be almost or quite absent; olivine (as pseudomorphs), augite, and biotite are sometimes present. Decomposition, probably in part juvenile, has often given rise to tremolitic hornblende, chlorite, albite, zoisite, epidote, and calcite".

Appinites with predominant orthoclase might be classed by some authors as basic or ultrabasic syenites; and those with predominant plagioclase as basic or ultrabasic diorites.

Quartz is usually about as abundant as felspar. With failure of quartz and felspar the appinites join with hornblendites.

The appinites approach the proterobases including the albitic sub-group called minverite by Dewey (1910, p. 46). They are distinguished mainly owing to the red-brown colour of the hornblende of the proterobases, which is combined with a purplish tint, sometimes very faint, in the augite. Also ilmenite is often a conspicuous accessory in the proterobases, but not in the appinites.

A few comments on Geological Survey slices will suffice. Where brown is not specially mentioned the hornblendes are usually green. For convenience localities are again taken in the same order as in chapter 15 where field relations are considered.

- Glen Tarhert (S10937) [NM 8922 6362]. Only one slice has been examined of the small outcrops of appinite fringing the Strontian Pluton. It differs from slices of appinite south-east of Loch Linnhe in having two generations of hornblende (both are stumpy). The rock is probably ultrabasic, but includes as much granular quartz as felspar (oligoclase) in its base.
- Ben Nevis (S14046) [NN 135 716]. Well crystallised quartz and microperthitic orthoclase are present in the base.
- Binnein Beag [NN 222 677] (S14082) [NN 2271 6854]. The base consists of hypidiomorphic crystals of albite moulded about acicular tremolitic growths that proceed from the main hornblende crystals.
- Eilean Balnagowan (S7002) [NM 952 537]. Some of the hornblende is brown. Perthitic orthoclase and quartz serve as base, with occasional micrographic intergrowth.
- Ardsheal [NM 995 574] Hill (Walker 1927). Hornblende is greenish brown at the summit and brown further south. Anal. 1, (Table 2), is an ultrabasic summit variety.

- S.E. border, Ballachulish Pluton (S11364) [NN 0495 5322]; (S11443) [NN 0603 5286] [NN 0603 5286]; (S11444) [NN 0549 5270] [NN 0549 5270]. Hornblende is predominantly brown. Biotite fairly abundant; and in (S11364) [NN 0495 5322] augite too — a rare feature. Much of the felspar accompanying quartz is oligoclase.
- Barnamuc Burn, Glen Creran (S11359) [NN 0520 4994]. Rare olivine pseudomorphs. Hornblendes bleached. A little biotite. Albite plates. Quartz and calcite in interspaces.
- N.E. of Glenure House [NN 043 481] (S11433) [NN 0510 4875]; (S11434) [NN 0526 4888]. Felspar of base largely plagioclase.
- Glen Chàrnan (S8267) [NN 122 515]. Approaching hornblendite.
- Leacantuim [NN 117 577], Glen Coe (S11036) [NN 1152 5810]. A beautiful rock (Plate 11), 2. Hornblende greenish brown. Base of idiomorphic plagioclase surrounded by graphic intergrowths of quartz and orthoclase. Subordinate biotite. Acid segregation veins consist of a similar crystallisation of felspars and quartz with a few long needles of hornblende growing in from the sides.

Hornblende-diorite variant and associates

Early Fault-Intrusion of Glen Coe

Some of the Early Fault-Intrusion is basic, though some is intermediate or even acid (Anal. 19, (Table 3)). The more basic types range from diorite to porphyrite in crystallisation. Among these are hornblendic varieties which, as noted on p. 194, are extremely similar to the basic phase of the Beinn a' Bhuiridh Diorite at the south-east corner of the Etive Complex (Anal. 6, (Table 2)).

Let us start with two slices (S9133) [NN 257 490]; (S13406) [NN 250 489] of this variety collected from the Coire an Easain [NN 250 496] outcrops (Figure 29). They may be called basic hornblendic diorite with subsidiary augite and biotite — a basic development of the intermediate banatites. They are more felspathic than the appinites or biotite-augite-diorites so far described. Their felspar is acid labradorite with a strong tendency to stout idiomorphism and marginal zoning; while their main ferromagnesian mineral is a rich brown hornblende. In one slice (S9133) [NN 257 490] this hornblende builds crystals measuring over half a centimetre across and often moulded on the plagioclase; whereas in the other (S13406) [NN 250 489] hornblende crystals are smaller and tend to be elongated and idiomorphic. Augite, passing over to pale hornblende, and biotite are minor constituents; and there is a little groundmass, which, in (S13406) [NN 250 489] carries appreciable quartz. A slice (S13404) [NN 200 580] from Sròn a' Choire Odhair-bhig [NN 200 579] ((Figure 24), p. 158) closely resembles (S13406) [NN 250 489], but is definitely a porphyrite with lamprophyric tendency.

All the above are contact-altered, and three specimens of porphyrite (S12358) [NN 189 587]; (S12359) [NN 1853 5935]; (S12360) [NN 1868 5947] from Coire Mhorair (Figure 24) show this feature very markedly. The first is cut across a junction with a granite to the west (mapped as "Granitite Fault-Intrusion" in (Figure 24)); while the last is separated by a contemporaneous aplite vein from adjoining schist (not seen in slice). This last (S12360) [NN 1868 5947] is probably intermediate, a definite banatite-porphyrite, as also another contact-altered specimen from Stob Mhic Mhartuin [NN 207 575] further east.

The analysed specimen (S14109) [NN 1928 5876]; Anal. 19 comes from the top of the ridge separating Coire Mhorair [NN 185 585] from Coire Odhar- mhòr [NN 196 583] (Figure 24) and is far from typical of the Early Fault-Intrusion. It is a biotite-porphyrite carrying oligoclase phenocrysts in a ground consisting largely of alkali-felspar set in quartz; and its SiO_2 percentage of 65.30 places it in the acid category, though practically on the border line. In addition to normal oligoclase phenocrysts, there are some earlier felspars honeycombed as if by corrosion.

Finally we may note that the small patch of Early Fault-Intrusion at the bend of Càm Ghleann (p. 165; (S10328) [NN 250 523]), though basic, is exceptional in that its hornblende is pale-green rather than rich brown. This pale-green hornblende is clearly developed after augite which is commonly preserved as irregular relics. The replacement looks like a result of juvenile reaction. There are several pseudomorphs with criss-cross pale-green hornblende which quite probably represent olivine. Otherwise in its development of stout idiomorphic basic plagioclase and accessory biotite the rock closely resembles the hornblende-diorites of Coire an Easain [NN 250 496].

Intermediate, acid and ultra-acid plutonic rocks

Main Fault-Intrusion of Glen Coe

Much of the Main Fault-Intrusion (6 of (Figure 18), p. 129), like its Early predecessor, varies in texture from plutonic to hypabyssal. In addition, towards the north-west it is intensely xenolithic and extremely prone to permeate adjoining schists. In such case, though often carrying felspar phenocrysts, it develops an abnormal ground texture recalling somewhat that of a coarse aplite; but much of its quartz is xenocrystal.

Both granitoid and porphyroid varieties may be grey or pink, while the permeating facies is pink. Pink varieties of all sorts are well developed, but not exclusively, in and about the An t-Sròn mass on the west, and also in the north (where they include a probably slightly later phase lettered G on Sheet 53).

Further east grey varieties are typically represented by the Fault-Porphyrite of Stob Mhic Mhartuin [NN 207 575] and the Fault-Tonalite of the Coupall River.

Whatever its general crystallisation, whether granitoid as at An t-Sròn or porphyroid as at Stob Mhic Mhartuin [NN 207 575] or permeative as in much of the intervening country, the Fault-Intrusion always chills against the Boundary-Fault of the Cauldron-Subsidence. If the intrusion is a normal porphyrite, as we have seen it is at Stob Mhic Mhartuin [NN 207 575], it also chills against adjoining schist away from the fault; but not otherwise.

We have already considered the relations between Fault-Intrusion and contemporaneous flinty crush-rock as revealed in slices from Stob Mhic Mhartuin [NN 207 575] (p. 162). Let us now see what has been learnt from specimens collected by Kynaston in the gorge eroded along the Boundary-Fault where it descends from An t-Sròn [NN 134 550] to Glen Coe ((Figure 20), p. 133) — one word of caution: a bedded ashy sediment, picked up in this gorge (S10313) [NN 136 558]; (S10313a) [NN 136 558], must not be mistaken for flinty crush-rock.

A slice (S10309) [NN 134 549] from near the fault illustrates the universal chilling in this position. It shows a red quartz-porphyry with phenocrysts of orthoclase, plagioclase, biotite and quartz (the last possibly derived) set in a felsitic groundmass. Its texture is definitely hypabyssal and contrasts strongly with the equally definitely plutonic crystallisation seen in the same intrusion (S10308) [NN 134 548] a short distance further from the fault. The chilled slice (S10309) [NN 134 549] cuts across a small pelitic xenolith, in one layer of which sillimanite and corundum occur. Felspar forming *lit par lit* laminae in this xenolith is more coarsely crystalline than groundmass felspar in the igneous host. It must have grown in the *lit par lit* position before the quenching of the host magma.

A neighbouring specimen (S10310) [NN 136 558] furnishes a much better example of sillimanite-corundum-hornfels included in an igneous matrix which has been quenched to hornblende-biotite-porphyrite, a greyish type more basic than the porphyry just considered (S10309) [NN 134 549]. The hornblende phenocrysts here are pseudomorphed in criss-cross biotite indicating contact-action, presumably owing to continued intrusion of magma to build the An t-Sròn boss.

Still another slice (S10311) [NN 136 558]; (Plate 11), 4 is cut from a pelitic hornfels with a number of conspicuous pink felspathic *lit par lit* layers — a fine example of a migmatite. While much well-crystallised felspar has grown in the hornfels the pink layers consist largely of spherulitic felsite, sometimes with fully grown biotite phenocrysts. One sees here a migmatite quenched while in course of development. It is abundantly clear that the introduced igneous fraction entered as magma. One need scarcely point out that the chilling of the An t-Sròn margin as a whole witnesses equally clearly to the magmatic origin of this little boss of granite.

While in the An t-Sròn [NN 134 550] neighbourhood let us cross the Boundary-Fault a very short distance to look at the biggest of the very few, just three or four, little outcrops of Fault-Intrusion, which have managed to trespass into the Cauldron-Subsidence. It is lettered Gp on Sheet 53, and it is a grey porphyrite (S11904) [NN 1362 5502], with abundant stout plagioclase phenocrysts up to about 4 mm long. These are more broken perhaps than usual; but otherwise the rock as a whole is closely similar to the Stob Mhic Mhartuin [NN 207 575] porphyrite, described below. Maufe collected from it a lava xenolith, originally augite-andesite or basalt, about 6 cm long and surrounded by a coat, one or two centimetres thick, of pink, highly quartzose rock, to be spoken of below as the "pink rock" — this is the "Fault-Intrusion loaded with clear xenocrysts of quartz" of (Plate 11), 6. The lava of the xenolith is seen under the microscope to be completely reconstructed into a very fine-grained hornblende-felspar-schist or schistose granulite. Greenish-brown biotite is usually a subordinate constituent, but may altogether take the place of hornblende towards the margins of the xenolith. Minute grains of magnetite are fairly common. The hornblende is pale-green and builds little prisms, rarely 0.1 mm long; while the biotite makes correspondingly small flakes. The schistosity is expressed in the orientation of these two minerals, but is not pronounced. Former phenocrysts of ferromagnesian minerals are now represented by oval groups of criss-cross hornblende. There is considerable resemblance between this hornblende-schist, with subordinate biotite, developed on a very small scale at Glen Coe from basic andesite or basalt lava, and the well-known biotite-schist, with subordinate hornblende, developed on a fairly large scale in the Beinn a' Bhuiridh screen from hornblende-andesite lava — this last was elucidated by Kynaston and more fully by Anderson (S7627) [NN 097 288]; (S7628) [NN 097 288]; (S8258) [NN 12 30]; (S8259) [NN 12 30]; (S8260) [NN 12 30]; (S9312) [NN 077 289]; (S9316) [NN 111 292]; Kynaston *in* Hill, Kynaston and others, 1908, p. 96; Anderson 1937a, p. 517).

The Glen Coe xenolith is crossed or margined by a number of shear planes running in different directions; in fact its boundaries have been in large measure determined by resultant planes of weakness. The oldest crush-line that is seen in a junction slice (S11905a) [NN 1362 5502] is filled with 1 mm of flinty crush-rock or something closely allied. This contains much-broken felspar along with a few bigger grains of quartz. The felspar has come in large measure from a recrystallised fringe of the biotite-facies of the xenolith. The quartz grains are forerunners of the "pink rock"; but most of this latter came somewhat later on the scene and swept across the film of crush-rock just described. It is probable that the time-interval was trivial. Both the early crush-seam and the later surrounding "pink rock" were responsible for developing marginal biotite in the xenolith.

Some of the border crushing of the xenolith has manifestly affected adjacent "pink rock". As a rule in such case the xenolith is still fringed, at contact, with biotite-facies, though the biotite may share in the crushing. Probably in such a case the movement was small and carried through while the "pink rock" was quite hot. Locally a crush-junction of xenolith and "pink rock" finds broken hornblende right up to the contact; and where this is observed it is likely that biotite-facies has been faulted out. Locally too there may be chloritic replacement of hornblende in a crush-zone, probably due to comparatively late, low-temperature adjustment.

The "pink rock" consists to about half its volume of roughly rounded grains of quartz, measuring up to a millimetre across; and it closely resembles the Fault-Intrusion, where this latter, north of Glen Coe, assumes an arkosic appearance through admixture with disintegrated quartzite (pp. 157, 219 and (Plate 11), 5). Only, in the present instance, the quartz grains are held in a microfelsitic matrix, very much finer than what is seen north of Glen Coe well outside the Boundary-Fault. This is important. We examine here (S11905) [NN 1362 5502] a quenched representative of permeated, mobilised quartzite, which probably no one would claim as a product of crystallisation from ultra-acid magma. It is inconceivable that such a magma could crystallise so large a proportion of its quartz in 1 mm grains before it started to crystallise any of its felspar.

The junction of the thin layer of "pink rock" with the surrounding intermediate grey porphyrite that constitutes almost all the little invasion of Fault-Intrusion is highly irregular. When the two met, their matrixes were liquid and mixed in complex fashion. Still one can see that the crystallisation of the "pink rock" matrix is just a shade more apparent than that of the adjacent grey porphyrite. This difference does not mean that the "pink rock" matrix was the hotter of the two, but merely that it was more acid, and therefore more crystallisable when dropping to the low temperature it found within the Cauldron-Subsidence. Actually the grey porphyrite matrix was the hotter of the two, for comparison of slices (S11905) [NN 1362 5502] with (S11904) [NN 1362 5502] shows that the phenocrysts of the grey rock are smaller, and that the groundmass is appreciably finer, at contact with the "pink rock" than at a little distance. Another interesting feature is that hornblende xenocrysts supplied to the "pink rock" from the grey show two successive types of alteration. They usually carry a narrow rim of criss-cross biotite surrounding interiors replaced by the same kind of chlorite as has been noted as a late-stage product in crushes crossing the xenolith.

To sum up: — The xenolith of basic andesite or basalt lava travelled a short distance into the Cauldron-Subsidence from the immediate proximity of the Boundary-Fault. While in the fault-zone it had been subjected to successive crushing, and involved in an uprise on a small scale of "pink rock" magma — which latter in depth had become charged with quartz xenocrysts through interaction with Glen Coe Quartzite. After that, along with some adherent "pink rock" magma, the xenolith was carried into its present position by intermediate grey Fault-Intrusion magma; and there it and its associates were quenched in the cold environment of the Cauldron-Subsidence.

Before proceeding further in regard to permeation (p. 219), let us note a few more details about apparently uncontaminated varieties of the Main Fault-Intrusion.

The analysed rock (S12351) [NN 208 575]; (S14117) [NN 2081 5748], Anal. 12, (Table 2) from Stob Mhic Mhartuin [NN 207 575] furnishes an excellent example of the grey, intermediate, porphyrite type, and may be classed as banatite-porphyrite. Under the microscope it proves to be surprisingly like much of the Early Fault-Intrusion. One says "surprisingly", for the two intrusions can be easily distinguished in the field — though this follows largely from disturbance and baking affecting the earlier. There are the same rather basic felspar phenocrysts, labradorite or andesine, and the same rich-brown phenocrysts of hornblende and biotite (here marginally resorbed as in a lava). Idiomorphic pyroxenes, both monoclinic and rhombic, make fairly frequent small phenocrysts. Magnetite is also an early mineral; while the felspathic groundmass carries but little quartz. Apatite is a fairly abundant accessory.

A more acid, pink porphyrite (S12350) [NN 1612 5848] from Meall Dearg [NN 163 585] is very similar, but with less pyroxene among the phenocrysts, and more quartz and alkali-felspar in the groundmass.

