The petrochemistry of some Lewisian granitic rocks

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Summary. The chemical compositions of eighty granitic rocks from the Lewisian of the North-West Highlands of Scotland, particularly from the Gairloch district, are set out in relation to geological occurrence and their normative proportions of albite, orthoclase, quartz, and anorthite compared with experimental data relating to the systems $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O and $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2. The field of composition for these Lewisian rocks moves from Ab–Q-rich for autochthonous granites to Ab = Or = Q (approximately) for parautochthonous granites to Or-rich for intrusive granites. This trend is related to the varying roles of mineral solubility under stress, selective melting, and potassium metasomatism.

GRANITIC rocks comprise a considerable proportion of the Lewisian complex of the North-West Highlands of Scotland. Much of the rock cropping out between Cape Wrath, Durness and the Loch Laxford district, and from Gruinard Bay to Loch Torridon and Raasay, is quartzo-feldspathic gneiss with hornblende and biotite, while dykes and sills of granite and pegmatite occur in these regions, being particularly common in the Loch Laxford and Ben Stack district (Peach *et al.*, 1907, pp. 37–40). The origin of the quartzo-feldspathic gneisses was ascribed by Peach *et al.* (1907, p. 35) to the 'plastic deformation' of an assemblage of igneous rocks, and Phemister (1948, pp. 10–11) refers to them as orthogneiss.

Recent investigations of the Lewisian gneisses and associated rocks in the Loch Tollie district, north of Gairloch, Ross-shire (Bhattacharjee, 1963*a*), in the Gairloch district (Park, 1964) and in the district south of Gairloch (Ghaly, 1965) have related geological occurrence and structural history to the nature of the rock types. This detailed work provides a basis for the comparison of the petrochemistry of naturally occurring granitic rocks with the results of phase equilibrium studies of systems with compositions resembling those of granitic rocks. Other investigations in the Lewisian that have provided information concerning geological occurrence and structural history (e.g. Nisbet, 1961; Bowes, Wright, and Park, 1964) further assist relevant comparison of petrochemical and experimental data.

The system most closely representative of granitic composition ($NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O) has been studied by Tuttle and Bowen (1958) and by Luth, Jahns, and Tuttle (1964). They showed that in this system minimum crystallization takes place with acid plagioclase, potassium feldspar, and quartz crystallizing together at temperatures from 760° C to 625° C with variations in water-vapour pressure of 500 to 10 000 bars. This minimum becomes (isobarically) a ternary eutectic at pressures above 3600 bars and its composition moves towards the $NaAlSi_3O_8$ apex with increase in water-vapour pressure (Tuttle and Bowen, 1958, Fig. 38; Luth, Jahns, and Tuttle, 1964, Fig. 4). The water content of the liquids varies from 3 % at 500 bars and 760° C to 10 % at 4000 bars and 640° C and 17 % at 10 000 bars and 625° C. This indicates that the compositions of granitic rocks formed largely by crystallization of albite, orthoclase, and quartz at a minimum melting point from a granitic magma containing a relatively low water content should correspond with the composition of the minimum at low water-vapour pressure in the experimental system (cf. Tuttle and Bowen, 1958, Fig. 42). Subsequent metamorphism of such rocks would have little effect on the bulk composition. On the other hand, the compositions of granitic rocks formed by the melting of sediments, a process considered to be significant by Wyllie and Tuttle (1961, p. 65) and von Platen (1965, p. 218), should be more sodium-(albite-)rich than in the former case, with compositions of the melted fractions related to the water content of the rocks being melted. The effects of other factors (cf. King, 1965) should be indicated by the bulk composition of the granitic rocks.

Tuttle and Bowen (1958) compared their experimental data with the normative Q, Or, and Ab proportions of all (571) analysed rocks in Washington's Tables (1917) in which normative $Q+Or+Ab > 80$ %. From the close relationship between the minimum melting point for low water-vapour pressures and the normative compositions of these granitic rocks, they concluded (p. 77) that there 'can be little doubt that magmatic liquids are involved in the genesis of granitic rocks'. Kleeman (1965) has set out the field of the low-temperature trough in the $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 system and shown 'that there is a closer correlation between the "average" granite composition and the low temperature trough in the Or–Ab–An–SiO_2 system than there is between the "average" granite composition and the minima in the Or–Ab–SiO_2 system . . . especially at P_{H_2O} greater than 2000 bars' (p. 38).

TABLE I. Chemical analyses and norms of granwisian citirocks. H.M.—Hunterian Museum rock catalogue number. Analyst (except where otherwise stated): C. C. Bhattacharjee (C.C.B.), D. R. Bowes (D.R.B.), or D. L. Skinner (D.L.S.)

Autochthonous granitic rocks—banded gneisses

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	No.
H.M.	9486	9487	9758	9475	9488	9759	9476	9770	9477	9760	9479	—	9035	9761	9489	H.M.
SiO_2	80·92	79·23	77·62	76·28	75·98	74·62	74·02	73·68	73·58	72·67	72·62	72·49	72·0	71·87	71·86	SiO_2
TiO_2	0·03	0·21	0·21	0·06	0·04	0·16	0·24	0·18	0·10	0·17	0·18	0·16	0·07	0·20	0·31	TiO_2
Al_2O_3	9·51	11·12	11·84	13·18	14·10	13·90	14·57	13·88	15·77	15·27	15·55	15·25	15·5	14·55	15·73	Al_2O_3
Fe_2O_3	0·49	0·46	0·96	0·37	0·35	0·51	0·73	0·63	0·25	0·45	0·24	0·76	0·50	0·77	0·23	Fe_2O_3
FeO	1·15	0·58	0·32	0·37	0·68	0·90	0·34	0·19	0·20	0·40	0·48	0·33	0·75	0·77	1·26	FeO
MnO	0·01	Abs.	Tr.	Abs.	0·03	0·01	Tr.	0·01	Tr.	Abs.	Abs.	0·03	Abs.	0·01	0·02	MnO
MgO	1·05	0·79	0·30	0·26	1·09	0·32	0·16	0·29	0·11	0·05	0·16	0·59	0·62	1·12	0·81	MgO
CaO	2·01	0·49	1·81	2·45	1·66	2·18	1·81	1·11	0·98	2·64	3·67	1·61	3·5	2·08	2·79	CaO
Na_2O	2·73	2·99	3·97	4·60	4·24	5·54	5·01	3·58	6·70	5·66	4·85	5·03	5·2	3·97	5·14	Na_2O
K_2O	0·53	3·10	1·23	0·67	1·40	1·31	1·80	5·59	0·86	1·34	0·92	3·05	1·4	3·12	1·83	K_2O
P_2O_5	0·02	Abs.	0·02	0·01	Abs.	0·05	0·01	0·03	0·01	0·03	0·03	0·01	0·13	0·06	0·08	P_2O_5
H_2O^+	0·81	0·75	0·70	0·63	0·68	0·77	0·58	0·37	0·75	0·49	0·62	0·73	0·32	0·67	0·25	H_2O^+
CO_2	—	0·12	0·34	0·17	—	0·06	Abs.	0·10	0·38	Abs.	0·13	—	—	0·21	—	CO_2
Total	99·26	99·84	99·32	99·05	100·25	100·33	99·27	99·64	99·69	99·17	99·45	100·04	100·0	99·40	100·31	Total
Weight norms																
Q	56·44	47·61	45·56	41·24	40·37	32·22	33·92	28·76	29·11	29·31	32·73	27·28	28·3	30·67	27·25	Q
Or	3·13	18·32	7·27	3·96	8·27	7·74	10·64	33·03	5·08	7·92	5·43	18·02	8·3	18·43	10·81	Or
Ab	23·09	25·29	33·57	38·90	35·86	46·85	42·37	30·28	56·66	47·87	41·02	42·54	44·0	33·57	43·47	Ab
An	9·85	2·43	8·86	12·09	8·23	9·20	8·91	5·30	4·80	12·31	17·95	7·93	14·8	9·96	13·37	An
Q+Or+Ab	82·66	91·22	86·40	84·10	84·50	86·81	86·93	92·07	90·85	85·10	79·18	87·84	80·6	82·67	81·53	Q+Or+Ab