In another specimen (S12495) [NN 2310 5546],a grey, intermediate rock from the River Coupall [NN 210 554], the phenocrysts have grown so large at expense of the groundmass that the rock is of plutonic aspect. Its pyroxene is less abundant than at Stob Mhic Mhartuin [NN 207 575], and tonalite or tonalite-porphyrite seems the appropriate name. Tonalite also fits three other slices (S9129) [NN 2492 5459]; (S12502) [NN 2445 5430]; (S12503) [NN 2408 5503] from the rivers Etive and Coupall, in which hornblende is paler and greenish, while pyroxene is almost wanting. Their crystallisation is plutonic. They, carry very little orthoclase or quartz. The idiomorphic tendency of their stout plagioclase felspars connects them texturally with the coarse porphyrite facies.

Another related grey coarse porphyrite merging into tonalite (S10305) [NN 12 58] is represented from the east side of the An t-Sròn boss; while grey quartz-biotite-diorite (S10307) [NN 129 565] from the River Coe [NN 155 569] in the same neighbourhood differs mainly through the absence of hornblende.

Pink adamellites (S10308) [NN 134 548]; (S10306) [NN 14 57] may be quoted from An t-Sròn and the opposite slope across the Coe. They contain a little biotite and a considerable proportion of quartz and orthoclase. It is always open to question how far the acid products of the Fault-Intrusion have been acidified through reaction with quartzite such as is described below.

In the Glen Etive region the Fault-Porphyrite (S11503) [NN 1794 5023]; (S11504) [NN 173 500]; (S11505) [NN 1685 4958]; (S11576) [NN 1610 5124] has suffered contact-alteration by the Cruachan "Granite".

The "Granitite Fault-Intrusion" partly included in (Figure 24) (p. 158) is an adamellite with little hornblende, but well developed biotite, oligoclase, orthoclase and quartz (S12349) [NN 1889 5928]; (S12352) [NN 183 591] — the latter with contemporaneous aplite). The texture is allotriomorphic though with oligoclase elongated. A probably related vein in schist that is shown as phyllite in the N.W. corner of (Figure 24) is almost a binary granite (S12353) [NN 181 593] with quartz in equidimensional grains upon which large crystals of cryptoperthitic orthoclase are moulded. A neighbouring little boss is even more acid (S13343) [NN 186 593] and very prone to graphic intergrowth. All three types can be matched fairly closely in the acid facies of the Cruachan "Granite" (see below), though the vein (S12353) [NN 181 593] also suggests slightly the permeation products of the Fault-Intrusion of the following paragraph, of which possibly it may be an extreme modification. The granitite, or adamellite, mass makes a narrow merging contact (S13342) [NN 186 593] with the Fault-Intrusion, in which age relations are not clear.

We are now in a position to consider more closely the permeation phenomena connected with the Fault-Intrusion, especially in the northern area between Garbh Bheinn and Glen Coe (p. 157). Several slices (S11517) [NN 1592 5970]; (S11518) [NN 1592 5970]; (S11519) [NN 1592 5970]; (S11520) [NN 1592 5970]; (S11521) [NN 1592 5970]; (S11522) [NN 1592 5970]; (S12354) [NN 1565 5974]; (S12355) [NN 1565 5974]; (S12356) [NN 1565 5974]; (S12357) [NN 1565 5974] have been examined from an extensive intrusion-breccia on the flanks of Garbh Bheinn [NN 170 601]. This is mapped on Sheet 53 as Fault-Porphyrite, and is exposed in a tributary that joins Allt Gleann a' Chaolais [NN 145 605] from the north-east rather more than a mile above Caolasnacon. The intrusion-breccia carries innumerable xenoliths derived from adjoining mica-schist and quartzite; and both xenoliths and country-rock show much contact-alteration including felspathisation.

The xenoliths lie at all angles, and where pelitic have generally developed numerous small flakes of intensely pleochroic biotite, occasionally accompanied by larger poikiloblastic crystals of the same. The small flakes may be distributed with marginal concentration (S11518) [NN 1592 5970]; (S12354) [NN 1565 5974]. Other almost constant features are little crystals of magnetite along with quartz and felspar. Andalusite may be common (S12355) [NN 1565 5974]; shimmer aggregate abounds; pinite, clearly after cordierite, is sometimes seen (S11518) [NN 1592 5970]; corundum also, occurring in small crystals (S11519) [NN 1592 5970]; (S11520) [NN 1592 5970]. *Lit par lit* injection is well exhibited in certain hand specimens (S11520) [NN 1592 5970]; (S11522) [NN 1592 5970].

It is to the enclosing matrix that attention is here specially directed. This may be of normal igneous appearance: for instance it may be coarse porphyrite with phenocrysts of oligoclase, orthoclase and biotite in a well crystallised groundmass of quartz graphically intergrown with alkali-felspar (S11519) [NN 1592 5970]; or, with practically no phenocrysts, it may be coarse felsite or fine binary granite (S11520) [NN 1592 5970]; or again it may be acid adamellite, with subdued porphyritic tendency, and on the whole of allotriomorphic texture (S12357) [NN 1565 5974]. The quartz in such cases occurs in grains, often in contact and usually measuring less than 1 mm across.

On the other hand, in most specimens in the Survey collection, the matrix, whether it carries fairly numerous felspar phenocrysts (S11518) [NN 1592 5970]; (S12354) [NN 1565 5974], or no (S11517) [NN 1592 5970]; (S11522) [NN 1592 5970]; (S12355) [NN 1565 5974]; (S12356) [NN 1565 5974], is definitely abnormal, for it is crowded with sub-rounded quartzes with irregular margins moulded upon smaller intervening crystals of alkali-felspar. A common size for the quartz grains is about 1 mm, and for the felspars 0.1 mm. In hand specimens the quartz grains give the containing rock a definitely arkosic appearance, as may be realised from (Plate 11), 5 (p. 211).

The quartz grains in these abnormal rocks closely resemble, as noted already, the quartz grains of the quenched "pink rock" south of Glen Coe (p. 217; (Plate 11), 6). They differ, however, in their marginal moulding upon intervening felspar crystals, for in the quenched "pink rock" such intervening crystals have not developed. They also recall abundant minute quartz grains seen in an aplite vein (S12515) [NN 206 528] cutting Cruachan "granite"; but the quartzes of this aplite are much smaller, and what is probably significant, are of the same general size as the accompanying felspars. Putting all this evidence together we may say:

1. In the quenched "pink rock" the quartz grains were present before the felspar crystallisation started — this is straight-forward observation.
2. In the unquenched permeation zone the quartz grains, to judge from their size, were in the main earlier than the felspar crystallisation, though they added marginally to their substance even after felspar crystallisation had almost ceased.
3. In the aplite the crystallisation of quartz and felspar seems to have been essentially simultaneous.

Slices (S11517) [NN 1592 5970]; (S11517a) [NN 1592 5970] from the present locality show the edge of a quartzite xenolith from which quartz grains, exactly similar to those that are widespread in the intrusion-breccia matrix, are being prised off through intergranular entry of alkali-felspar ((Plate 11), 5). It appears certain from what is seen in the field and under the microscope that a great quantity of quartzite has thus been subdivided into isolated xenocrysts (subsequently modified), while associated mica-schist has preferentially given xenoliths — there are also plenty of xenoliths of quartzite, some of which, according to Hardie (1955), are gigantic. We may recall that Teall (1899, p. 642), following Horne, long ago described a granite contact in the Southern Uplands, at which "coarse-grained quartz rock"., resulting from thermal crystallisation of radiolarian chert, "becomes more or less disintegrated", so that "detached grains… may be isolated in the igneous matrix" (S4953) NX 52 91]; (S4954) NX 52 91]; (S4955) NX 50 90]; (S4956) NX 50 89]; (S4957) NX 49 90]; (S4958) NX 49 90]; (S4959) NX 49 89]; (S4960) NX 49 89]; (S4961) NX 49 90]; (S4962) NX 48 87]; (S4963) NX 42 81]; (S4964) NX 48 89]; (S4965) NX 48 89]; (S4966) NX 49 87]; (S4967) NX 49 87]; (S4968) NX 48 87]; (S4969) NX 48 87]. His evidence, like that conveyed in (S11517) [NN 1592 5970] quoted above, is completely convincing; but it might be discounted as concerning only a small-scale phenomenon. In the Glen Coe area we seem to have evidence of grain by grain subterranean erosion of quartzite by magma on a large scale. The process may be styled, by those who like long words, dispersive permeation accompanied by mobilisation. It is probable that important volumes of quartzite were thus tranferred to upper regions, perhaps to the surface.

Etive Complex

The following brief account of the rocks of the Etive Complex (8 of (Figure 18), p. 129, excluding 6, the Fault-Intrusion of Glen Coe) must be read in conjunction with chapter 13, where a full statement of subdivisions and field relations will be found. As there mentioned, Anderson's description (1937a) should be consulted for further detail.

Southern lobe of the Cruachan "Granite"

The southern lobe of the Cruachan "Granite" is only represented in the Geological Survey collection from Sheet 53 by a contact specimen (S15877) [NN 0604 4745]; but its low-level grey facies is like a sliced rock (S7758) [NN 161 348] from Sheet 45, Geol. This is a tonalite with biotite more abundant than green hornblende, much oligoclase, a fair proportion of quartz and extremely little orthoclase. Anderson describes upward merge into acid types, such as is outlined below for the northern lobe. In the southern lobe he finds the average specific gravity to be 2.73 below 2000 ft and 2.67 above (1937a, p. 516). He raises a further interesting point in recording contact-alteration of the Cruachan "Granite" at three-quarters of a mile from the Starav Granite, and apparent absence of change at close quarters.

Northern lobe of the Cruachan "Granite"

The northern lobe of the Cruachan "Granite" is everywhere pink and acid. The characteristic type at low levels (S11559) [NN 200 470]; (S11562) [NN 199 497]; (S12513) [NN 207 512]; (S12514) [NN 2103 5265]; (S12515) [NN 206 528]; (S14112) [NN 2252 5237]; (S14176) [NN 1392 4742] is a hornblende-biotite adamellite, with green hornblende, brown highly pleochroic biotite, and a good development of oligoclase-andesine, or oligoclase, and cryptoperthitic orthoclase. Sphene and apatite are accessories, the former often conspicuous. As a rule the oligoclase gives the biggest and best-formed crystals, which sometimes function as vague phenocrysts. A slice (S14112) [NN 2252 5237] from the analysed specimen (Anal. 26, (Table 3)) shows a patchy development of its more basic minerals; and some of its hornblende crystals include relics of augite. In another (S11562) [NN 199 497] there is an approach to the still more acid types of high levels; and microcline twinning is fairly frequent, an unusual feature for Sheet 53. Two slices (S11561) [NN 207 485]; (S12515) [NN 206 528] have been cut to illustrate acid veins. The former shows throughout fine graphic intergrowth of quartz and alkali-felspar, occasionally twinned on the microcline pattern. The latter (S12515) [NN 206 528] has only a 2-mm graphic fringe, and is mainly an aplite with minute subrounded grains of quartz and alkali-felspar, of roughly equal size.

The upward passage of the Cruachan "Granite" of the northern lobe, from adamellite at low levels into binary granite at higher, has been vouched for by Kynaston, Grabham and J. G. C. Anderson. Two slices (S11533) [NN 218 507]; (S11543) [NN 2077 5075] collected by Grabham represent middle levels and compositions. They show highly quartzo-felspathic granites, with biotite as the ferromagnesian mineral and with crypto- or micro-perthitic orthoclase preponderant over oligoclase.

The summit type, represented by Grabham's specimens (S11534) [NN 218 504]; (S11542) [NN 2041 5036]; (S11552) [NN 2211 4568]; (S11553) [NN 218 497]; (S11569) [NN 212 489]; (S11570) [NN 214 487] comes very close to binary granite through further reduction of biotite and oligoclase. In fact the term binary granite or near-binary granite conveys the essentially quartz-orthoclase composition much better than plain granite. The texture varies, and in three of the slices (S11542) [NN 2041 5036]; (S11553) [NN 218 497]; (S11570) [NN 214 487] there is some graphic intergrowth. Local abundance of drusy cavities is noted in the field description. The composition must often be ultra-acid.

Meall Odhar Granite

The pink Meall Odhar Granite of the Etive Complex (S11497) [NN 177 477]; (S11498) [NN 185 473]; (S11499) [NN 1777 4787] is in its type locality a coarse binary granite with a little oligoclase and biotite, this latter sometimes altered to chlorite. By far its most abundant felspar is more or less perthitic orthoclase. The texture tends in part to be graphic. The rock very locally (S11498) [NN 185 473] has suffered from granulitisation along shear planes developed probably at a fairly high temperature.

The only known difference between the Meall Odhar Granite and the hilltop facies of the Cruachan "Granite", noted above, is that the former is definitely the younger of the two (see chapter 13). What Anderson, with good justification, takes to be Meall Odhar Granite at Stob Gaibhre [NN 063 467], south of Glen Ure [NN 070 475], is again of similar type, but is not represented in the Survey collection. Its southern continuation is represented in Anal. 31, (Table 3).

Starav Granite

The Starav Granite of the Etive Complex is later than the Meall Odhar Granite (chapter 13). Most of what enters Sheet 53 belongs to the porphyritic margin of this boss, here half a mile wide and merging very gradually into nonporphyritic interior, which latter is mostly included in Sheet 45 (Geol.) to the south. The porphyritic facies (S7752) [NN 160 377] is represented from Glen Kinglass [NN 140 360] in Sheet 45. In the available slice a big pink felspar, 2 cm long and 1 cm broad, is partially shown. It is one that helps to give a porphyritic appearance to the rock; but even with no more than a pocket lens it is seen to be completely allotriomorphic. We shall find presently at Ben Nevis that such crystals have resulted from continuous outgrowth of phenocrysts. The specially big pink felspar in the slice (S7752) [NN 160 377] is perthitic orthoclase. It includes among others oligoclase crystals, which are fairly idiomorphic but not of outstanding size. Kynaston, however, noted that the large phenocrysts of the porphyritic zone in general are both pink and white; and examination of hand specimens shows that the latter are clearly plagioclase with twinning stripes. It is quite common among hypabyssal porphyrites to find both orthoclase and plagioclase occurring together as phenocrysts.

The Glen Kinglass rock (S7752) [NN 160 377] has more than twice as much orthoclase as plagioclase. It can be classed as a biotite-granite allied to adamellite. It is rich in quartz, but its fairly abundant hornblende and biotite as well as its felspar phenocrysts distinguish it from the hill-top binary facies of the Cruachan "Granite". Accessory sphene is less conspicuous than in the adamellite facies of the latter found lower down.

The analysed specimen (Anal. 29, (Table 3); (S14111) [NN 1429 4662] is from the transition zone between porphyritic and non-porphyritic. It differs from the Glen Kinglass rock (S7752) [NN 160 377] in having rather smaller allotriomorphic crystals of microperthitic orthoclase; but otherwise it is so similar as not to require separate description.

The fully developed non-porphyritic interior contains less ferromagnesian constituents, but is not represented among Geological Survey slices from Sheet 53.

Ben Nevis Complex

Chapter 14 has been devoted to the field relations of the Ben Nevis Complex (1 of (Figure 18), p. 129). These were elucidated by Maufe, except for the subdivision of the usually grey, non-porphyritic portion of the Outer "Granite". Here we are indebted to J. G. C. Anderson (1935b), whose work on the petrology of the resulting subzones, 1 fine, 2 medium and 3 coarse-grained is summarised below.

Subzone 1 of the Outer "Granite" of Ben Nevis

((Figure 31), p. 178) is a fine-grained rock, usually a grey quartz-diorite of Banat type — what we call in this memoir a banatite. Its ferromagnesian minerals are augite, biotite and hornblende; while its felspar is mainly oligoclase, and interstitial quartz is abundant. Analysis 11, (Table 2) is representative. Low-level outcrops on the west and north have specific gravity averaging 2.73, and are more basic than high-level outcrops on the east, where a specimen gave 2.64.

The only slice (S8817) [NN 1577 7664] in the Geological Survey collection comes from Allt na Caillich (Figure 31) near the schists on the west, and seems exceptional. Its augite mostly occurs as scant relics in plentiful hornblendes, but it also builds a few small independent crystals. Its biotite is abundant; and so is its orthoclase, in large poikilitic crystals enclosing oligoclase, etc. Hill and Kynaston have drawn attention to its monzonitic affinities (1900, p. 540). The plagioclase crystals often show needly clouding suggestive of contact-alteration.

Subzone 2 of the Outer "Granite" of Ben Nevis

(Figure 31) is medium-grained, and is usually a grey banatite (Anal. 15, (Table 2)), though at high levels in the east it becomes a biotite-granite. Average specific gravity at low levels in the west and north is 2.75, and at high levels in the east 2.65.

Subzone 3 of the Outer "Granite" of Ben Nevis

(Figure 31) is the innermost and latest of the three outer, non-porphyritic subzones; and it makes a merging contact with the porphyritic Subzone 4 next to be described. It is the coarsest of the three non-porphyritic subzones, and in the lower ground of the west and north, away from its contact with Subzone 4, the main type is once more banatite (Anal. 8, (Table 2)), with fairly abundant hypersthene and augite, hornblende (frequently rimming augite), late-crystallised biotite, andesine or oligoclase and a little orthoclase and quartz. A slice (S8816) [NN 1286 7401] from the tributary which enters Glen Nevis just south of Claggan [NN 123 742] farm seems abnormal in that much of its pyroxene is replaced by irregular sheaves of pale hornblende suggesting contact-alteration rather than normal auto-reaction. The plagioclase also shows faint needle clouding. Possibly the specimen has been taken from an enclosure belonging primarily to Subzone 2.

The banatite of Subzone 3 passes into adamellite as we ascend to the high exposures on the east side of the complex. Anderson found an average specific gravity of 2.79 on the west and 2.69 on the east. "It is interesting to note", he remarks (1935b, p. 343), "that the difference of height between the highest exposure of the Coarse Type [Subzone 3], that on Aonach Mòr [NN 193 730], and the lowest, that in the River Nevis [NN 200 680], is over 3900 feet, the greatest exposed vertical thickness of any igneous intrusion in the British Isles".

The banatite of Subzone 3 also passes into adamellite in the transition belt connecting it with the porphyritic Subzone 4, the innermost subdivision of the Outer "Granite". A specimen taken from this transition belt at about the 800-ft level on the tourist path to the summit is in hand-specimen (S14420) [NN 1355 7192] a pinkish granitic-looking rock with inconspicuous porphyritic texture. Under the microscope, pyroxene is wanting, while hornblende, biotite, oligoclase, cryptoperthitic orthoclase and quartz, all build big, rather ill-formed crystals, which can be termed phenocrysts, set in a coarse granular matrix of quartz and alkali-felspar. Sphene and iron ore are the main accessories. This rock is better described as an adamellite-porphyrite or porphyry rather than plain adamellite. Some of its plagioclase shows very faint needle clouding.

Subzone 4 of the Outer "Granite" of Ben Nevis

(Figure 31) is thorough biotite-hornblende-granite (Anal. 21, (Table 3)) with more than twice as much cryptoperthitic or microperthitic orthoclase as plagioclase (S8814) [NN 1460 7357]. This orthoclase makes conspicuous pink patches, sometimes 2 cm long, which evidently, from analogy with what is seen in (S14420) [NN 1355 7192], just described, should be interpreted as outgrown phenocrysts. Under the microscope the phenocrystal appearance is lost owing to the allotriomorphic outgrowth. Quartz is abundant and builds big crystals and groups of crystals in much the same manner as the orthoclase; but it does not achieve a phenocrystal appearance. Zoned plagioclase, near oligoclase, biotite and hornblende are more idiomorphic. Sphene continues an accessory.

The Inner "Granite" of Ben Nevis

(Anals. 24, 28, 30, (Table 3)) has already been discussed as in large measure a trondhjemite. It is in general a pale pinkish rock, of fine-grained granitoid appearance, and with very subdued porphyritic tendencies. Maufe has collected several interesting specimens. Two from Allt a' Mhuilinn [NN 161 730], (S8815) [NN 1558 7365] a little upstream from the Porphyritic Subzone 4 of the Outer "Granite" and (S14421) [NN 1655 7242] approaching the downfaulted andesites, are both essentially made of biotite, plagioclase, orthoclase and quartz. The plagioclase is roughly twice as abundant as the orthoclase; and its stumpy crystals, rarely 3 mm long, are highly zoned. They may start with labradorite and end up fringed with clear primary albite.

An actual junction (S14043) [NN 1556 7371] between Inner and Outer "Granites" from Allt a' Mhuilinn [NN 161 730] shows a closely similar, but rather more alkali adamellite facies of the Inner "Granite", which is characterised by oligoclase and abundant orthoclase. As seen in all exposures of this contact, the Inner "Granite" exhibits no sign of chilling. Also the slice reveals no contact-alteration of the Outer "Granite", though, it will be remembered, an important phase of dyke intrusion separates the two "granites" in time. Maufe has collected two specimens from one of the dykes above Allt Daim [NN 179 740] mentioned on p. 182. The dyke is a microdiorite; in the first specimen (S14047) [NN 1817 7396] we see its fine-grained edge (granulitised by subsequent recrystallisation) cutting typical Outer "Granite"; while in the second (S14048) [NN 1821 7386] its coarser interior is crossed by the Inner "Granite". The hand-specimens tell the complicated story much more clearly than the micro-slices. Then from Allt Coire Gaimhnean [NN 140 705], on the other side of the complex, Maufe's collection shows a baked dyke (S14049) [NN 1421 7064] with close beside it later trondhjemitic Inner "Granite" (S14050) [NN 1421 7064], p. 182). The dyke is thoroughly crystallised with more graphic intergrowth than usual.

The contact of Inner "Granite" with the cold down-thrown volcanics of the cauldron-subsidence is very strikingly different: a specimen (S14044) [NN 1661 7067], collected by Maufe from Coire Eoghainn [NN 165 705] 600 yd S.S.W. of Ben Nevis summit [NN 163 713], shows that the "granite" has passed into a fluxion rhyolite with 2-mm phenocrysts of oligoclase and 1-mm phenocrysts of biotite; and that this rhyolitic margin is separated from andesite lava by 1.5 mm of flinty crush-rock — indistinguishable from the andesite in hand specimen. The andesite is slightly baked with development of exceedingly small flakes of biotite.

The flinty crush-rock in this specimen (S14044) [NN 1661 7067] is recognisable under the microscope on comparison with Glen Coe analogues (p. 161). It appears as a microscopic to ultra-microscopic breccia with recognisable debris derived from both andesite and rhyolite. The marginal fluxion of the rhyolite is wavy, and its drag involves the adjacent crush-rock; while its phenocrysts, where they touch the latter, bend or break. Presumably the flinty crush-rock has been brought down from a higher level where it formed along the Boundary-Fault of the Ben Nevis Cauldron-Subsidence, up which Inner "Granite" magma was just starting to ascend.

Another specimen, from Allt a' Mhuilinn [NN 161 730] (S14045) [NN 1655 7240], shows that the flinty crush-rock may be fully 4 cm thick in places. Again debris from both the marginal Inner-"Granite" -rhyolite and the andesite lavas is recognisable.

Mullach nan Coirean and Meall a' Chaoruinn Granites

The granite of the twin outcrops (2 of (Figure 18), p. 129) of Mullach nan Coirean (S8487) [NN 136 667] and Meall a' Chaoruinn (S8276) [NN 112 657] affords an almost ideal example of a binary granite. In the hand it appears as a well crystallised pink to red granite, with quartz showing a tendency to a blue tint. Muscovite may here and there be seen.

Under the microscope quartz sometimes shows crystal faces; and very occasionally it joins the orthoclase in pegmatitic growths. The great bulk of the felspar is microperthitic orthoclase, but albite and oligoclase and also micro-cline are represented. Biotite and magnetite constitute very minor accessories. The rock is probably often ultra-acid.

Loch Linnhe Granites

The red granites following the north-west shore of Loch Linnhe (*e.g.* 3 of (Figure 18), p. 129 have not been microscopically studied, so that we cannot add here to what has been said of them in chapter 15.

Strontian Complex

The Strontian Complex (4 of (Figure 18), p. 129) scarcely enters Sheet 53. Chapter 15 has supplied a brief summary of a paper on the complex by MacGregor and Kennedy (1932), and a fuller account is being prepared for the forthcoming

Geological Survey memoir on Sheet 52 (Geol.). Slices cut from Sheet 53 exposures are (S10930) [NM 8573 6079]; (S10931) [NM 8832 6143]; (S10932) [NM 8848 6135]; (S10935) [NM 8853 6206]; (S10936) [NM 8849 6153]; (S10937) [NM 8922 6362]; (S11029) [NM 8991 5611]; (S11030); (S11032) [NM 874 528]; (S11033) [NM 883 555]; (S11034) [NM 8832 5613]; (S11035) [NM 8718 5610]. They come in large measure from a fringe of small intrusions extending a little outside the boundary of the coherent complex.

Ballachulish Complex

The Ballachulish "Granite" Complex (5 of (Figure 18), p. 129) has been separated in chapter 15, following Lawrie, into a grey, more or less outer, early tonalite and a pink, more or less inner, later granite. There is also at Rudh' a' Bhaid Bheithe [NN 025 595] a local marginal strip of "white granite" described by Walker.

The strip of "white granite"(Anal. 27, (Table 3)) has been dealt with sufficiently in regard to its sulphur content in chapter 15, and has been mentioned again in relation to the use of the name trondhjemite. Similar rock (S11363) [NN 0690 5309] on the other side of the main pluton makes a small isolated "granitic" boss in Allt Eilidh [NN 067 530].

The well known grey tonalite (Anals. 10, 13, (Table 2)) resembles the main Fault-Intrusion of Glen Coe in carrying a multitude of xenoliths. It is of very even, medium-grained texture (S7052) [NN 022 590], and consists of comparatively idiomorphic brown biotite, green hornblende and andesine, in a subordinate matrix of allotriomorphic quartz and cryptoperthitic orthoclase. The last-named occurs in rather large poikilitic crystals. Sphene, apatite, magnetite and zircon are accessory. The sphene, as Teall has pointed out, is moulded on the plagioclase and ferromagnesian constituents.

The later pink granite is shown by Anals. 20, 25 of (Table 3) to include varieties with much the same compositions as the unusually acid Early Fault-Intrusion (Anal. 19) and the Cruachan adamellite (Anal. 26).

Rannoch "Granite"

The western margin of the Moor of Rannoch "Granite" (7 of (Figure 18), p. 129) enters Sheet 53 between the Blackwater Reservoir [NN 250 605] and Càm Ghleann [NN 247 515]; and a short description is given in chapter 15. The next two paragraphs are based on specimens collected from a little way into Sheet 54 (Geol.) in the neighbourhood of Kingshouse [NN 260 546] Hotel.

Specimen (S9128) [NN 26 55] was taken by Kynaston to represent the main grey, slightly foliated type with conspicuous alined blebs of quartz. It is an unusually quartzose tonalite with abundant green hornblende, brown biotite and oligoclase. A little microperthitic orthoclase occurs in rather large allotriomorphic crystals, sometimes invaded by myrmekite. Sphene is a conspicuous accessory. Another specimen (S12794) [NN 268 550] selected by Grabham, also as typical, is very similar, though the slice includes so much quartz that the rock should probably be classed as a trondhjemite rather than a tonalite.

Incoming of additional orthoclase as the margin of the intrusion is approached is seen in a specimen (S12793) [NN 265 523] collected by Grabham to illustrate this feature. It is also shown in the analysed rock (S14110) [NN 260 550], Anal. 23, (Table 3)). In this last biotite predominates over hornblende, but oligoclase remains more than twice as abundant as orthoclase. The analyses shows that the rock is acid, and as an acid granodiorite it is here classed as trondhjemite.

Sheet 53 affords excellent examples (S11528) [NN 2463 6037]; (S12749) [NN 2493 5459]; (S12750) [NN 2499 5466]; (S14080) [NN 2480 6046] of the thoroughly acid pink, slightly porphyritic marginal facies. They come from the dam site of the Blackwater Reservoir [NN 250 605] and from the Rivers Coupall [NN 210 554] and Etive [NN 190 510]. They are thoroughly acid, coarse, biotite-granites in which orthoclase generally strongly predominates over plagioclase. There has been so much outgrowth from early phenocrysts that the ill-marked porphyritic texture seen in hand specimens practically disappears under the microscope.

"Granite" boulders in Lower Old Red Sandstone conglomerates

The "granite" boulders from various conglomerates of Glen Coe are fairly decomposed, with biotite their only ferromagnesian as yet found fresh. Pseudomorphs that are probably after hornblende occur in certain cases. Alkali-felspar is cryptoperthitic orthoclase as in the local plutonic assemblages. This orthoclase is sparingly developed, so that most of the boulders are tonalite or quartzbiotite-diorite (S10285) [NN 1594 5870]; (S10286) [NN 1594 5870]; (S10287) [NN 1594 5870]; (S10288) [NN 1594 5870]; (S10326) [NN 24 51]; (S12334) [NN 1590 5870]; (S12335) [NN 1590 5870]; (S12788) [NN 2488 5191]; (S12789) [NN 2488 5191]. The last two specimens cited come from Càm Ghleann, and have been justifiably compared by Grabham with the marginal facies of the Moor of Rannoch "Granite" close at hand (p. 147). The reader may be reminded that the plutonic types found in the conglomerates are far outnumbered by lava types such as make up the volcanic pile of Glen Coe. Hypabyssal types are rare, though quartz-porphyry has been collected (S10289) [NN 1594 5870].

A similar suite of granitic boulders (S10295) [NM 847 311]; (S10296) [NM 847 311]; (S10299) [NM 792 267]; (S18692) [NM 8526 3134]; (S18694) [NM 8526 3134] has been found near Oban [NM 860 300] in the Lower Old Red Sandstone conglomerates of Lorne (Sheets 44, 45, Geol.). Here too there is an occasional quartz-porphyry, (S18693) [NM 8526 3134]; while granophyre is another rarity (S10297) [NM 847 311]. The latest account (Bailey 1925, p. 26) follows Kynaston in assigning these boulders, both in Lorne and Glen Coe, to "granites" of the Lower Old Red Sandstone suite, brought to the surface by explosion or possibly sometimes by erosion (*cf.* p. 131).

Basic hypabyssal rocks

Lamprophyre: introduction

The rocks here considered are dark, medium-to fine-grained lamprophyres rich in ferromagnesian minerals that are generally hornblende though sometimes with a considerable proportion of biotite, augite and olivine. The ferromagnesian minerals, apart from the biotite, are idiomorphic. The biotite usually occurs in small hypidiomorphic flakes. The felspar often builds big groundmass crystals; but more basic plagioclases may occur as laths, in which case the general texture is panidiomorphic. Apatite is an abundant accessory, and, in keeping with this, juvenile reaction is frequent, producing green biotite, colourless amphibole, albite, calcite and occasional epidote. It will be pointed out (p. 259) that such juvenile alteration is often very difficult to distinguish from subsequent contact-alteration.

Three species of lamprophyre are represented in the district, namely hornblendic spessartites and vogesites and biotitic kersantites. The spessartites and vogesites should be distinguishable from one another by predominance of plagioclase in the base of the former and of orthoclase in that of the latter; but as the plagioclase is often alkaline, little-twinned and turbid the difference may be impossible to establish in detail. Taken together the spessartites and vogesites of the district correspond in every respect, except for their finer texture and an absence or rarity of micropegmatite, with the appinites described above.

In 1902 Flett showed that most of the rocks previously styled camptonites on the mainland of Scotland should be transferred to the spessartite group (Sum. Prog. 1902, p. 69). In this he was confirmed by Rosenbusch (1907, p. 170), who regarded the camptonites and spessartites as belonging to the essexite and diorite families respectively. The camptonites tend to have purple augite, deep-brown (basaltic) hornblende and late analcite; whereas in spessartites augite is pale-green to colourless, hornblende is pale-brown often greenish, and analcite is absent.

Kersantites may be defined as biotite-lamprophyres with plagioclase as their felspar. They are sparingly represented in Sheet 53; and it is very seldom that anything is found that might be called a mica-trap.

Early lamprophyre sheets

The widely distributed, early, low-angled lamprophyre sheets of chapter 16 almost all belong to the spessartite suite; and more typical lamprophyres could not be desired. Their felspar furnishes an allotriomorphic, poikilitic base, and consists largely of oligoclase or albite. Prisms of hornblende may supply almost all their ferromagnesian component, stout (S11527) [NN 1829 6189]; (S12888) [NN 2244 6707]; (S12889) [NN 2171 6399]; (S15876) [NN 085 583], or needly (S12888a) [NN 2244 6707] (S12890) [NN 1974 6641]. The sheet represented by (S15876) [NN 085 583] is a conspicuous feature in the main Ballachulish slate quarry, but is very decomposed. There may be in addition big phenocrysts of augite largely made over to pale-green hornblende (S11495) [NN 1687 5008]. A slice (S12348) [NN 2186 6038] from Allt a' Choire Odhair-mhoir[NN 220 606] suggests that a plutonic rock consisting of richly sagenitic biotite, colourless augite and brown hornblende may have been dismembered by an invasion of what seems to have been felspathic magma. In others, calcite (S11527) [NN 1829 6189]; (S12888) [NN 2244 6707], green biotite (S12888) [NN 2244 6707]; (S12888a) [NN 2244 6707], tremolite (S11527) [NN 1829 6189], epidote (S12889) [NN 2171 6399] and chlorite (S12890) [NN 1974 6641] are well represented.

Lamprophyre dykes: Etive Swarm and older associates

Two lamprophyre dykes (S11523) [NN 1592 5970]; (S11524) [NN 1592 5970] from the permeation zone north of Glen Coe have been contact-altered by the Fault-Intrusion, and are therefore earlier than the Etive Swarm. They will be referred to more fully in chapter 18. Even if all other lamprophyre dykes within the belt traversed by the Etive Swarm belong properly to that swarm, there are very few compared with the prevailing porphyrites; also, as pointed out on p. 195 some of them may quite likely antedate the swarm.