Banded quartzo-feldspathic gneisses

1. Grey acid gneiss composed of quartz, plagioclase, and hornblende with biotite and epidote; Loch Tollie district (NG 854788) (C.C.B.).
2. Muscovite-microcline gneiss composed of quartz, plagioclase, muscovite, microcline, and biotite with a little epidote; Loch Tollie district (NG 827804) (C.C.B.).
3. Pink coarse-grained acid gneiss composed of quartz, plagioclase, and biotite; south of Gairloch (NG 800716) (D.L.S.).
4. Grey acid gneiss composed of quartz and plagioclase with a little biotite; Loch Tollie district (NG 853788) (D.L.S.).
5. Grey acid gneiss composed of quartz, plagioclase, biotite, and a little epidote; Loch Tollie district (NG 829803) (C.C.B.).
6. Pink fine-grained acid gneiss composed of plagioclase, quartz, and biotite; south of Gairloch (NG 788736) (D.R.B.).
7. Pink acid gneiss composed of quartz, plagioclase, and biotite with little epidote; Loch Tollie district (NG 848786) (D.L.S.).
8. Coarse-grained pegmatitic acid gneiss composed of plagioclase, quartz, and microcline; south of Gairloch (NG 799713) (D.L.S.).
9. Pink acid gneiss composed of quartz and plagioclase with biotite and epidote; Loch Tollie district (NG 820810) (D.L.S.).
10. Pink fine-grained acid gneiss composed of plagioclase and quartz; south of Gairloch (NG 784734) (D.R.B.).
11. Grey acid gneiss composed of quartz, plagioclase, and biotite; Loch Tollie district (NG 832783) (D.L.S.).
12. Plagioclase–quartz–potassium-feldspar–biotite–muscovite–epidote gneiss; Gairloch district—Park, 1963 (R.G. Park anal.).
13. Coarse-grained acid gneiss, between 9038 and 9039, Sceapull, North Rona—Bowes, 1961, p. 188 (D.R.B.).
14. Well-foliated grey coarse-grained acid gneiss composed of plagioclase, quartz, and biotite; south of Gairloch (NG 792725) (D.L.S.).
15. Grey acid gneiss composed of plagioclase, quartz, and biotite with eopidte; Loch Tollie district (NG 825781) (C.C.B.).

TABLE I—*continued*

Autochthonous granitic rocks—banded gneisses—continued

No.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	No.
H.M.	9490	9491	9492	—	9701	9702	9493	9034	—	9703	—	9494	9704	9762	9763	H.M.
SiO_2	71·72	71·62	71·62	71·06	70·98	70·9	70·84	70·8	70·76	70·6	70·45	70·44	70·4	70·25	70·21	SiO_2
TiO_2	0·03	0·27	0·14	0·26	0·22	0·23	0·24	0·25	0·30	0·17	0·43	0·30	0·10	0·31	0·30	TiO_2
Al_2O_3	15·69	15·30	14·85	14·90	15·09	15·4	14·70	15·1	14·56	15·1	14·86	13·88	16·5	15·12	14·75	Al_2O_3
Fe_2O_3	0·24	0·54	0·93	0·88	0·45	0·86	0·95	0·70	2·08	0·96	1·34	1·77	0·51	0·94	1·39	Fe_2O_3
FeO	0·69	1·69	0·82	0·71	1·06	0·74	0·95	1·2	1·09	1·2	1·46	0·95	0·94	1·62	0·89	FeO
MnO	Abs.	0·01	0·02	0·03	0·02	0·02	0·03	Abs.	0·06	0·04	0·23	0·06	0·02	0·03	0·03	MnO
MgO	0·72	1·17	0·86	0·79	0·14	0·08	1·04	0·73	1·26	1·1	1·47	0·99	0·75	1·50	0·37	MgO
CaO	1·79	2·46	1·20	2·37	3·04	2·9	3·04	2·2	2·68	3·1	3·18	2·56	3·9	3·46	3·04	CaO
Na_2O	5·28	5·09	5·40	5·69	4·44	4·4	3·87	4·6	5·78	5·0	4·92	4·44	5·7	4·82	5·00	Na_2O
K_2O	2·53	1·10	3·08	2·35	3·00	2·8	2·83	2·9	0·40	1·2	1·10	2·70	1·0	0·64	2·41	K_2O
P_2O_5	0·03	0·05	0·05	0·08	0·08	0·08	0·03	0·14	0·07	0·06	0·11	0·09	0·05	0·07	0·07	P_2O_5
H_2O+	0·45	1·10	0·73	0·92	0·65	0·81	0·67	0·44	0·92	0·39	0·49	0·82	0·23	0·81	0·78	H_2O+
CO_2	0·21	—	0·20	—	0·24	0·08	0·24	—	0·25	0·53	—	0·35	0·34	Abs.	0·10	CO_2
Others	—	—	—	0·07	—	—	—	—	—	—	0·08	—	—	—	—	Others
Total	99·38	100·40	99·90	100·11	99·41	99·3	99·43	99·1	100·21	99·5	100·12	99·35	100·4	99·56	99·34	Total
Weight norms																
Q	26·06	29·92	24·48	23·52	27·09	28·3	29·36	27·0	28·25	28·3	28·33	28·05	24·1	29·52	27·02	Q
Or	14·95	6·50	18·20	13·88	17·72	16·5	16·72	17·1	2·36	7·1	6·50	15·95	5·9	3·78	14·24	Or
Ab	44·65	43·05	45·67	48·12	37·55	37·2	32·73	38·9	48·88	42·3	41·61	37·55	48·2	40·76	42·29	Ab
An	8·70	11·91	5·66	8·12	12·39	13·9	14·39	10·1	12·61	15·0	15·13	9·98	16·5	16·75	10·70	An
Q+Or+Ab	85·66	79·47	88·35	85·52	82·36	82·0	78·81	83·0	79·49	77·7	76·44	81·55	78·2	74·06	83·55	Q

16. Pink acid gneiss composed of plagioclase, quartz, biotite, and microcline; Loch Tollie district (NG 833785) (C.C.B.).
17. Grey acid gneiss composed of plagioclase, quartz, and biotite with epidote; Loch Tollie district (NG 843802) (C.C.B.).
18. Pink acid gneiss composed of plagioclase, quartz, and biotite; Loch Tollie district (NG 820778) (C.C.B.).
19. Plagioclase-quartz-muscovite-biotite gneiss (with potassium feldspar and epidote); Gairloch district—Park, 1963 (R.G. Park anal.).
20. Pink acid gneiss composed of quartz, plagioclase, microcline, and biotite; Loch Torridon district (NG 830587) (D.R.B.).
21. Grey acid gneiss composed of quartz, plagioclase, microcline, and muscovite; Gruinard Bay district (NG 958877) (D.R.B.).
22. Grey acid gneiss composed of plagioclase, quartz, and muscovite with biotite; Loch Tollie district (NG 828795) (C.C.B.).
23. Acid gneiss, northern end of Fianuis, North Rona—Bowes, 1961, p. 189 (D.R.B.).
24. Plagioclase–quartz–potassium-feldspar–biotite gneiss; Gairloch district—Park, 1963 (R.G. Park anal.).
25. Grey acid gneiss composed of plagioclase, quartz, microcline, and biotite; Loch Laxford district (NC 206474) (D.R.B.).
26. Biotite-gneiss; ESE. of Eileen a' Chlamhuinn—Peach *et al.*, 1910, p. 31 (E. G. Radley anal.).
27. Pink ribbed acid gneiss composed of plagioclase, quartz, biotite, and epidote; Loch Tollie district (NG 815799) (C.C.B.).
28. Grey acid gneiss composed of plagioclase, quartz, microcline, and hornblende; Loch Laxford district (NC 206474) (D.R.B.).
29. Grey fine-grained acid gneiss composed of quartz and plagioclase with little microcline; south of Gairloch (NG 800723) (D.L.S.).
30. Pink fine-grained acid gneiss composed of plagioclase, quartz, and biotite; south of Gairloch (NG 788737) (D.R.B.).