Among the suspects is a hornblende-spessartite that has located the E. N. E. gorge along which the Coe flows 400 yd S.W. of Clachaig Hotel [NN 128 567]. Petrographically it is just like the spessartites of the early sheets. An additional feature of interest is its intrusion by very irregular felsitic material, probably penecontemporaneous (S11612) [NN 1126 5486]; (S39702) [NN 1240 5643]; (S39703) [NN 1247 5647]; (S39704) [NN 1247 5647]; (S39705) [NN 1247 5647]. A dyke of like character (S11040) [NN 141 580] on the northern slopes of Glen Coe may be a continuation. Maufe noted that it was cut by a number of porphyrite associates. Another dyke seven miles further south-east at Sròn na Crèisee [NN 240 522] is similar (S9738) [NN 2390 5258]; as are also others (S12480) [NN 2137 5428]; (S12517) [NN 2000 5227]; (S11571) [NN 214 487]; (S12893) [NN 1978 6652]; (S12895) [NN 2219 6614]; (S13763) [NN 1304 5086] from various localities.

It would, however, be unsafe to assume that all the above are earlier than the Etive Swarm. Thus very much the same type of spessartite reappears in a patchy dyke (S12943) [NN 2293 5632]; (S12944) [NN 2293 5632]; (S12945) [NN 2293 5632]; (S12946) [NN 2293 5632] which certainly belongs to the swarm, since it cuts the Fault-Intrusion of Glen Coe. It gives rise to a gorge on the south-west side of Stob Beinn a' Chrùlaiste [NN 232 564] near the east margin of the map, where it is lettered L. It approaches specially closely in type such of the early sheets as carry augite and biotite. It differs mainly through a tendency of the felspar to be idiomorphic with a little intervening micropegmatite. The augite too is often rimmed with hornblende.

A rather finer-grained dyke (S14106) [NN 1048 5757], further west, is an olivine-augite-hornblende-spessartite, differing from the early sheets in having less hornblende and in the lath-shaped habit of its plagioclase. Slices (S11550) [NN 2129 4756]; (S11582) [NN 1225 5288] are comparable, while (S11475) [NN 1810 5112]; (S11526) [NN 1167 6006] carry sufficient biotite to approach kersantite. This feature is accentuated in a fine-grained kersantite (S12338) [NN 1938 5874] cutting Fault-Intrusion.

Three other kersantite slices of a different type come from the Binnean Mòr–Binnein Beag [NN 222 677] area north-east of Kinlochleven: (S12891) [NN 1974 6642] was collected by Wright as a dyke; (S12896) [NN 2229 6881] as a dyke or sheet; and (S12897) [NN 1899 6446] as a sheet. They are with some hesitation referred to the Etive Swarm. Biotite is abundant in parallel flakes, often more than half a millimetre long. Olivine is represented in bigger, and augite in smaller pseudomorphs. All minerals except biotite and magnetite are decomposed.

Lamprophyre dykes: Ben Nevis Swarm

Lamprophyres are also scarce in the Ben Nevis Swarm; spessartites are represented by four slices (S6559) [NN 0811 6856]; (S8488) [NN 1362 6686]; (S8822) [NN 1337 7205]; (S14427) [NN 1379 7185]. Of these (S6559) [NN 0811 6856] is of the same type as the early sheets, while the three others have lath-shaped felspars (S8488) [NN 1362 6686] cuts Mullach nan Coirean Granite, while (S8822) [NN 1337 7205]; (S14427) [NN 1379 7185] cut the Outer "Granite" of Ben Nevis and seem to have suffered a little contact-alteration by the Inner "Granite".

Kersantites with a multitude of stout little crystals of biotite are represented by specimens (S8823) [NN 1389 7183]; (S14423) [NN 1395 7180]; (S14428) [NN 1360 7189]; (S14438) [NN 1911 7348], all cutting the Outer "Granite" of Ben Nevis. Here again it is difficult to be sure how far these dykes have been altered by the Inner "Granite". Early phenocrysts of olivine or augite are replaced by clusters of pale amphibole.

Intermediate to acid hypabyssal rocks

Microdiorite: introduction

A fair number of dykes in the district are closely allied to spessartites and kersantites, but are too felspathic to be included with them among the lamprophyres. As a rule much of their felspar is of medium basicity and gives rather stout lath-shaped sections in the groundmass along with inconspicuous phenocrysts; while quartz fills minute interspaces. Typically these felspathic relatives of the lamprophyres are of intermediate composition.

In the first edition of this memoir they were called malchites, because, as Flett recognised, they resembled rocks already carrying this name in the Odenwald. It has, however, been found that the type malchite is a contact-altered rock (MacGregor 1931, p. 527); accordingly the name has been dropped in the present description in favour of microdiorite, suggested by MacGregor — Kynaston used diorite for corresponding rocks in Sheet 45, to the south.

The microdiorites previously called malchites can be divided into spessartitic and kersantitic varieties, according to prominence of hornblende or biotite as the case may be. Very often both minerals occur together and in several of the slices examined it is probable that the biotites have been reinforced by contact-alteration. Magnetite is an accessory.

Like the lamprophyres these microdiorites are very prone to juvenile reactions; and it has been found impossible in some cases to distinguish with certainty between juvenile change and subsequent contact-alteration.

In addition there are in the Etive Swarm certain dykes which it seems advisable to class as microdiorite, although they are altogether too felspathic to qualify for the adjectives spessartitic or kersantitic. They were grouped in the first edition of this memoir as "highly felspathic pyroxene-porphyrites" with the remark that, "as their porphyritic structure is but faintly marked, it might perhaps be better to class them with the malchites than the porphyrites". At the time it had been overlooked that Tyrrell had described similar rocks of like age in Ayrshire as plagiophyres (1914, p. 77, pl. ix, 2; see also MacGregor 1939).

In the field, plagiophyres are red-grey rocks of fine-grained holocrystalline appearance, suggesting at the same time lamprophyre and felsite. They characteristically carry a few inconspicuous phenocrysts of felspar along with small black spots that are chlorite pseudomorphs after rhombic pyroxene. These last weather into holes giving a "pock-marked" surface.

In slice (S12339) [NN 2220 5960] there are unusually many, but very small, plagioclase phenocrysts, and also an exceptional number of chlorite pseudomorphs after' pyroxene; while in addition there are a few fresh crystals of augite. Albitisation is pronounced with development of epidote. The chilled edge (S12340) [NN 2220 5960] of the same dyke is a very fine-grained pyroxene-andesite.

In normally crystallised specimens the texture varies between trachytic and orthophyric. The felspar is oligoclase with albitised appearance, sometimes, as noted above, accompanied by epidote (S12482) [NN 1970 5364]. The characteristic ferromagnesian mineral (as also in Tyrrell's type material) is rhombic pyroxene replaced by chlorite with indigo polarisation. Augite is subordinate (S12346) [NN 2186 6038]. A second chilled edge (S12347) [NN 2186 6038] shows particularly clearly the association of pseudomorphed rhombic pyroxene with fresh monoclinic pyroxene. Other plagiophyre slices from our neighbourhood are (S11909) [NN 1423 5422]; (S13410) [NN 2439 7066]. Quartz and magnetite are very minor accessories.

Microdiorite dykes: Etive Swarm

In the Etive Swarm microdiorites are most frequent in Glen Etive itself, though here as elsewhere outnumbered by porphyrites.

Wherever they occur they are commonly spessartitic (S11469) [NN 1901 4917]; (S11473) [NN 1797 5107]; (S11476) [NN 1890 5131]; (S11477) [NN 1749 4783]; (S11478) [NN 1827 4845]; (S11506) [NN 1706 4928]; (S11525) [NN 1837 6188]; (S11540) [NN 2045 5058]; (S11545) [NN 2045 5058]; (S11578) [NN 1353 5392]; (S11581) [NN 1229 5291]; (S11609) [NN 1610 5124]; (S14089) [NN 2394 6057]; (S14116) [NN 2078 5757]; (S14135) [NN 1043 5755]; (S14401) [NN 1802 5110]; (S14402) [NN 1982 5129]; (S14403) [NN 2000 5136]; (S14405) [NN 1701 5348]. Their general character has been sufficiently described. In ((S11476) [NN 1890 5131], (S11545) [NN 2045 5058] we see, along with phenocrysts of fresh augite, large pseudomorphs in green hornblende that must be after pre-augite olivine or rhombic pyroxene. Slices (S11609) [NN 1610 5124]; (S11536) [NN 2241 5148] may be cited as andesitic representatives of the spessartitic microdiorites. Three other slices (S12892) [NN 1977 6650]; (S14396) [NN 1802 5110]; (S14400) [NN 1802 5110] may also be included though of quite exceptional character. They carry needles of hornblende and minute flakes of biotite enclosed in a subvariolitic felspathic base.

Kersantitic microdiorites are less frequent (S11467) [NN 1861 4922]; (S11474) [NN 1722 5110]; (S11501) [NN 1787 4771]; (S11541) [NN 1980 5048]; (S12894) [NN 2104 6429]; (S14406) [NN 2058 5130]; (S14412) [NN 1538 5160]; (S14415) [NN 1538 5160]; (S14416) [NN 1538 5160]. Hornblende is always present in addition to biotite, and there is no sharp line of separation between the spessartitic and kersantitic varieties. In the analysed specimen Anal. 18, (Table 2); (S14406) [NN 2058 5130] there is a group of comparatively large phenocrysts of almost colourless augite accompanied by uralitic pseudomorphs after olivine or rhombic pyroxene; but most of the rock consists of oblong zoned andesine, with idiomorphic biotite and hornblende, and a small proportion of interstitial quartz and alkali-felspar.

The plagiophyres of the Survey collection have already been enumerated. It is easy to obtain specimens of these pock-marked dykes in the vicinity of Stob Mhic Mhartuin [NN 207 575].

Microdiorite dykes: Ben Nevis Swarm

J. G. C. Anderson considers that there are almost as many microdiorites in the Ben Nevis Dyke-Swarm as porphyrites.

In the Geological Survey collection (S8563) [NN 1443 6847]; (S14424) [NN 1421 7185]; (S14426) [NN 1402 7178]; (S14427) [NN 1379 7185]; (S14428) [NN 1360 7189]; (S14429) [NN 1368 7188]; (S14437) [NN 1865 7393]; (S14439) [NN 1836 7426]; (S14441) [NN 1764 7487] may be classed as spessartitic, and (S8821) [NN 1467 7430]; (S14049) [NN 1421 7064]; (S14440) [NN 1763 7490]; (S14442) [NN 1765 7483]; (S14443) [NN 1769 7451] as kersantitic. There is no original feature in which these rocks differ from representatives in the Etive Swarm. Some of them owe part of their biotite to baking by the Inner "Granite" of the Ben Nevis Complex.

Porphyrite: introduction

The porphyrites are in large measure intermediate (corresponding with the plutonic banatites and tonalites), but their range extends well into the acid (corresponding with the adamellites).

Porphyrite is here used in Teall's sense to denote rocks with hornblende or biotite, in which phenocrysts of plagioclase are conspicuous without accompanying phenocrysts of orthoclase or quartz. The plagioclase phenocrysts mostly occur in stout tables under 3 mm long, and usually consist of oligoclase or andesine, though occasionally (S14404) [NN 2102 5146] of labradorite. In the field the porphyrites are more often red than grey.

Exceptionally the dominant ferromagnesian phenocrysts are pyroxenes. A dyke (S11908) [NN 1430 5473], cutting the Glen Coe lavas, is a pyroxene-bearing porphyrite with abundant phenocrysts of andesine and pale-green augite, reaching up to 3 mm long, accompanied by equally numerous pseudomorphs in chlorite after rhombic pyroxene. The base is felspathic with quartz, magnetite, biotite and hornblende as accessories. In another case (S14048a) [NN 1821 7386], from Ben Nevis, the phenocrysts are zoned andesine and hypersthene, in separate crystals and glomeroporphyritic groups. The groundmass consists of plagioclase and orthoclase, with accessory hornblende, biotite and magnetite. The rock has been contact-altered, but there is no doubt that hypersthene was present before this happened.

Biotite and hornblende are the most frequent ferromagnesian phenocrysts, often idiomorphic. The hornblende is generally green, but sometimes brown. Exceptionally a dyke is met, which combines the character of a porphyrite and a spessartite through carrying two well developed generations of idiomorphic felspar, hornblende and biotite, as in (S11544) [NN 1978 5071] from Glen Etive -this dyke also contains pseudomorphed phenocrysts after rhombic pyroxene *cf.* ((S11572) [NN 2084 4681]. More often the ferromagnesian constituents, though well developed among the phenocrysts, do not recur prominently in the groundmass (S11537) [NN 2255 5153]; (S11567) [NN 1965 4817], or *vice versa* ((S14404) [NN 2102 5146].

The groundmass of porphyrites (S11539) [NN 2157 5066]; (S14404) [NN 2102 5146] often resembles that of the spessartitic or kersantitic microdiorites; but more frequently it takes the form of small laths of plagioclase embedded in subordinate micropegmatite (S9131) [NN 243 537], or else is microfelsitic (S12496) [NN 2379 5521].

There are two analyses of hornblende-porphyrite dykes in (Table 2) and (Table 3). One (Anal. 14) has been quoted from Walker, and represents a grey rock in the middle of the intermediate suite with a composition much the same as that of the grey tonalite of Ballachulish (Anals. 10, 13). It is probably a member of the Ben Nevis Swarm. The other (Anal. 22; S 14398) belongs to a dyke of the Etive Swarm, which has phenocrysts of oligoclase with a few small prisms of pale green hornblende and some biotite. The base consists of stumpy crystals of oligoclase, with interstitial alkali-felspar and quartz. Magnetite, apatite and sphene are accessories, and chlorite and epidote are alteration products. The rock is compact and pink in hand specimen, with an acid appearance that corresponds with its $Si0_2$ percentage of 66.71. It agrees closely in composition with the porphyritic member (Subzone 4, Anal. 21) of the Outer "Granite" of Ben Nevis.

Porphyrite dykes: Etive Swarm

Most of the porphyrite specimens in the Geological Survey collection come from the Etive Swarm. They may be grouped as follows:

Porphyrites with augite phenocrysts corresponding roughly with the plutonic banatites: fresh augite occurs in slices (S11502) [NN 1812 4734]; (S11539) [NN 2157 5066]; (S11554) [NN 2198 4914]; (S11577) [NN 1937 5401]; (S11908) [NN 1430 5473]; (S12340) [NN 2220 5960]; (S14090) [NN 2388 6059] and pseudomorphs after augite in (S11479) [NN 1812 5113]; (S12493) [NN 2312 5547].

Porphyrites with groundmass of spessartitic or kersantitic microdiorite: (S6560) [NN 1000 6871]; (S11538) [NN 2217 5132]; (S11544) [NN 1978 5071]; (S11549) [NN 2137 4935]; (S11563) [NN 196 490]; (S11572) [NN 2084 4681]; (S11577) [NN 1937 5401]; (S14395) [NN 1717 5113]; (S); (S14397) [NN 1717 5113]; (S14404) [NN 2102 5146]; (S14414) [NN 1538 5160].

Porphyrites with more or less granophyric groundmass corresponding in many cases with the adamellites (S9131) [NN 243 537]; (S11480) [NN 1923 5020]; (S11496) [NN 1791 4767]; (S11537) [NN 2255 5153]; (S11547) [NN 2186 4929]; (S11551) [NN 2194 4916]; (S11557) [NN 209 474]; (S11558) [NN 2071 4956]; (S11560) [NN 199 490]; (S11566) [NN 1925 4775]; (S12496) [NN 2379 5521]; (S13411) [NN 2436 7069]; (S14108) [NN 232 530]; (S14115) [NN 186 564]; (S14175) [NN 1392 4747]; (S14178) [NN 1383 4746]; (S14398) [NN 1717 5113]; (S14399) [NN 2102 5146]; (S14410) [NN 1538 5160]; occasionally small phenocrysts of augite are found in such rocks (S12900) [NN 2229 6627]; (S13757) [NN 1823 5278]; (S13756) [NN 1702 5105]; (S13757) [NN 1823 5278]; (S13758) [NN 1882 5450]; (S13760) [NN 1873 5446].

Porphyrites approaching quartz-porphyry and obviously thoroughly acid: (S11907) [NN 1430 5473]; (S12336) [NN 1886 6079]; (S12337) [NN 1835 6140]; (S12898) [NN 1903 6422]; (S13756) [NN 1702 5105]; (S14087) [NN 224 619]; (S12337) [NN 1835 6140] carries a few small phenocrysts of quartz.

Some of the rocks quoted above have been affected by contact-alteration, a matter dealt with in chapter 18. Albitisation, too, is widespread and may be accompanied by crystallisation of epidote (S12494) [NN 2375 5524].