TABLE I—*continued*

Autochthonous granitic rocks—banded gneisses—continued

No.	31	32	33	34	35	36	37	38	39	40	41	42	43	44	No.
H.M.	9764	9040	—	9495	9039	9765	9496	9766	—	9767	—	9768	9037	9038	H.M.
SiO_2	70·18	69·5	68·97	68·69	68·6	68·40	67·93	67·31	66·76	66·33	66·19	65·76	65·2	65·0	SiO_2
TiO_2	0·40	0·24	0·38	0·25	0·38	0·31	0·44	0·38	—	0·39	0·54	0·25	0·55	0·42	TiO_2
Al_2O_3	15·87	15·4	14·66	16·56	15·0	17·24	16·31	15·04	14·38	15·55	15·58	16·85	15·4	15·6	Al_2O_3
Fe_2O_3	1·16	1·0	1·36	0·39	1·0	0·60	0·75	2·62	2·04	2·34	1·38	1·17	0·80	2·1	Fe_2O_3
FeO	0·60	1·4	1·92	2·36	2·2	1·00	1·47	1·34	3·75	1·35	2·90	2·00	4·8	2·8	FeO
MnO	0·01	Abs.	0·38	0·04	Abs.	0·02	0·04	0·07	0·14	0·06	0·37	0·04	0·07	0·06	MnO
MgO	0·48	1·1	1·88	1·61	2·3	0·70	1·60	1·94	2·71	1·24	2·11	1·36	2·1	2·2	MgO
CaO	2·27	3·8	4·28	2·74	3·4	3·29	2·28	3·61	4·62	4·70	4·20	4·52	2·0	4·3	CaO
Na_2O	4·60	4·8	4·18	3·93	4·4	5·20	4·96	3·87	1·44	4·63	3·64	4·60	3·1	3·7	Na_2O
K_2O	2·78	1·8	1·42	2·10	2·0	1·82	1·73	2·15	3·33	1·54	2·18	1·57	4·1	2·0	K_2O
P_2O_5	0·07	0·16	0·13	0·06	0·16	0·04	0·17	0·08	—	0·10	0·13	0·12	0·09	0·18	P_2O_5
H_2O+	0·69	0·26	0·47	1·58	0·59	0·74	1·53	0·80	—	1·15	0·63	0·67	1·7	0·69	H_2O+
CO_2	Abs.	—	0·13	—	—	0·14	0·37	Abs.	—	0·61	0·39	0·14	—	—	CO_2
Others	—	—	0·03	—	—	—	—	—	0·49	—	0·04	—	—	—	Others
Total	99·11	99·5	100·19	100·31	100·0	99·50	99·58	99·21	99·66	99·99	100·28	99·05	99·9	99·1	Total
Weight norms															
Q	27·41	25·3	27·21	28·03	24·0	22·83	25·00	26·19	29·23	23·07	23·14	20·75	21·0	22·6	Q
Or	16·42	10·6	8·39	12·41	11·8	10·75	10·22	12·70	19·67	9·10	12·88	9·28	24·2	11·8	Or
Ab	38·90	40·6	35·35	33·24	37·2	43·98	41·95	32·73	12·18	39·16	30·78	38·90	26·2	31·3	Ab
An	10·85	15·2	17·05	13·24	15·3	16·08	10·31	17·32	22·91	17·11	19·74	20·70	9·4	20·1	An
Q+Or+Ab	82·73	76·5	70·95	73·68	73·0	77·56	77·17	71·62	61·08	71·33	66·80	68·93	71·4	65·7	Q+Or+Ab

31. Pink medium-grained acid gneiss composed of plagioclase, quartz, and biotite; south of Gairloch (NG 806707) (D.L.S.).

32. Acid gneiss, transition series, Sceapull, North Rona—Bowes, 1961, p. 188 (D.R.B.).

33. Hornblende-biotite gneiss; Coll—Richey and Thomas, 1930, p. 8 (E. G. Radley anal.).

34. Grey acid gneiss composed of plagioclase, quartz, and biotite with epidote; Loch Tollie district (NG 828802) (C.C.B.).

35. Acid gneiss, transition series, Sceapull, North Rona—Bowes, 1961, p. 188 (D.R.B.).

36. Grey fine-grained acid gneiss composed of plagioclase, quartz, and little hornblende; south of Gairloch (NG 803704) (D.L.S.).

37. Pink acid gneiss composed of plagioclase, quartz, microcline, biotite, and muscovite; Loch Tollie district (NG 842802) (C.C.B.).

38. Grey medium-grained acid gneiss composed of quartz, plagioclase, and little cummingtonite; south of Gairloch (NG 796711) (D.L.S.).

39. Biotite-gneiss; Durness—Peach, et al., 1907 p. 67 (J. S. Grant-Wilson anal.).

40. Pink fine-grained acid gneiss composed of plagioclase, quartz, and biotite with hornblende; south of Gairloch (NG 797728) (D.L.S.).

41. Hornblende-biotite gneiss; Coll—Richey and Thomas, 1930, p. 8 (E. G. Radley anal.).

42. Grey coarse-grained acid gneiss composed of plagioclase, quartz, and muscovite; south of Gairloch (NG 804704) (D.L.S.).

43. Acid gneiss, transition series, Sceapull, North Rona—Bowes, 1961, p. 188 (D.R.B.).

44. Acid gneiss, transition series, Sceapull, North Rona—Bowes, 1961, p. 188 (D.R.B.).

TABLE I—*continued*

Autochthonous granitic rocks—segregation patches and bands in gneisses and amphibolites