Chilled edges are extremely well marked among the porphyrite dykes. It was noted that such chilled edges may carry skeletal phenocrysts of felspar (S11466) [NN 189 507]; (S11470) [NN 1948 5103]; (S11548) [NN 2183 4922]; (S11555) [NN 2118 4957]-the two last are from the same occurrence). In the light of this evidence a large number of well crystallised slices were examined, and it was found that the plagioclase phenocrysts fairly commonly gave suggestions of having passed through a skeletal phase of development. This is specially well seen in slice (S11547) [NN 2186 4929], the crystalline interior of the chilled edge (S11548) [NN 2183 4922]; (S11555) [NN 2118 4957]. The matter certainly deserves special research to see whether these suggestions can be verified or shown to be misleading.

Another feature of interest is that three junction specimens (S11466) [NN 189 507]; (S11548) [NN 2183 4922]; (S11555) [NN 2118 4957] show marginal micro-brecciation of country-rock. Another (S11470) [NN 1948 5103] gives a clean contact. In still another (S11532) [NN 2154 5108], cut to show a contact between quartz-porphyry and later porphyrite, the country-rock (porphyry) has suffered micro-brecciation along the contact; but in this case the porphyrite does not exhibit marginal chilling, instead appearing to be a breccia, quite possibly an explosion-breccia.

Porphyrite dykes: Ben Nevis Swarm

Five sliced specimens of porphyrites in the Geological Survey collection can be grouped in the same fashion as those of the Etive Swarm, though they come from within the aureole of the Inner "Granite" of Ben Nevis:

1. With augite: (S14048a) [NN 1821 7386], already described.
2. With microdioritic groundmass (S8820) [NN 1341 7205]; (S14422) [NN 1379 7185].
3. With more or less granophyric groundmass: (S8819) [NN 1410 7177]; (S14425) [NN 1400 7177].

Thoroughly acid to ultra-acid hypabyssal rocks

Felsite: Introduction

The felsite intrusions of Sheet 53 are pink compact rocks in which small phenocrysts of alkali-felspar are a common, but very subsidiary, feature. The groundmass consists of cryptocrystalline aggregates grouped about crowded centres. These aggregates are generally irregular (S12342) [NN 1578 5949], but sometimes develop into spherulites (S11041) [NN 1875 5640]. Associated intrusive rhyolites show very little devitrification, and are often flow-banded (S11051) [NN 14 58]; (S13401) [NN 1578 5949].

Felsite Dykes of Ardgour

The big east-north-east dykes either side of Glen Tarbert [NM 910 600] are very typical felsites (S10940) [NM 9220 5968].

Felsite Intrusions of Glen Coe District

(Figure 33), p. 196, shows the outcrops of a number of early felsite and andesite intrusions in the Glen Coe district. Certainly most, possibly even all, of the felsites south-east of Loch Linnhe are earlier than the Etive Dyke-Swarm, in which acid representatives are mainly porphyrites or porphyries.

Slices (S11051) [NN 14 58]; (S12341) [NN 1578 5949]; (S12342) [NN 1578 5949]; (S13401) [NN 1578 5949] come from a broad dyke along the main Boundary-Fault of the Glen Coe Cauldron, west of Meall Dearg, and (S12344) [NN 1613 5852] from a branch of this fault northeast of Meall Dearg [NN 163 585] (both are shown in (Figure 23), p. 156). Of these (S12341) [NN 1578 5949] is in part xenolithic and breccioidal; while (S12342) [NN 1578 5949]; (S13401) [NN 1578 5949] come from a central rhyolitic member, cutting (S12341) [NN 1578 5949] and noteworthy for carrying aggregates of well defined micropegmatite. These are sometimes irregularly bounded, but sometimes have the outlines of component felspars. They greatly resemble a photomicrograph from the Braemar district (Flett 1905, pl. vii, 1; see also 1899).

The slice (S12344) [NN 1613 5852], from the branch of the Boundary-Fault north-east of Meall Dearg, and (S11460) [NN 1808 4989]; (S11462) [NN 1808 4989]; (S11462) [NN 1808 4989]; (S11463) [NN 1808 4989] from Beinn Ceitlein, Glen Etive, afford good examples of contact-alteration.

Slice (S11041) [NN 1875 5640] has already been mentioned for its spherulites. It is from an early felsite dyke cutting the Glen Coe lavas.

Slice (S12343) [NN 1749 6147] is from a conspicuous branching dyke on Garbh Bheinn [NN 170 601], on the south side of Loch Leven. The various branches of this dyke run E.N.E., N.E. and N., and are cut by neighbour N.E. porphyrites. The whole may perhaps antedate the Etive Swarm, or it may be just an early member of the same. It is more porphyritic as regards alkali-felspar than the usual felsites, but carries scarcely any phenocrysts of quartz.

Quartz-porphyry dykes, Etive Swarm

While it is not absolutely certain that any of the felsites of the district belong to the Etive or the Ben Nevis Dyke-Swarm, there are quite a few quartz-porphyries undoubtedly referable to the former. One at least is thought to have been fed by the Meall Odhar ring-dyke of binary granite (pp. 172, 201).

The quartz-porphyries carry fairly conspicuous phenocrysts of alkali-felspar and quartz. The felspar phenocrysts are generally tables between two and three millimetres long, and are mostly untwinned or simply twinned — though albite twinning can often be detected. They are seldom clear. Quartz phenocrysts show crystal faces though with rounded angles. They are generally subordinate, but are well represented in the analysed specimen (Anal. 33, (Table 3); S 14114). Biotite phenocrysts are almost always present. Hornblende is rare, but one prism, seen in (S12481) [NN 2072 5405], is 4 mm long. The groundmass varies from felsitic, with micrographic textures grouped about little alkali-felspars (S11481) [NN 1818 5107]; (S12481) [NN 2072 5405], to aplitic, with small quartz grains scattered among crystals of alkali-felspar of about the same size (S11546) [NN 2015 5018]; (S14114) [NN 248 546].

Quartz-porphyry slices in the Geological Survey collection may be distributed among five dykes of the Glen Etive district. These can be recognised on the one-inch map from N.W. to S.E. as follows:

1. Member (not separately coloured on Sheet 53) of the Allt Fhaolain [NN 158 510] multiple dyke illustrated in (Figure 34): (S14413) [NN 1538 5160].
2. Discontinuous dyke, Stob na Bròige [NN 190 523] to W. of Stob Dearg: (S11481) [NN 1818 5107]; (S12479) [NN 2105 5460]; (S12481) [NN 2072 5405]; (S12519) [NN 1955 5202].
3. Dyke passing quarter of a mile E. of Alltchaorunn: (S12518) [NN 2110 5250].
4. Dyke passing 1 mile E. of Alltchaorunn: (S11535) [NN 2169 5130]; (S11546) [NN 2015 5018]; ((S14114) [NN 248 546] — Anal. 33, (Table 3)).
5. Dyke passing 1½ mile E. of Alltchaorunn [NN 196 509]: (S9130) [NN 240 520]; (S11565) [NN 2016 4865]; (S11568) [NN 1948 4762].

Dyke (3) is the one almost certainly fed from the Meall Odhar binary granite. Dyke (5) has given a granitic specimen (S11568) [NN 1948 4762] where it is mapped as terminating half a mile from this granite outcrop — which rather suggests that it too may have been fed from this source.

Quartz-porphyry boulders in Lower Old Red Sandstone conglomerates

Afeature of the Lower Old Red Sandstone conglomerates of Glen Coe is their extremely small content of boulders or pebbles of hypabyssal crystallisation; but Kynaston collected a specimen of felsitic quartz-porphyry with quartz phenocrysts ranging up to 2.5 mm across (S10289) [NN 1594 5870].

Basic to sub-basic lavas

Basalt and allied pyroxene-andesite lavas, Glen Coe

Though well developed in the Glen Coe succession, and even more so in Lorne, basalts and allied pyroxene-andesites are absent from Ben Nevis. In Glen Coe they are dark compact rocks of a blue-black colour when fresh, but often mottled, purplish, and pistachio-green through decomposition. The compact texture of even the most basic types suggests andesite rather than basalt in hand-specimen. Olivine pseudomorphs can, however, often be recognised owing to their red, flaky character coupled with their shape. The red material is a haematitic residue after iddingsite. The lavas are generally very inconspicuously porphyritic.

An unusually fresh example of olivine-basalt (Anal. 3, (Table 2); (S9628) [NM 989 276] has been analysed from near Taynuilt [NN 004 311] in Lorne (Sheet 45, Geol.). It carries numerous pseudomorphs, up to 1.5 mm long, after olivine in serpentine, talc and iron ore. The groundmass is well crystallised and consists of 0.5-mm laths of andesine or labradorite, small idiomorphic prisms of pale-green augite, octahedra and rods of magnetite, and a cement of alkali-felspar-in which Analysis 3 shows there must be considerable potash (see p. 208).

Two slices from Glen Coe ((S10317) [NN 135 553], (S14134) [NN 171 564] are very similar to the Taynuilt specimen, but not so fresh; and it is very doubtful whether they contain as much potash. Another (S14409) [NN 1403 5590] is of finer texture, as also (S11615) [NN 1729 5662] — the flow with withamite amygdales (p. 138). Occasionally fresh phenocrysts of augite accompany the olivine pseudomorphs in well characterised olivine-basalts (S10319) [NN 147 575]; (S14104) [NN 1762 5662].

Analysis 5, (Table 2) (S14408) [NN 1403 5590], from the Glen Coe area, represents an olivine-free basalt, which carries a number of small chlorite pseudomorphs after rhombic pyroxene in a groundmass of short unoriented plagioclase laths with sparse little prisms of augite and scattered iron ore. The analysis shows that this rock is basic and close in composition to the Taynuilt [NN 004 311] lava (Anal. 3), except that its potash is lower. Similar types are seen in other slices (S10314) [NN 139 552]; (S10316) [NN 139 544]; (S11042) [NN 172 564]; (S12490) [NN 2185 5564]; (S12772) [NN 2312 5323]; (S39706) [NN 1565 5714]. In the first two of these, olivine appears to be represented by pseudomorphs. In another slice (S10318) [NN 137 551], little augite phenocrysts are seen, and apparently there are no pseudomorphs after olivine. In still another (S9716) [NN 248 517], from Càm Ghleann, there are numerous phenocrysts of augite up to 1 mm across, pseudomorphs suggesting rhombic pyroxene, and scattered phenocrysts of plagioclase up to 2 mm.

The felspar laths of the base in the slice (S39706) [NN 1565 5714] listed above are sufficiently parallel to give trachytic texture. Finer- and much finer-grained texture is found in other cases (S11044) [NN 1577 5689]; (S11045) [NN 1577 5689]; (S11616) [NN 1592 5707]; (S12436) [NN 1826 5650], all collected from Group 1 of (Figure 20), p. 133. It is quite possible that these finer-grained types are andesites; but the condition of the material does not warrant an attempt to separate pyroxeneandesites from basalts. Where trachytic texture is developed, some of the Glen Coe and Lorne lavas, under the microscope, closely resemble mugearites as described from the Scottish Tertiary and Carboniferous. They lack, however, the platy fluxion so characteristic of mugearites in the field.

Intermediate lavas

Hornblende- and biotite-andesite lavas of Glen Coe and Ben Nevis

The hornblende-andesites of Ben Nevis are of special interest as having furnished Teall (1888, p. 287; pl. xxxvii) with the first good British instance of the type. It is now known that hornblende-andesites are widely developed among lavas of Old Red Sandstone age elsewhere in Scotland; and nowhere, as Kynaston has shown, more typically than in Glen Coe.

There may be slight differences distinguishing the Ben Nevis and Glen Coe examples. For instance, the hornblendes of the former (S8824) [NN 1535 7166]; (S8826) [NN 1515 7171]; (S8828) [NN 1664 7124]; (S13736) [NN 1526 7173]; (S13737) [NN 1536 7165]; (S13738) [NN 1573 7154]; (S13741) [NN 1680 7127]; (S13742) [NN 1668 7127]; (S14025) [NN 1592 7209]; (S14030) [NN 1588 7215]; (S14032) [NN 1650 7121]; (S14033) [NN 1590 7219]; (S14036) [NN 165 708] seem often to be greenish, while those of the latter (S9132) [NN 243 537]; (S9164) [NN 248 502]; (S10321) [NN 147 553]; (S11583) [NN 1446 5417]; (S11590) [NN 1583 5329]; (S14576) [NN 146 545] appear to be more definitely brown. Moreover, it may be a related fact that biotite-andesites are commoner in the Ben Nevis collection (S14026) [NN 1592 7209]; (S14027) [NN 1587 7203]; (S14028) [NN 1585 7205]; (S14029) [NN 1583 7213]; (S14035) [NN 1567 7250];

(S14037) [NN 168 713] than in that from Glen Coe (S11043) [NN 1840 5639]; (S11614) [NN 1789 5652]. In either district transitional types occur in which both hornblende and biotite phenocrysts are well developed (S14036) [NN 165 708], Ben Nevis; (S9132) [NN 243 537], (S11579) [NN 1575 5337], Glen Coe.

Dacites, with abundant phenocrysts of quartz, oligoclase, andesine, hornblende and biotite in a fluxional devitrified base, have been collected by Grabham on Stob na Bròige [NN 190 523] north-east of Dalness (S11605) [NN 1696 5207]; (S12761) [NN 187 520]; (S12765) [NN 1902 5256]; (S12766) [NN 1902 5256]; (S14407) [NN 208 532]. They are closely related to associated rhyolite lavas, with which indeed they have been mapped.

In hand-specimens the hornblende- and biotite-andesites are of even finer texture than the basalts and pyroxene-andesites. They are of a dull green colour which changes to purplish or greenish grey on weathering. Usually they contain abundant small felspar phenocrysts along with prisms of hornblende or plates of biotite, all of which are visible to the unaided eye, though not so conspicuous as in the porphyrites.

Under the microscope the small felspar phenocrysts prove to be andesine or labradorite, sometimes beautifully zoned (S14030) [NN 1588 7215]. The hornblende and biotite have almost invariably suffered magmatic resorption, producing a black border of iron oxide. Within this border the hornblende is generally replaced by chlorite, calcite or epidote. Kynaston noted a few small augite phenocrysts in two examples (S9179) [NN 2378 5045]; (S10321) [NN 147 553]. There are also fairly frequent chloi itic or uralitic pseudomorphs (S2054) [NN 16 71]; (S11590) [NN 1583 5329]; (S14032) [NN 1650 7121], which, as Maufe has suggested, may be after rhombic pyroxene. Little apatites may sometimes figure as phenocrysts (S14102) [NN 1546 5412].

In a few cases phenocrysts are so poorly developed that the andesites are nearly non-porphyritic (S2054) [NN 16 71], (S9714) [NN 2510 5207], (S11604) [NN 1716 5245].

The groundmass is commonly composed of minute felspar laths and cryptocrystalline material, often with innumerable dust-like crystals of magnetite. On the assumption that much of the cryptocrystalline material represents glass the prevalent groundmass texture is pilotaxitic grading to hyalotaxitic (S14031) [NN 1646 7117], on the one side, and to microtrachytic (S11599) [NN 1502 5320], on the other. One example of biotite-andesite (S14037) [NN 168 713] is microspherulitic. Flow-orientation may be well developed (S11584) [NN 1451 5416], (S13770) [NN 166 533]. Flow-brecciation is also common.

The analysed specimen from Glen Coe (Anal. 16, (Table 2); (S14576) [NN 146 545] is typical, with well marked phenocrysts of brown hornblende and labradorite to oligoclase-andesine. The hornblendes within their black rims are unusually fresh; but the plagioclase is considerably attacked. The base is hyalopilitic and altered. Chemically this andesite agrees closely with the banatitic Subzone 2 of the Outer "Granite" of Ben Nevis (Anal. 15).

Representative slices from Glen Coe not mentioned above include (S9155) [NN 210 535]; (S9165) [NN 246 501]; (S9718) [NN 240 509]; (S9719) [NN 240 509]; (S11586) [NN 1477 5395]; (S11589) [NN 1545 5365]; (S11592) [NN 1512 5369]; (S11593) [NN 1501 5375]; (S11601) [NN 1698 5508]; (S11608) [NN 1699 5232]; (S11912) [NN 139 544]; (S12473) [NN 2088 5441]; (S13771) [NN 169 534]; (S14101) [NN 1540 5417]; (S14132) [NN 151 539]; (S14133) [NN 1487 5385]. Others, both from Glen Coe and Ben Nevis, will be cited in the next chapter where contact-alteration is discussed.

Acid and ultra-acid lavas

Rhyolite lavas of Glen Coe

The rhyolite lavas of Glen Coe are the finest development of the type in Britain. They vary greatly in colour. They may be reddish-purple, grey, brown or even black. They are generally distinguishable in the field by their tendency to weather a pale tint, their frequently pronounced fluxion, their flinty fracture and the rarity of ferromagnesian phenocrysts, among which biotite alone occurs. Also they furnish particularly massive crags.