No.	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	No.
H.M.	9478	9705	9706	9797	9521	9536C	9538A	9538B	9542	9798	9520 Felsic	9800	9707	9708	9709	H.M.
SiO_2	73·17	66·14	77·2	72·80	72·3	69·4	68·8	68·8	68·6	67·35	65·8	75·17	74·2	69·3	67·4	SiO_2
TiO_2	0·07	0·31	Abs.	0·09	0·09	0·08	0·23	0·10	0·12	0·13	0·45	0·11	0·01	0·49	0·72	TiO_2
Al_2O_3	15·07	18·38	11·8	14·88	14·3	17·4	14·3	15·6	16·6	19·05	17·1	13·52	13·5	12·6	16·9	Al_2O_3
Fe_2O_3	0·52	0·81	0·33	0·34	0·51	0·65	1·1	1·0	1·2	0·11	1·1	0·43	0·73	0·77	0·83	Fe_2O_3
FeO	0·55	0·63	0·78	0·24	0·76	0·34	1·8	1·5	0·76	0·13	1·9	0·49	0·62	4·2	1·5	FeO
MnO	Tr.	0·01	0·01	0·02	0·01	Tr.	0·02	0·01	0·01	0·02	0·06	0·03	0·02	0·05	Abs.	MnO
MgO	0·43	0·69	0·20	0·64	0·90	0·62	2·2	2·2	0·88	Tr.	1·4	0·55	0·09	4·2	1·4	MgO
CaO	3·64	3·87	4·0	2·48	3·2	3·1	2·1	1·6	3·6	3·84	5·6	2·11	4·9	1·9	3·2	CaO
Na_2O	5·05	6·61	3·0	5·05	4·0	5·8	5·5	5·1	4·7	7·70	4·9	5·30	4·4	2·7	5·2	Na_2O
K_2O	0·22	0·66	1·0	1·83	2·5	0·56	1·1	1·2	0·80	0·28	0·50	0·26	0·61	2·9	2·3	K_2O
P_2O_5	0·01	0·05	0·01	0·01	0·02	0·01	0·02	Abs.	0·03	0·06	0·10	0·01	0·05	Tr.	0·03	P_2O_5
H_2O+	0·54	0·88	1·0	1·56	0·29	0·62	1·3	1·6	1·0	1·31	0·45	1·49	0·51	1·2	0·90	H_2O+
CO_2 etc.*	Abs.	Abs.	0·21	0·18	0·24	0·25	0·38	0·46*	0·31	0·33	0·18	0·17	0·01	0·08	0·16	CO_2 etc.*
Total	99·27	99·04	99·5	100·12	99·1	98·8	98·9	99·2	98·6	100·31	99·5	99·64	99·7	100·4	100·5	Total
Weight norms																
Q	34·39	16·08	49·1	30·18	31·4	26·0	24·0	27·1	29·2	13·90	21·6	37·86	38·2	29·3	19·1	Q
Or	1·30	3·89	5·9	10·81	14·8	3·3	6·5	7·1	4·7	1·65	3·0	1·53	3·6	17·1	13·6	Or
Ab	42·71	55·90	25·4	42·71	33·8	49·1	46·5	43·1	39·7	65·12	41·4	44·82	37·2	22·8	44·0	Ab
An	17·81	18·54	15·8	12·24	13·7	15·3	10·3	7·9	17·7	16·68	23·2	10·41	15·3	9·4	15·7	An
Q+Or+Ab	78·40	75·87	80·4	83·70	80·0	78·4	77·0	77·3	73·6	80·67	66·0	84·21	79·0	69·2	76·7	Q+Or+Ab

* by loss on ignition.

Segregation bands in quartzo-feldspathic gneisses

45. Felsic band in pinkish-grey acid gneiss composed of quartz, plagioclase, and biotite; Loch Tollie district (NG 816797) (D.L.S.).

46. Felsic band in grey acid gneiss composed of plagioclase and quartz with biotite and hornblende; south of Gairloch (NG 786736) (D.R.B.).

Segregation bands in hornblende schist-amphibolite

47. Quartzo-feldspathic segregation band; Gruinard Bay district (NG 954879) (D.R.B.).

48. Medium fine-grained felsic bands composed predominantly of quartz and acid plagioclase; south of Gairloch (NG 797712) (T. S. Ghaly anal.).

49. Quartzo-feldspathic band composed of plagioclase, quartz, biotite, and microcline; Loch Tollie district (NG 850783) (D.R.B.).

50, 51, 52, 53. Plagioclasites—Loch Kery basite, Gairloch—Bowes and Park, 1966, Table 4 (D.R.B.).

54. Coarse-grained felsic band adjacent to hornblendic ball; south of Gairloch (NG 812705) (T. S. Ghaly anal.).

55. Segregation band composed of plagioclase and quartz with biotite and hornblende; Loch Tollie district (NG 850783) (D.R.B.).

Segregation patches in hornblende schist-amphibolite

56. Medium-grained felsic pod composed predominantly of quartz and acid plagioclase; south of Gairloch (NG 812706) (T. S. Ghaly anal.).

57. Coarse-grained quartzo-feldspathic patch adjacent to hornblendite balls; Gruinard Bay district (NG 958878) (D.R.B.).

58. Coarse-grained quartzo-feldspathic patch adjacent to hornblendite balls; Gruinard Bay district (NG 958879) (D.R.B.).

59. Coarse-grained quartzo-feldspathic patch adjacent to hornblendite balls; Gruinard Bay district (NG 939898) (D.R.B.).

TABLE I—*continued*

Parautochthonous and intrusive granitic rocks—granitic, aplitic, and pegmatitic veins and sheets

No.	60	61	62	63	64	65	66	67	68	69	70	71	72	73	No.
H.M.	9509	9513	9514	9515	9516	9769	9510	9511	9771	9512	—	9518	—	9519	H.M.
SiO_2	77·5	75·72	75·6	75·5	75·11	74·9	74·82	72·90	72·7	76·58	76·54	74·81	74·71	74·70	SiO_2
TiO_2	Abs.	Abs.	Abs.	Abs.	Abs.	Tr.	Abs.	0·13	Abs.	Abs.	—	0·06	0·03	Abs.	TiO_2
Al_2O_3	12·4	14·09	13·0	13·3	14·03	14·0	15·43	14·84	14·7	13·86	14·09	14·13	14·18	13·81	Al_2O_3
Fe_2O_3	0·12	Tr.	0·58	1·0	0·43	0·29	0·44	0·43	0·08	0·26	1·47	Abs.	0·05	Abs.	Fe_2O_3
FeO	0·06	0·24	0·16	0·11	0·63	0·11	0·20	0·71	0·08	0·19	—	0·1	—	0·09	FeO
MnO	0·03	Abs.	0·03	0·01	Tr.	Abs.	0·02	0·02	0·03	0·01	—	Abs.	—	Abs.	MnO
MgO	0·32	0·01	0·61	0·67	0·20	0·44	0·14	0·29	0·02	0·25	0·10	Tr.	0·78	0·02	MgO
CaO	1·3	1·18	0·98	0·59	1·20	0·89	2·22	2·83	0·38	0·74	0·19	0·44	0·08	0·32	CaO
Na_2O	4·7	3·66	3·6	3·7	4·66	3·7	5·20	4·66	3·1	4·40	2·32	2·42	2·20	1·88	Na_2O
K_2O	2·2	4·58	5·0	5·3	3·25	4·4	1·35	1·90	8·1	3·90	4·64	8·07	7·91	8·27	K_2O
P_2O_5	Abs.	Abs.	Abs.	Abs.	Tr.	Abs.	0·01	0·05	Abs.	Abs.	—	Abs.	—	Abs.	P_2O_5
H_2O+	0·30	0·27	0·51	0·32	0·36	0·24	0·31	0·43	0·19	0·14	—	0·33	0·14	0·20	H_2O+
CO_2	—	—	—	—	—	Tr.	—	—	Tr.	—	—	—	0·02	—	CO_2
Loss on ignition	—	—	—	—	—	—	—	—	—	—	0·74	—	—	—	Loss on ignition
Total	99·0	99·75	100·1	100·5	99·87	99·0	100·14	99·19	99·4	100·33	100·09	100·39	100·10	99·29	Total
Weight norms															
Q	38·5	34·18	32·6	31·5	32·36	34·0	34·47	31·83	22·8	34·06	44·75	28·86	30·35	31·34	Q
Or	13·0	27·06	29·5	31·3	19·20	26·0	7·98	11·23	47·9	23·04	27·41	47·68	46·73	48·86	Or
Ab	39·7	30·95	30·4	31·3	39·41	31·3	43·98	39·41	26·2	37·21	19·62	20·47	18·61	15·89	Ab
An	6·3	5·85	4·6	2·9	5·95	4·4	10·95	13·74	1·9	3·67	0·94	2·18	0·29	1·59	An
Q+Or+Ab	91·2	92·19	92·5	94·1	90·97	91·3	86·43	82·47	96·9	94·31	91·78	97·01	95·69	96·09	Q+Or+Ab

Parautochthonous granitic, aplitic, and pegmatitic veins

60. Gneissose aplitic vein composed of plagioclase, quartz, and biotite; Loch Tollie district (NG 844788) (D.R.B.).

61. Concordant granitic vein composed of plagioclase, quartz, microcline with muscovite, and biotite; Loch Tollie district (NG 850781) (C.C.B.).