Under the microscope they are found to be thoroughly leucocratic. Plagioclase felspar, near albite, may occur as small scattered phenocrysts, in some cases accompanied by a fair proportion of quartz (S9134) [NN 241 525]; (S9141) [NN 240 521]; (S9144) [NN 221 538]; (S9152) [NN 216 538]; (S9153) [NN 216 538]; (S10331) [NN 236 520]; (S11491) [NN 1780 4954]; (S11588) [NN 1539 5345]; (S12776) [NN 216 536]; (S12777) [NN 2195 5383], in others, more or less alone (S9135) [NN 241 525]; (S9137) [NN 240 524]; (S9145) [NN 225 545]; (S9146) [NN 2244 5437]; (S9726) [NN 236 525]; (S11596) [NN 1535 5336]; (S12471) [NN 2126 5442]. As the proportion of phenocrysts decreases the texture approaches or attains to non-porphyritic (S9136) [NN 240 524]; (S9138) [NN 240 523]; (S9143) [NN 228 538]; (S9725) [NN 249 514]; (S9727) [NN 225 540]; (S9728) [NN 2253 5403]; (S12469) [NN 2095 5449]; (S12472) [NN 2079 5405]; (S12489) [NN 2201 5546]; (S12937) [NN 184 572]; (S14100) [NN 1638 5518]; (S14105) [NN 2193 5533].

The analysed specimen (Anal. 32, (Table 3); (S14100) [NN 1638 5518] is chemically very similar to the Quartz-Porphyry (Anal. 33), though it is itself almost non-porphyritic with a few albitic phenocrysts in a somewhat banded, devitrified base that shows microlites of alkali-felspar.

Occasionally quartz phenocrysts in these rhyolites have skeletal form due either to growth or corrosion (S9144) [NN 221 538]; (S10331) [NN 236 520]. Biotite, generally pseudomorphed, may occur in small amount (S9145) [NN 225 545]; (S9146) [NN 2244 5437]; (S12776) [NN 216 536]. Minute flakes of fresh muscovite appear sometimes to be of igneous origin (S9728) [NN 2253 5403]; (S12471) [NN 2126 5442], though possibly detached from schist xenoliths.

The groundmass is fairly often cryptocrystalline, suggesting original glass; but more commonly it is patchily microfelsitic (S9145) [NN 225 545]; (S10331) [NN 236 520] and may have reached this stage when the rock consolidated. Perlitic cracks have only been noted in one case (S9135) [NN 241 525]. Microspherulitic growths are also uncommon (S9136) [NN 240 524]; (S9143) [NN 228 538]. Quartz has often developed in small granular aggregates (S9727) [NN 225 540], in certain cases occupying original cavities.

Beautiful flow-banding is common (S9143) [NN 228 538]; (S9725) [NN 249 514]; (S9727) [NN 225 540]; (S11491) [NN 1780 4954]; (S12776) [NN 216 536]; (S12777) [NN 2195 5383]. As Kynaston early recognised, many of the rhyolite flows are extremely xenolithic, enclosing fragments of rhyolite, andesite (probably also basalt) and schist (S9152) [NN 216 538]; (S11491) [NN 1780 4954]; (S12776) [NN 216 536]; (S12777) [NN 2195 5383]. E. B. B.

TABLE 2

Analyses of Devonian Igneous Rocks of Sheet 53, 45 and 62 (Geol.)

	Ult.-B.	Basic						Intermediate										
	1	2	3	4	5	6	7	8	9	10 (see 13)	11	12	13 (see 10)	14	15	16	17	18
SiO_2	40·26	48·00	49·86	50·60	50·73	53·05	53·22	56·25	56·50	59·11	59·25	59·43	60·05	60·45	60·80	61·49	61·50	62·21
Al_2O_3	15·74	12·52	16·33	14·67	17·08	16·96	17·20	16·30	21·15	17·85	17·30	17·24	18·55	19·89	16·25	14·98	17·35	14·43
Fe_2O_3	3·44	8·74	3·62	2·81	4·59	2·95	2·64	1·60	1·55	1·78	1·15	2·58	0·93	1·76	1·70	1·51	1·27	1·77
FeO	7·95		4·34	6·47	4·06	5·40	4·84	5·05	3·70	3·24	4·07	3·24	3·41	2·27	3·38	3·84	3·87	3·65
MgO	12·09	15·26	7·80	7·04	6·12	6·15	6·33	5·12	2·55	3·85	3·60	2·92	3·46	1·54	3·72	3·22	4·22	5·66
CaO	12·03	7·94	6·47	10·05	7·32	7·45	6·79	6·55	6·15	5·05	4·95	5·14	5·44	4·04	4·75	4·56	3·80	4·43
Na_2O	2·25	3·11	3·42	3·13	3·55	3·36	2·38	4·13	4·37	4·10	4·45	4·11	3·84	4·77	4·05	3·59	2·38	2·65
K_2O	1·36	2·68	2·10	2·65	1·18	1·45	4·12	2·02	2·56	3·06	2·50	2·53	2·72	3·53	3·05	2·80	2·94	2·75
H_2O+	1·75	1·36	2·77	0·50	2·00	1·10	0·61	0·95	0·65	0·73	0·50	0·84	0·35	0·70	0·60	1·68	1·00	0·66
H_2O-	0·48		1·25	0·30	0·33	0·60	0·19	0·10	0·15	0·11	1·00	0·33	0·05	0·45	0·30	0·23	0·50	0·40
TiO_2	2·42	0·22	1·06	1·25	1·90	0·92	0·69	0·90	0·45	0·30	0·70	1·11	0·42	0·30	0·90	0·96	0·75	0·88
P_2O_5	0·04	—	0·54	0·24	0·35	0,54	0·28	0·40	0·22	0·14	0·21	0·26	0·29	0·23	0·28	0·32	0·17	0·20
MnO	0·03	—	0·40	0·23	0·20	0·20	0·25	0·40	tr.	0·05	0·15	0·20	0·16	tr.	0·10	0·21	0·07	0·23
CO_2	0·03	—	0·23	nil	0·82	nil	0·57	nil	nil	—	nil	0·06	—	nil	nil	0·92	nil	0·06
Cl	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—	—
S	nil	—	—	nil	—	—	—	—	0·08	0·19	—	—	—	tr.	—	—	—	—
(Ni,Co)O	—	—	nt. fd.	—	nt. fd.	—	nt. fd.	—	—	—	—	nt. fd.	—	—	—	nt. fd.	—	nt. fd.
BaO	—	—	0·10	—	0·07	—	0·08	—	—	0·23	—	0·13	—	—	—	0·11	—	0·07
ZnO	—	—	—	—	—	—	—	—	—	—	—	—	0·27	—	—	—	—	—
Li_2O	—	—	tr.	—	nt. fd.	—	tr.	—	—	—	—	nt. fd.	—	—	—	nt. fd.	—	nt. fd.
Total	99·87	99·83	100·29	99·94	100·30	100·13	100·19	99·77	100·08	99·70[1]	99·83	100·12	99·94	99·93	99·88	100·45	99·82	100·05
Sp.Gr.	3·19	2·95	2·76	3·00	2·82	2·86	2·85	2·81	—	—	2·71	2·75	—	2·64	2·76	2·71	2·76	2·76

[1] After subtracting 0'09 for S

1 : Appinite ; Ardsheal Hill. 2 : Kentallenite ; Kentallen. 3 : Olivine-basalt with orthoclase ; lava, Taynuilt, Lorne. 4 : Olivine-basalt with orthoclase ; intrusion, Ardsheal Hill. 5 : Hypersthene-basalt ; lava, Glen Coe. 6 : Biotite-diorite with hornblende and augite ; basic phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite. 7 : Monzonite ; Glen Creran. 8 : Banatite ; Inner non-porphyritic Subzone 3 of Outer "Granite," Ben Nevis. 9 : Tonalite ; intermediate phase of Beinn a' Bhuiridh (Cruachan Quarry) Diorite. 10 : Tonalite ; Outer "Granite," Ballachulish (see 13). 11 : Banatite ; Outer non-porphyritic Subzone 1 of Outer "Granite," Ben Nevis. 12 : Banatite-porphyrite ; Fault-Intrusion, Glen Coe. 13 : Tonalite ; Outer "Granite," Ballachulish (see 10). 14 : Hornblende-porphyrite ; dyke, Ben Nevis Swarm, W. of Ballachulish Pluton. 15 : Banatite ; Mid non-porphyritic Subzon e 2 of Outer "Granite," Ben Nevis. 16 : Hornblende-andesite ; lava, Glen Coe. 17 : Hornblende-andesite ; lava, contact-altered in Beinn a' Bhuiridh screen. 18 : Kersantitic microdiorite ; dyke, Etive Swarm, Glen Etive.

(Table 2) Analyses of Devonian igneous rocks of sheet 53, 45 and 62 (Geol.).

TABLE 3

Analyses (continued), Sheets 53, 45, 54 and 62 (Geol.) — *Norwegian*

	Acid 19	20 (see 25)	21	22	23	24 (28, 30)	25 (see 20)	26	27	28 (24, 30)	29	30 (24, 28)	31	Ultra-Acid 32	33	Trondhjemites A	B	C
SiO_2	65·30	65·72	66·50	66·71	66·91	67·30	67·78	68·02	68·40	70·27	71·35	71·70	73·70	75·71	76·14	70·30	71·95	72·11
Al_2O_3	15·20	15·49	15·15	15·33	15·09	16·50	16·64	14·16	17·21	15·52	13·68 }		13·62	12·25	11·91	15·36	15·76	15·25
Fe_2O_3	2·49	2·35	1·34	1·46	1·70	1·20	1·07	1·82	tr.	0·90	1·75 }	16·81 {	0·48	1·23	1·26	0·56	0·76	0·64
FeO	2·41	2·07	2·39	2·26	1·95	1·98	1·74	1·95	0·92	0·94	0·97 }		1·28	0·31	0·25	2·37	0·03	0·84
MgO	1·80	1·23	1·88	1·53	2·02	1·27	1·19	1·91	1·03	0·67	0·84	0·47	0·32	0·20	0·13	1·03	0·31	0·38
CaO	3·05	2·69	3·15	2·72	3·27	2·85	2·38	2·81	3·05	1·60	1·85	2·42	0·94	0·61	0·47	3·52	1·65	1·98
Na_2O	4·13	4·49	3·90	3·67	4·16	4·70	4·27	3·90	4·48	4·45	3·75 }	9·00 {	4·05	3·79	3·37	4·30	6·63	5·43
K_2O	3·37	4·38	3·68	3·96	3·16	2·75	3·48	3·92	2·88	4·16	4·36 }		4·85	4·73	5·30	1·45	2·22	2·04
H_2O+	0·81	0·49	0·90	0·28	0·56	0·50	0·48	0·56	0·30	—	0·51	—	Nil	0·52	0·30	0·79 }	0·42 {	0·66
H_2O-	0·19	0·12	0·20	0·88	0·14	0·20	0·30	0·20	0·12	—	0·19	—	0·55	0·08	0·36	0·05 }		0·03
TiO_2	0·83	0·61	0·55	0·69	0·67	0·30	0·36	0·63	0·28	0·31	0·47	—	0·36	0·21	0·15	0·35	0·08	0·17
P_2O_5	0·23	0·43	0·18	0·19	0·17	0·16	0·12	0·16	0·14	0·17	0·11	—	tr.	0·06	0·05	0·12	—	0·06
MnO	0·12	0·04	0·10	0·18	0·18	nil	—	0·22	—	0·04	0·18	—	nil	0·10	0·19	0·04	—	0·02
CO_2	tr.	—	nil	0·15	nt. fd.	nil	—	nt. fd.	—	—	nt. fd.	—	nil	0·19	0·26	0·13	—	0·22
S	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·03	—	0·06
FeS_2	—	—	—	—	—	—	—	—	1·08	—	—	—	—	—	—	—	—	—
(Ni,Co)O	nt. fd.	—	—	nt. fd.	nt. fd.	—	—	nt. fd.	—	—	nt. fd.	—	—	nt. fd.	nt. fd.	—	—	—
BaO	0·11	0·19	—	0·10	0·05	—	—	0·06	—	—	0·05	—	—	0·08	0·01	tr.	—	0·03
Li_2O	nt. fd.	—	—	?	nt. fd.	—	—	nt. fd.	—	—	tr.	—	—	?	nt. fd.	—	—	—
Total	100·04	100·30	99·92	100·11	100·03	99·71	99·81	100·32	99·89	99·03	100·06	100·40	100·15	100·07	100·15	100·40	99·81	99·92
Sp. Gr.	2·70	—	2·68	2·69	2·69	2·67	—	2·69	—	—	2·65	—	2·62	—	—	2·71	2·64	2·68

19 : Biotite-hornblende-porphyrite ; Early Fault-Intrusion, Glen Coe. **20** : Granite ; Inner Granite, Ballachulish (see **25**). **21** : Granite ; porphyritic subzone of Ben Nevis Outer "Granite". **22** : Hornblende-porphyrite ; dyke, Etive Swarm, Glen Etive. **23** : Trondhjemite ; Moor of Rannoch "Granite". **24** : Trondhjemite ; Inner "Granite," Ben Nevis (see **28, 30**). **25** : Granite ; Inner Granite, Ballachulish (see **20**). **26** : Adamellite ; Northern Lobe, Cruachan "Granite". **27** : Trondhjemite ; "White Granite," Ballachulish. **28** : Granite ; Inner "Granite," Ben Nevis (see **24, 30**). **29** : Granite ; Starav Granite. **30** : Trondhjemite ; Inner "Granite," Ben Nevis (see **24, 28**). **31** : Binary Granite ; referred to Meall Odhar Granite. **32** : Rhyolite ; lava, Glen Coe. **33** : Quartz-porphyry ; dyke, Etive Swarm, Glen Etive. **A, B, C** : Three Norwegian Trondhjemites to compare with **23, 24, 27, 30**.

Further details regarding Tables 2, 3 are given on pp. 208-9.

(Table 3) Analyses of Devonian igneous rocks of sheet 53, 45, 54 and 62 (Geol.) continued.

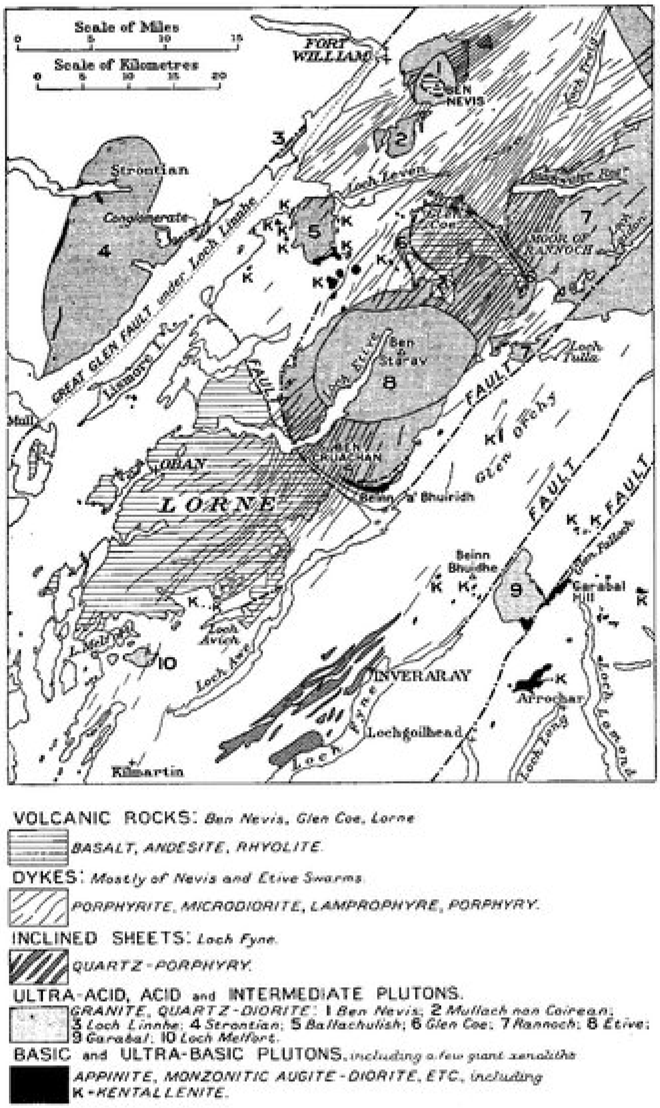


FIG. 18. Map of igneous rocks of South-West Highlands referred to Lower Old Red Sandstone Period

(Figure 18) Map of igneous rocks of South-West Highlands referred to Lower Old Red Sandstone Period.