62. Centre of concordant granitic vein composed of plagioclase, quartz, microcline with biotite, and muscovite; Loch Tollie district (NG 844788) (D.R.B.).

63. Margin of concordant granitic vein 62 (D.R.B.).

64. Gneissose concordant granitic vein composed of plagioclase and quartz with microcline and biotite; Loch Tollie district (NG 812809) (C.C.B.).

65. Quartz-oligoclase-microcline pegmatitic vein; south of Gairloch (NG 784737) (D.R.B.).

66. Banded aplitic vein composed of plagioclase, quartz, and elongate patches of biotite; Loch Tollie district (NG 850785) (C.C.B.).

67. Gneissose aplitic vein composed of plagioclase, quartz, and biotite; Loch Tollie district (NG 838802) (C.C.B.).

68. Coarse-grained quartz-microcline-oligoclase pegmatite; south of Gairloch (NG 784736) (D.R.B.).

Intrusive granitic and pegmatitic veins and sheets

69. Discordant pegmatitic vein composed of plagioclase, quartz, microcline, and biotite; Loch Tollie district (NG 849787) (C.C.B.).

70. Granite vein, Archean gneiss, Heights of Kinlochewe—MacKie, 1905, p. 54 (W. MacKie anal.).

71. Rodded pegmatite sheet composed of microcline, quartz, and plagioclase with muscovite; Loch Tollie district (NG 855788) (C.C.B.).

72. Granitic pegmatite, South Harris—Davidson, 1943, p. 108.

73. Rodded pegmatite sheet composed of microcline, quartz, and plagioclase with muscovite; Loch Tollie district (NG 838802) (C.C.B.).

TABLE I—*continued*

Parautochthonous and intrusive granitic rocks—granitic, aplitic, and pegmatitic veins and sheets—continued

No.	74	75	76	77	78	79	80	No.
H.M.	9517	—	9044	9710	—	—	—	H.M.
SiO_2	73·6	72·10	71·3	66·9	—	—	—	SiO_2
TiO_2	0·01	0·00 ?	0·09	0·11	—	—	—	TiO_2
Al_2O_3	13·1	15·14	15·6	17·3	—	—	—	Al_2O_3
Fe_2O_3	0·32	0·63	0·33	0·30	—	—	—	Fe_2O_3
FeO	0·40	0·05	0·51	0·42	—	—	—	FeO
MnO	0·02	0·06	Abs.	Abs.	—	—	—	MnO
MgO	0·38	0·03	0·35	0·69	—	—	—	MgO
CaO	1·7	0·27	2·4	0·46	—	—	—	CaO
Na_2O	3·7	2·05	4·4	3·2	2·12	2·39	2·11	Na_2O
K_2O	5·6	9·35	4·1	8·9	8·73	9·69	9·09	K_2O
P_2O_5	Abs.	0·10	0·08	0·07	—	—	—	P_2O_5
H_2O+	0·44	0·21	0·15	0·41	—	—	—	H_2O+
CO_2	—	—	—	—	—	—	—	CO_2
Loss on ignition	—	—	—	—	—	—	—	Loss on ignition
Total	99·3	99·99	99·3	98·8	—	—	—	Total
Weight norms								
Q	29·1	24·04	24·5	12·3	—	—	—	Q
Or	33·1	55·24	24·2	52·6	—	—	—	Or
Ab	31·3	17·34	37·2	27·1	—	—	—	Ab
An	2·6	0·75	10·7	1·9	—	—	—	An
Q+Or+Ab	93·5	96·62	85·9	92·0	—	—	—	Q+Or+Ab

74. Discordant pegmatitic vein composed of microcline, plagioclase, and quartz with muscovite and biotite; Loch Tollie district (NG 844788) (D.R.B.).
75. Feldspar rock, dyke in Lewisian Gneiss; near Loch Inchard, Sutherland —*Summ. Progr. Geol. Surv. Gt. Brit.* for 1919, p. 44 (E. G. Radley anal.).
76. Pegmatite—bulk sample—west of ruins, North Rona—Bowes, 1961 p. 189 (D.R.B.).
77. Feldspar-rich pegmatite sheet; Loch Tollie district (NG 858787) (C.C.B.).
78. Graphic granite; Loch Laxford district—*Mem. Geol. Surv. Gt. Brit.* Min. Res. vol. v, 'Potash-felspar', 1916, p. 11 (Geological Survey anal.).
79. Graphic granite; Durness district—*Ibid.*
80. Graphic granite; Durness district—*Ibid.*

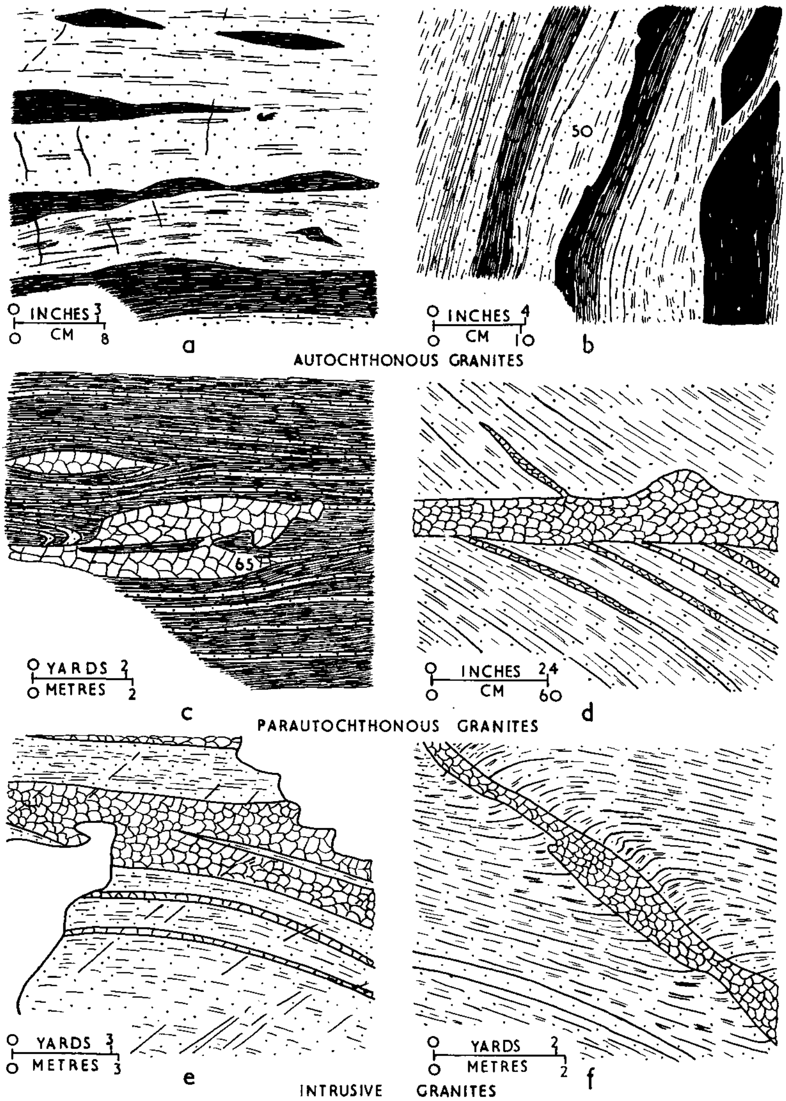

FIG. 1. Nature of Lewisian granitic rocks: (*a*) Autochthonous granite bands with gneissose structure associated with bands and lenses of hornblende-rich rock; Gairloch district. (*b*) Autochthonous granite bands (analysis 50) with banded hornblende–feldspar gneiss and lenses of hornblende-rich rock; Gairloch district. (*c*) Parautochthonous pods (analysis 65) in banded hornblende-schist; south of Gairloch. (*d*) Parautochthonous granitic veins, with foliation parallel to that of the host gneissose autochthonous granite, merging into the gneiss at one end, and at the other end passing into an intrusive granitic vein; Loch Tollie district. (*e*) Intrusive pegmatitic granite sheets in gneissose autochthonous granite; sub-horizontal face, Loch Laxford district. (*f*) Intrusive pegmatitic granite sheet intruded along the axial plane of a fold, which affects the foliation banding of the host gneissose autochthonous granite; cliff face, Loch Laxford district