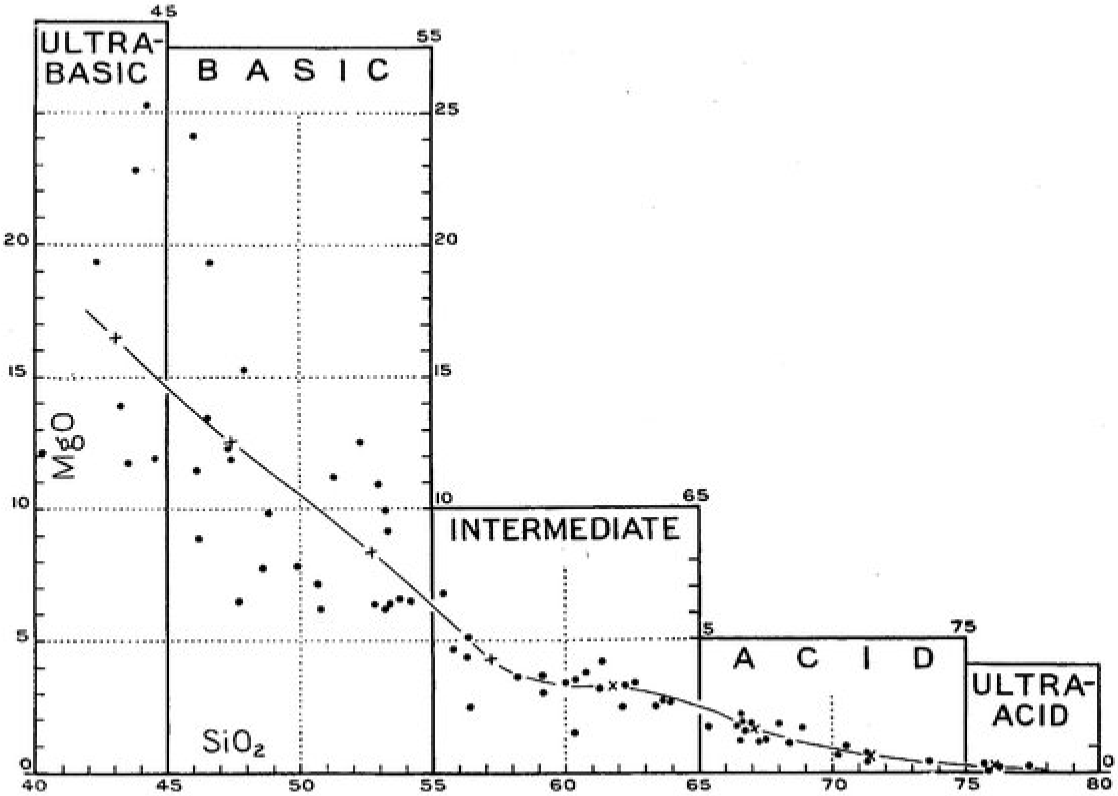


FIG. 37. Graph comparing MgO and SiO_2 percentages of individual Devonian igneous rocks of South-West Highlands. Crosses correspond with averages used in Fig. 37

(Figure 37) Graph comparing MgO and SiO_2 percentages of individual Devonian rocks of S.W. Highlands. Crosses correspond with averages used in (Figure 37).

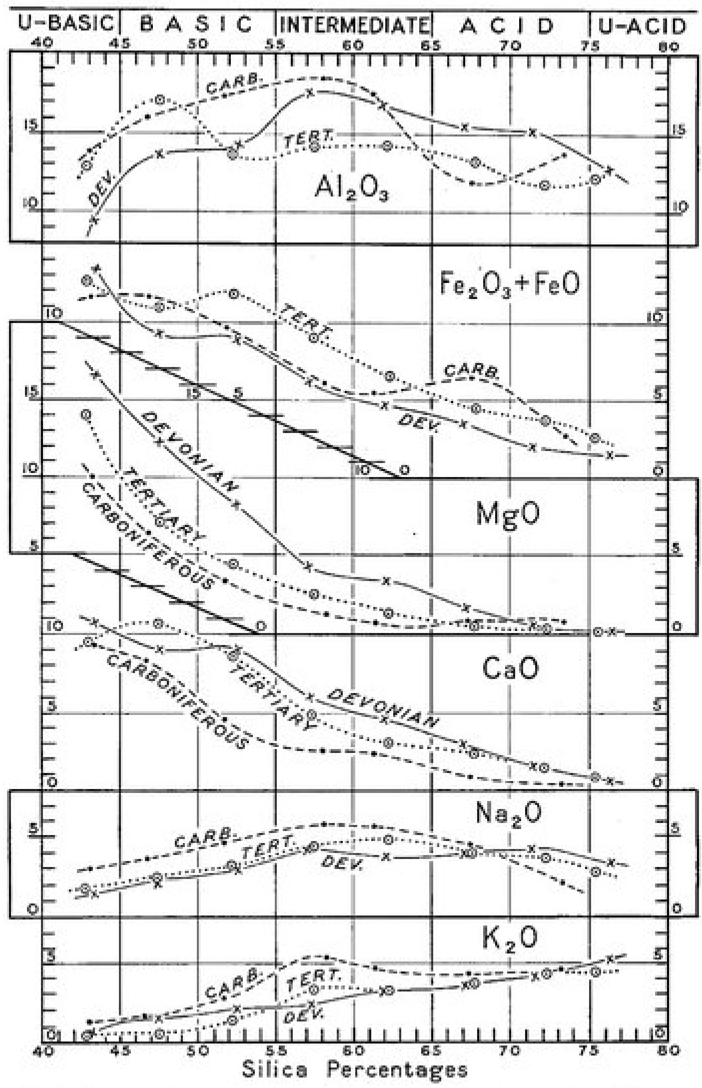


FIG. 38. Graphs comparing average analyses of igneous rocks spaced according to SiO_2 percentages. Tertiary and Carboniferous for all Scotland, Devonian for South-West Highlands

(Figure 38) Graphs comparing average analyses of Scottish Tertiary, Carboniferous and Devonian igneous rocks, the last-named restricted to S.W. Highlands.

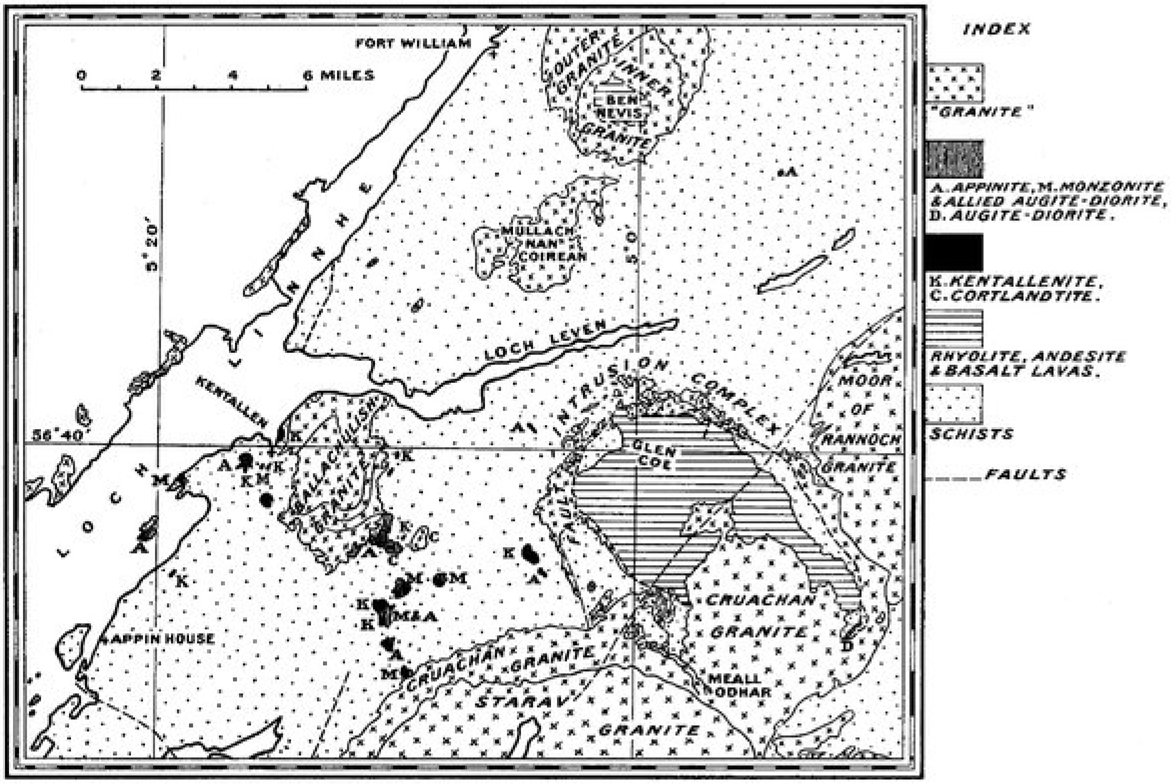
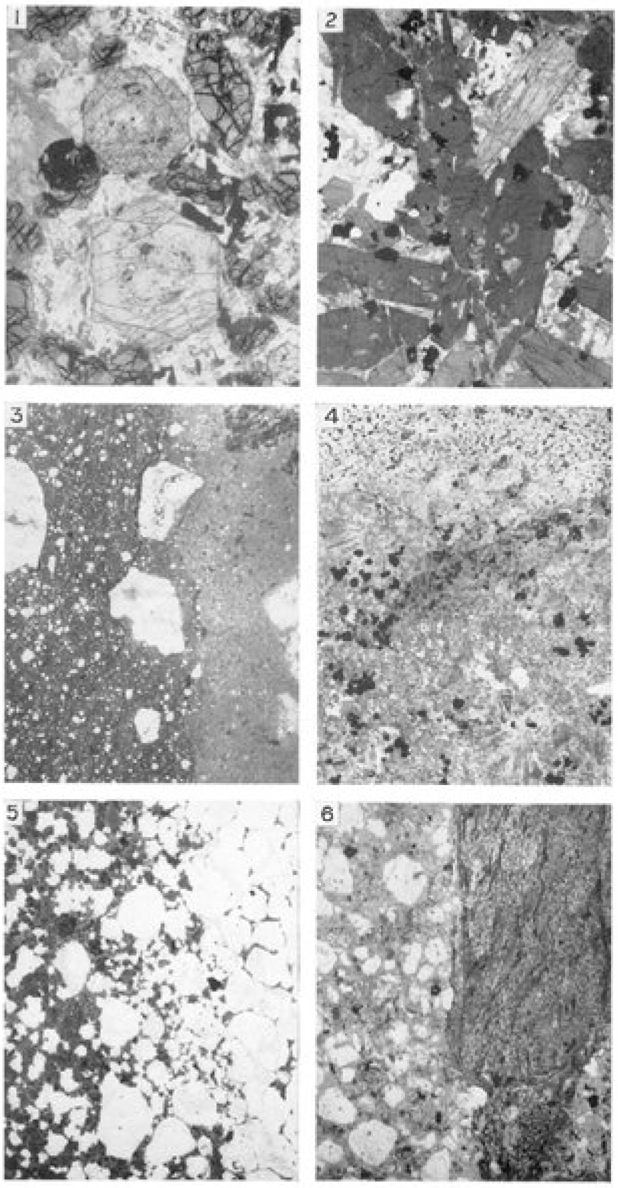


FIG. 32. Map of plutonic and volcanic rocks of Sheet 53 referred to the Lower Old Red Sandstone Period

(Figure 32) Map of plutonic and volcanic rocks of Sheet 53 referred to the Lower Old Red Sandstone Period.



(Plate 11) Photomicrographs of Kentallenite, Appinite and rocks connected with the Fault-Intrusion of Glen Coe. × 10 Dia. Explanation of (Plate 11) 1. Kentallenite, type quarry (S7053) [NN 009 577]. Olivine, with black cracks; augite, idiomorphic, grey; felspar, clear; biotite, pale or dark. (photo M.2436; p. 212). 2. Appinite, N. of Leacantuim [NN 117 577], Glen Coe (S11036) [NN 1152 5810]. Hornblende, mainly dark; felspar and quartz, clear. (M.2441; p. 215). 3. Junction of flinty crush-rock (left) with chilled Fault-Intrusion (right) at Boundary-Fault, Stob Mhic Mhartuin (S13403) [NN 207 575]. The minute clear grains in the flinty crush-rock are quartz. The four larger crystals in the same are xenocrysts of felspar derived from the Fault-Intrusion. The four crystals in the Fault-Intrusion are felspar phenocrysts, one showing dark. (M.2444; p. 162). 4. Junction of pelitic hornfels (upper third of photo) with lit par lit vein (remainder) in xenolith in Fault-Intrusion, taken from quenched zone at Boundary-Fault, An t-Sròn (S10311) [NN 136 558]. Due to quenching the vein has completed its crystallisation by developing spherulites — right at bottom corner and left at margin against hornfels. (M.2445; p. 216). 5. Fault-Intrusion (felspar shows grey) detaching quartz xenocrysts (clear) from quartzite xenolith. Permeation area north of Glen Coe (S11517b) [NN 1592 5970]. (M.2440; p. 219). 6. Greatly sheared xenolith of basic lava (right), recrystallised with much minute hornblende. It is enclosed in chilled Fault-Intrusion (left), loaded with clear xenocrysts of quartz, and has been carried just inside Cauldron-Subsidence of Glen Coe at An t-Sròn (S11905) [NN 1362 5502]. (M.2439; p. 217).

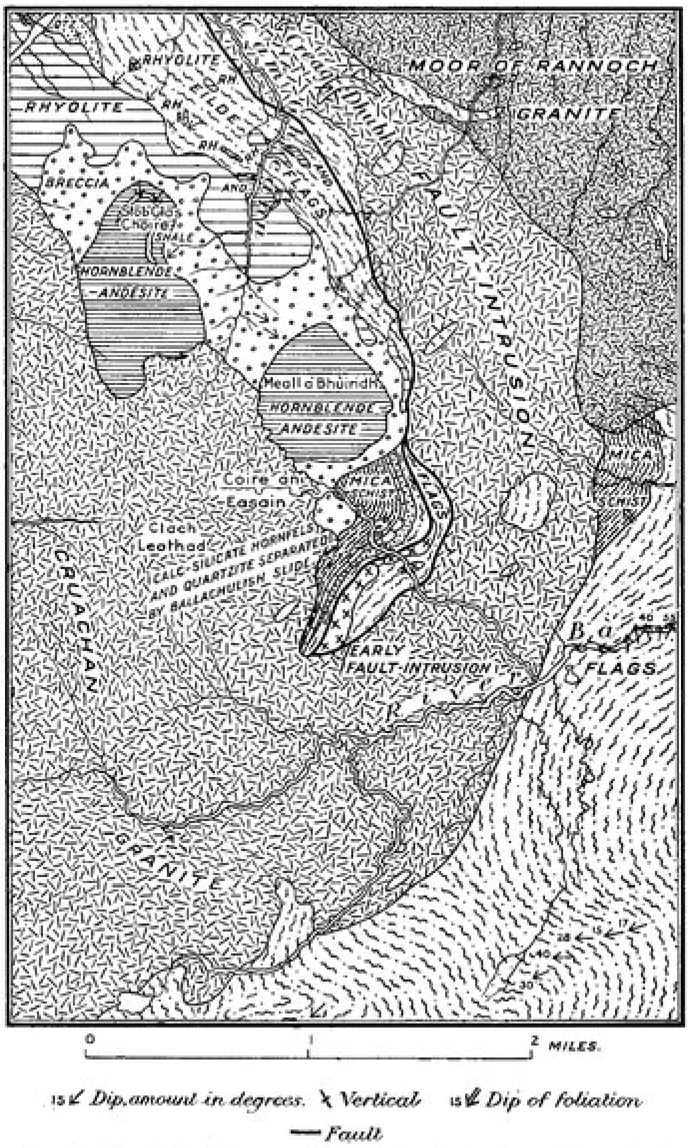


FIG. 29. Map of Càm Ghleann and Coire an Easain. North-east dykes omitted

(Figure 29) Map of Càrn Ghleann and Coire an Easain. North-east dykes omitted.

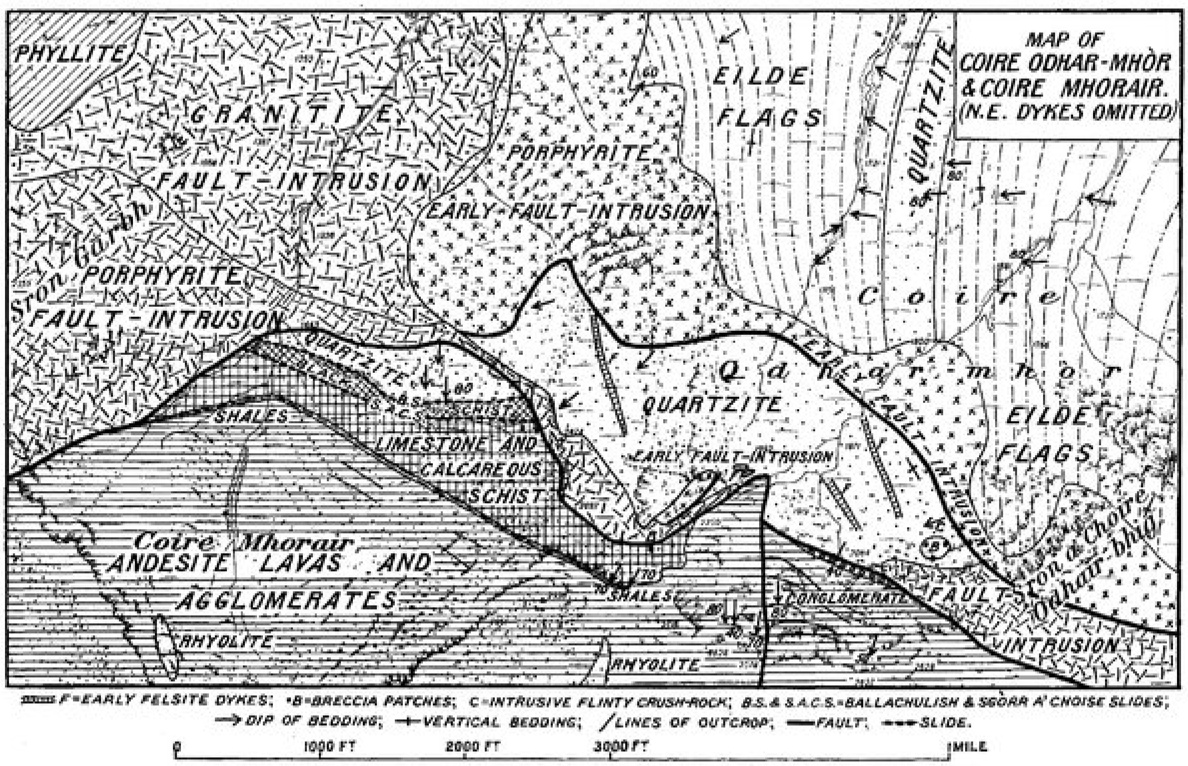


Fig. 24. Map of Coire Mhorair and Coire Odhar-mhòr

(Figure 24) Map of Coire Mhorair and Coire Odhar-mhòr [NN 196 583].