In this paper, the normative Q, Or, Ab, An proportions of seventy-seven of the Lewisian granitic rocks are plotted and the results compared with the experimental data of Tuttle and Bowen (1958) and their plots of normative Q, Or, Ab proportions in naturally occurring granites (figs. 2*a*, 3*a*, 4*a*, 5*a*) and the Or–Ab–An data of Kleeman (1965) (figs. 2*b*, 3*b*, 4*b*, 5*b*). All the Lewisian granitic rocks for which analytical data are presented are holocrystalline, medium-coarse grained, made up essentially of quartz, potassium feldspar, and acid plagioclase in varying proportions, and contain $> 65\ \%$ SiO_2 in their chemical analysis. These rocks, which are of plutonic aspect (Read, 1957, p. xv), with granite in the strict sense a somewhat subordinate member (cf. Turner and Verhoogen, 1960, p. 330; Walton, 1955, p. 1), have been divided into autochthonous, parautochthonous, and intrusive types (cf. Read, 1957, pp. 364–365) on the basis of field relations. Of the 77 analysed rocks for which normative Q, Or, Ab, An proportions are plotted, 47 contain $> 80\ \%$ Q+Or+Ab, and the compositions of these rocks are in sufficiently close accord with the compositions of the experimental systems for comparison to be made (cf. Tuttle and Bowen, 1958). Of the remainder, 17 contain 80–75 % and 13 contain $< 75\ \%$ Q+Or+Ab.

Seventy of the rock analyses presented were carried out in the Geochemical Laboratories of the Department of Geology, University of Glasgow as part of a programme dealing with the petrochemistry of Lewisian rocks. The analytical methods used were largely based on those of Riley (1958*a*, 1958*b*). With each batch of rocks, powders M149 and T13 of Mercy (1956) were analysed and the accuracy of the analyses is within the range given by Mercy (1956, Tables 3, 4), with the standard deviations for SiO_2 and Al_2O_3 considerably lower.

Autochthonous granitic rocks (figs. 2 and 3)

These rocks have a metamorphic fabric, most are banded (fig. 1*a*), and on a large scale they are heterogeneous. Some are striped and made up of bands, which are, alternately, relatively felsic- and mafic-rich (fig. 1*b*), some of the more felsic bands trending towards trondhjemite compositionally (46). However, the vast majority of the autochthonous granites are coarse grained, poorly banded quartzo-feldspathic gneisses (fig. 1*d*, *e*, *f*; table I, nos. 1–44) with which bands or pods rich in hornblende or biotite or both are commonly associated (Nisbet, 1961, p. 176). Mineralogically they are generally rich in oligoclase, and with few

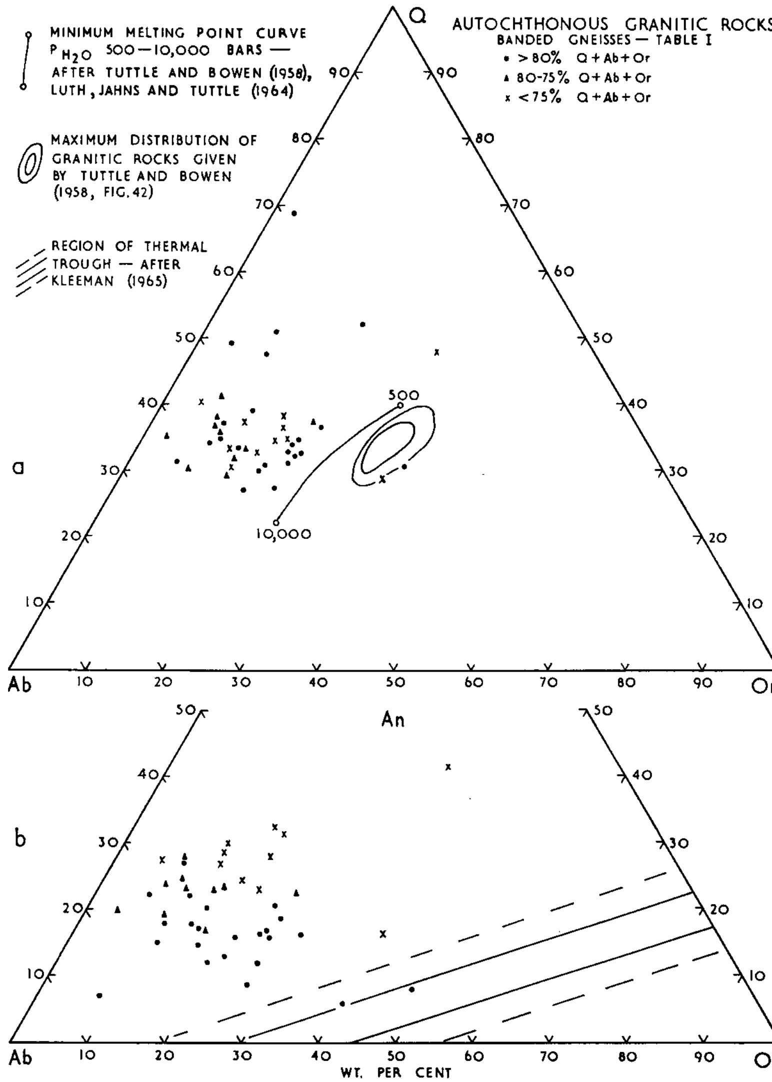

FIG. 2. Normative Q–Or–Ab proportions (*a*) and Or–Ab–An proportions (*b*) for autochthonous granitic rocks (banded gneisses—table I, nos. 1–44). To facilitate comparison, figs. 2*a*, 3*a*, 4*a*, 5*a* show a line representing the variation in position of the minimum melting point in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O with variations in water-vapour pressure from 500 to 10 000 bars (after Tuttle and Bowen, 1958, and Luth, Jahns, and Tuttle, 1964) and contours illustrating the maximum distribution of normative albite, orthoclase, and quartz in all the (571) analysed plutonic rocks in Washington's Tables (1917) that carry 80 % or more normative Q+Or+Ab, this distribution being taken as typical of that of granitic rocks by Tuttle and Bowen (1958, Fig. 42). Figs. 2*b*, 3*b*, 4*b*, 5*b* show the position of the thermal trough in the system $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 (after Kleeman, 1965)