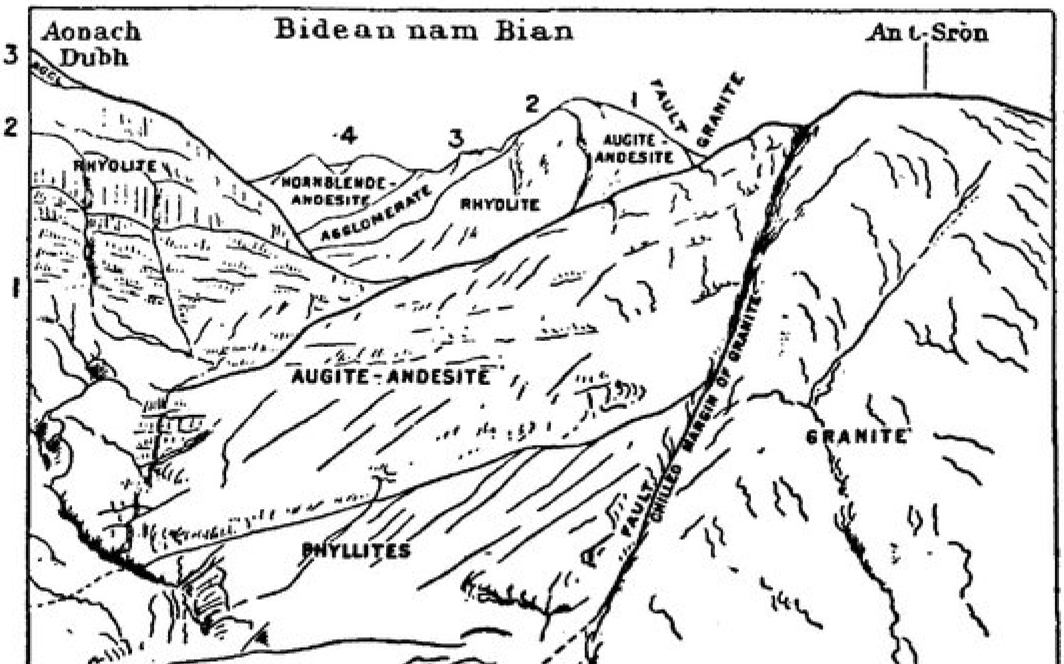


Fig. 20. View of Boundary-Fault of the Cauldron-Subsidence of Glen Coe as exposed in An t-Sròn

(Figure 20) View of Boundary-Fault of the Cauldron-Subsidence of Glen Coe as exposed in An t-Sròn.

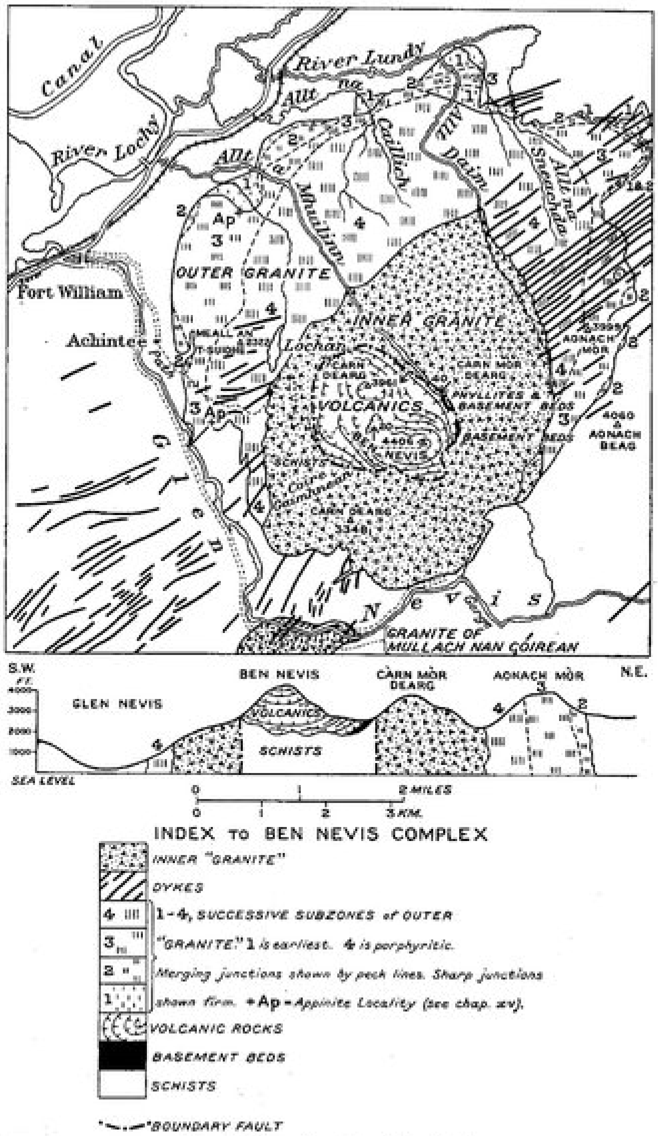


FIG. 31. Map and section of Ben Nevis

(Figure 31) Map and section of Ben Nevis.

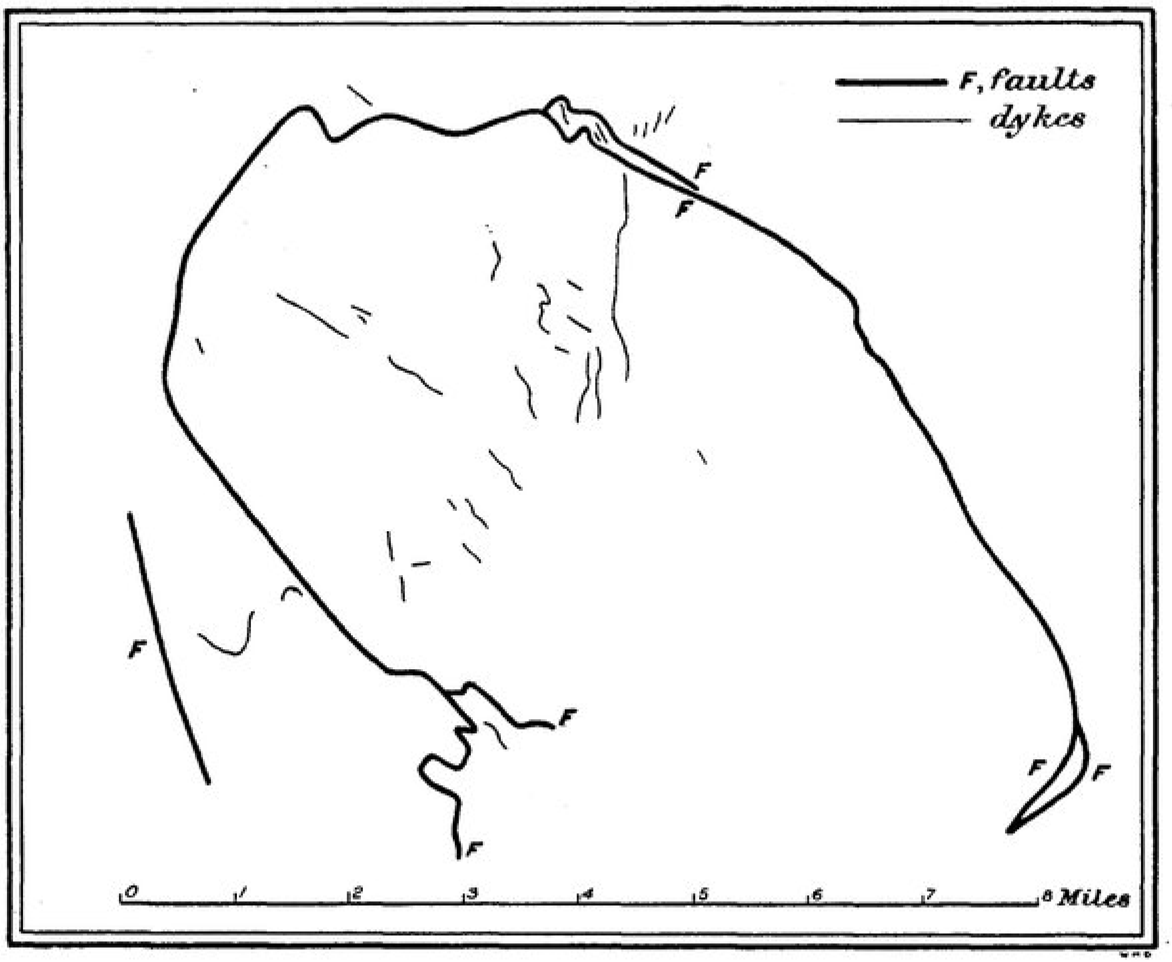


FIG. 33. Map of early felsite and andesite dykes of Glen Coe

(Figure 33) Map of early felsite and andesite dykes of Glen Coe.

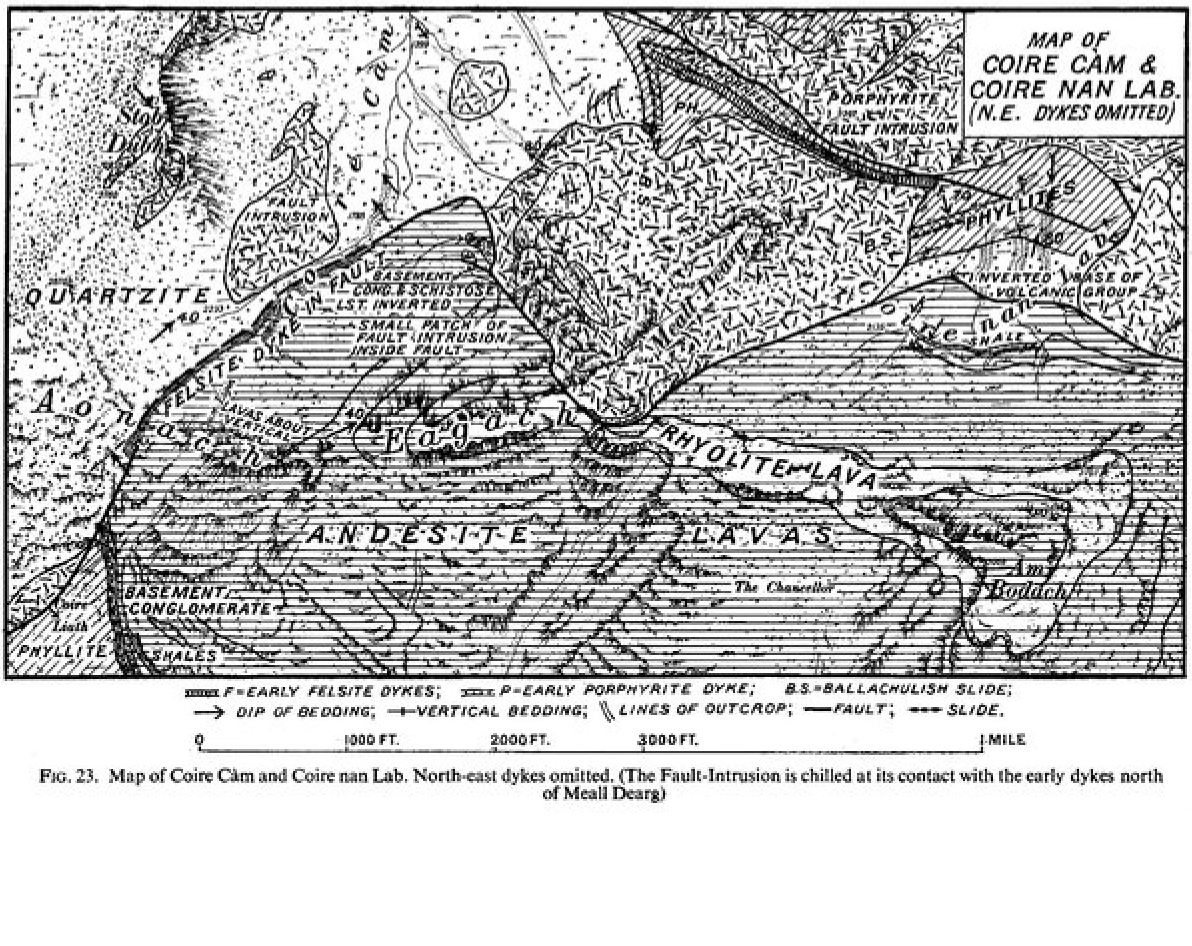


FIG. 23. Map of Coire Càm and Coire nan Lab. North-east dykes omitted. (The Fault-Intrusion is chilled at its contact with the early dykes north of Meall Dearg)

(Figure 23) Map of Coire Càm [NN 154 585] and Coire nan Lab [NN 167 584]. North-east dykes omitted. (The Fault-Intrusion is chilled at its contact with the early dykes north of Meall Dearg [NN 163 585]).

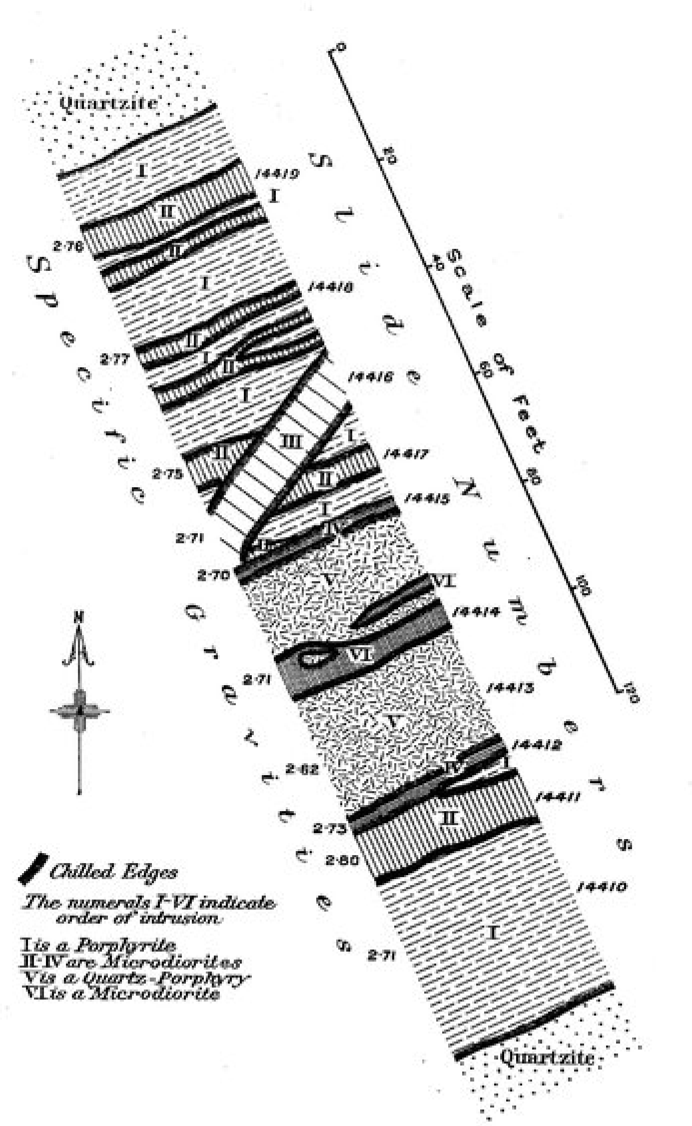


FIG. 34. Map of multiple dyke in the bed of Allt Fhaolain, ½ mile above the bridge, Glen Etive

(Figure 34) Map of multiple dyke in the bed of Allt Fhaolain [NN 158 510], ½ mile above bridge, Glen Etive.