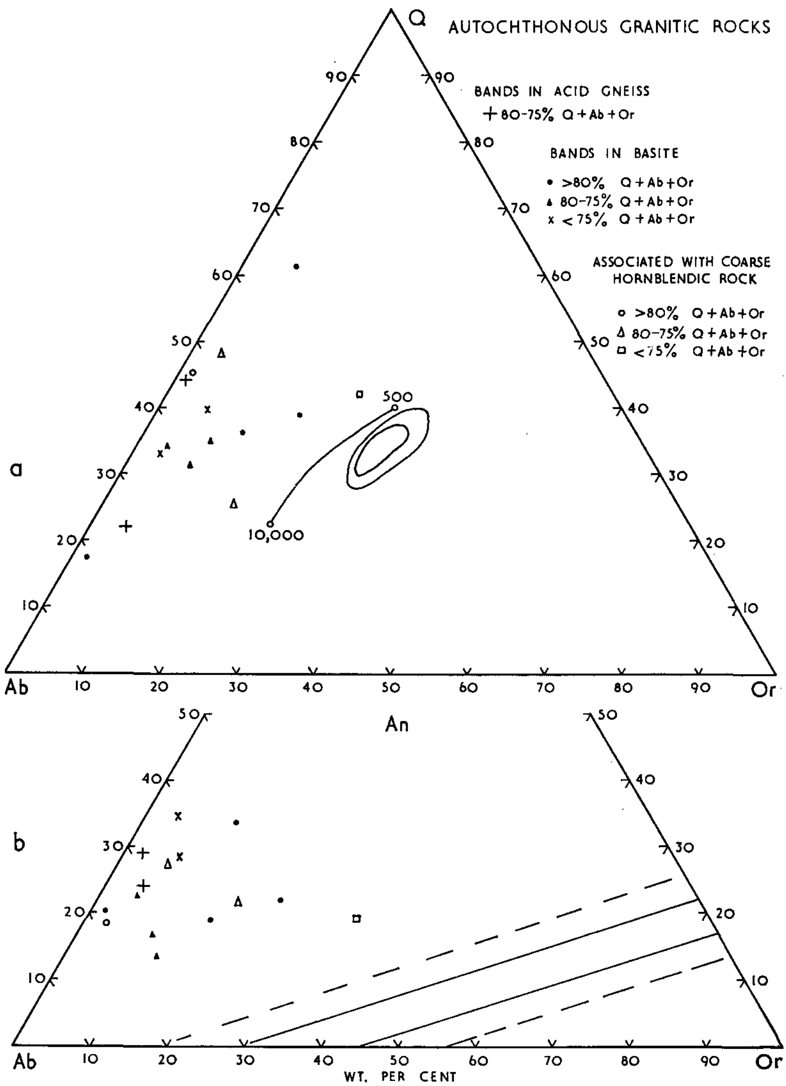

FIG. 3. Normative Q–Or–Ab proportions (*a*) and Or–Ab–An proportions (*b*) for autochthonous granitic rocks (segregation bands and patches in gneisses—table I, nos. 45–59)

exceptions their chief chemical characteristics are richness in sodium and dominance of sodium over potassium.

Many of the analysed rocks developed under conditions of amphibolite-facies metamorphism and intense deformation at the expense of rocks of sedimentary derivation (Bhattacharjee, 1963*a*; Park, 1964; Ghaly, 1965). In places prominent segregation bands and patches developed (table I, nos. 45–59), both within dominantly quartzo-feldspathic gneisses (45, 46) and also in dominantly hornblende-schist–amphibolite units (47–59). The compositions of the bands formed in the latter environment have been shown to be unlike the compositions of igneous rocks (Bowes and Park, 1966).

The fields of composition shown by plots (figs. 2, 3) of normative Q–Or–Ab and Or–Ab–An for rocks with $> 80\ \%$ Q+Ab+Or are very similar to those with $< 80\ \%$ Q+Ab+Or, apart from some rocks containing high proportions of Q, which probably represents an original composition effect (cf. Bhattacharjee, 1963*a*). Hence it is considered legitimate to compare the compositions of all those granitic rocks with compositions of the experimental systems. The normative compositions of these autochthonous granites show little relationship to either the low-water-vapour-pressure minimum melting point in the $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O system or to the thermal trough in the $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 system. The compositions of some of the rocks are close to the minimum melting-point at moderate to high water-vapour pressures in the $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O system. However, most plot close to the Q–Ab sideline, some are very similar to trondhjemite and the trend of the transition series in North Rona (Bowes, 1961) is away from the minimum melting-point composition towards the Q–Ab sideline. The field of composition of the Lewisian autochthonous granites shows considerable similarity to those of basement autochthonous (synkinematic) granitic rocks in Finland (Eskola, 1956, Fig. 1), Norway (Barth, 1955, Fig. 4), and West Africa (Marmo, 1955).

Parautochthonous granitic rocks (fig. 4)

These rocks (table I, nos. 60–68) occur as relatively small masses that are generally concordant with the foliation of the gneisses or hornblende-schists–amphibolites in which they occur and at the expense of which they have developed. They can often be traced from more felsic bands in the host rock (fig. 1*c*, *d*), where they exhibit weak foliation, to lobes and concordant sheets without foliation and showing features indicative

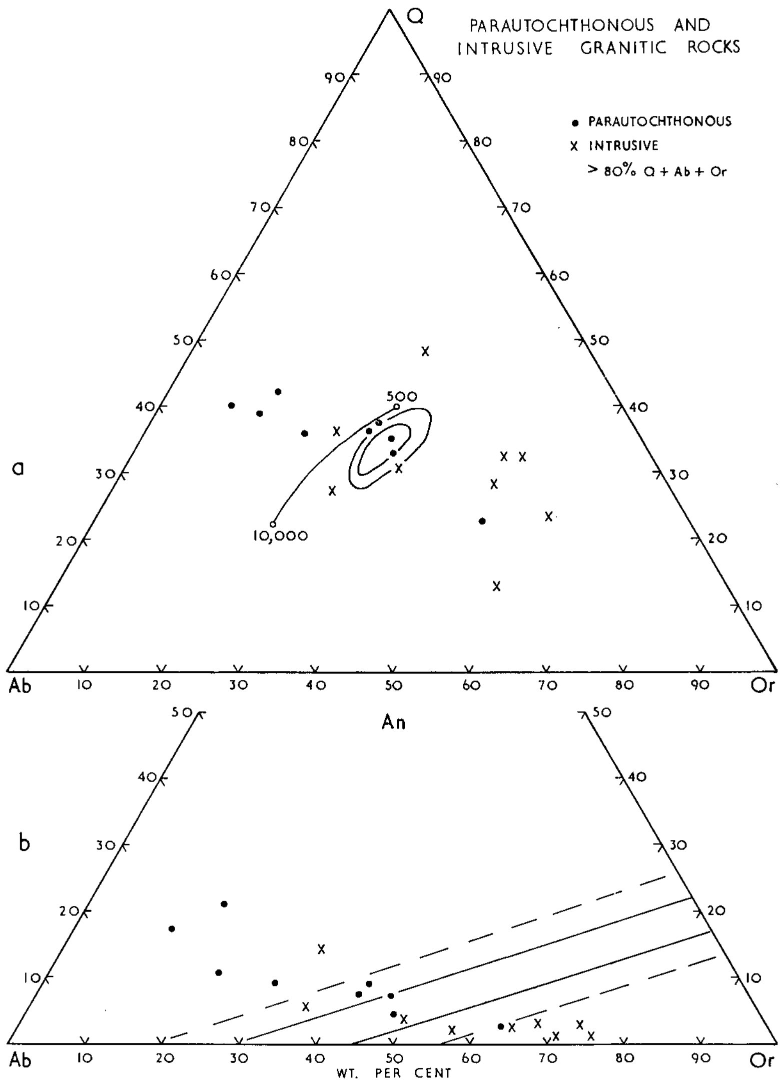

FIG. 4. Normative Q–Or–Ab proportions (*a*) and Or–Ab–An proportions (*b*) for parautochthonous and intrusive granitic rocks (table I, nos. 60–80)

of the beginnings of mobility. In parts parautochthonous granitic streaks and pods show cross-cutting relations (fig. 1*c*) and some can be traced into granitic and pegmatitic sheets and veins (fig. 1*d*).

Mineralogically the rocks are composed almost entirely of quartzo-feldspathic constituents, with only minor amounts of ferromagnesian minerals present. In some of the rocks acid plagioclase, potassium feldspar, and quartz are present in approximately equal proportions, as are potassium and sodium. Plots of normative Q, Or, and Ab proportions of these rocks (fig. 4*a*) fall within the field of composition taken as typical of granitic rocks by Tuttle and Bowen (1958). Plots of Or, Ab, An proportions of these rocks correspond with compositions in the thermal trough in the system $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 (fig. 4*b*). Other parautochthonous granitic rocks, including coarser-grained elongate pods, are more oligoclase-(sodium-)rich and the Q–Or–Ab and Or–Ab–An proportions plot within the respective fields shown by the autochthonous granitic rocks. One parautochthonous granite is orthoclase-(potassium-)rich and compositionally is similar to a number of intrusive granitic rocks.

Intrusive granitic rocks (fig. 4)

These rocks are coarse grained, often of pegmatitic habit, and occur as cross-cutting veins and sheets. Their form is generally controlled by structure, both by the foliation of the surrounding gneisses and by the axial planes of folds that deform the gneissose banding (fig. 1*f*). Hence they commonly occur as a series of parallel veins (fig. 1*e*). Cross-cutting relations with autochthonous granitic rocks are clearly displayed, as are gradations with parautochthonous granites (fig. 1*d*). In composition they differ considerably from the rocks they intrude and their characters and geological occurrence indicate that they occupy planes of weakness, up which there has been intrusive movement of volatile-rich magma.

The intrusive granitic rocks in the Loch Tollie district were emplaced after at least two major deformational phases, viz. the main phase during which the autochthonous granitic rocks were formed and the mid phase during which the dominant foliation of the gneisses was folded and structures, including the Tollie anticline, whose axial planes act as a structural control for the uprise of the intrusive granitic rocks were developed (Bhattacharjee, 1963*a*). Subsequently they and the host rocks were affected by brittle deformation in the late phase (Bhattacharjee, 1963*b*). The time relations and geological occurrence of the intrusive granitic rocks in the Loch-Laxford–Ben-Stack district (cf. Peach *et al.*, 1907, p. 37) show considerable correspondence with those observed in the Loch Tollie district (cf. fig. 1*e*, *f*) and the Lewisian intrusive granitic rocks can, in general, be referred to as being late-kinematic. The general correspondence of the average composition of the Lewisian parautochthonous and intrusive granitic rocks (table I, nos. 60–80) with the average composition of the late-kinematic granites in the Svecofennidic rock crust of southwestern Finland (Simonen, 1948, p. 16) is worth noting.

Mineralogically the Lewisian intrusive granitic rocks are generally characterized by abundance of potassium feldspar (microcline) together with quartz and subordinate amounts of acid plagioclase. Evidence of the development of microcline as a replacement of acid plagioclase is common (Bhattacharjee, 1963*a*; cf. Langer, 1966). Generally potassium is abundant and its dominance over sodium characteristic, as, for example, in the granitic-pegmatitic sheets of the Loch Laxford district (78–80). The normative proportions of Q, Or, and Ab plot well towards the Or apex with reference to the minimum melting point in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O and to the field of composition taken by Tuttle and Bowen (1958) as typical of granitic rocks (fig. 4*a*). The normative proportions of Or, Ab, and An, in a number of instances, lie on the Or side of the thermal trough (fig. 4*b*). However, a few of the intrusive granitic rocks have compositions that correspond more closely with the minimum melting-point composition in the $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O system and with the thermal trough in the $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 system. The compositions of these rocks are generally similar to the compositions of some of the parautochthonous granitic rocks.

Discussion

While some of the Lewisian granitic rocks show correspondence in composition with the minimum melting-point compositions in the $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O system and the thermal trough compositions in the $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 system, the majority of the analysed granitic rocks bear little relation to compositions expected, on the basis of experimental work, from magmatic crystallization (or melting followed by crystallization). In addition, the general trend of the field of composition from autochthonous to parautochthonous and intrusive types, a geological sequence that can be established in both

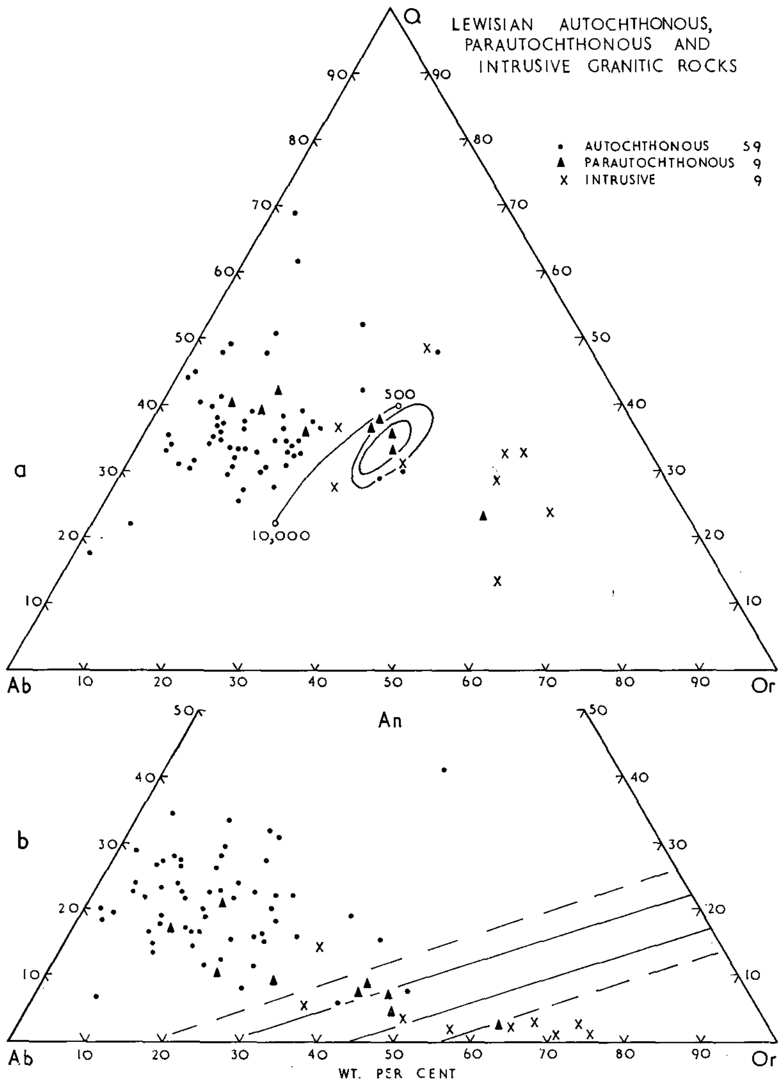

Fig. 5. Normative Q–Or–Ab proportions (*a*) and Or–Ab–An proportions (*b*) for autochthonous, parautochthonous, and intrusive granitic rocks

place and time, is from Ab–Q-rich towards Or-rich. This is transverse to the compositional trend that the evidence of experimental studies suggests would be the case if melting and magmatic crystallization were the dominant processes involved. Hence the geological sequence of development of these granitic rocks cannot have resulted from the action of igneous processes or the introduction of material of igneous derivation. This conclusion is supported by the compositions of the coarser-grained felsic-rich bands present in both the banded quartzo-feldspathic gneisses and the hornblende-schists–amphibolites. However, the geological evidence of the beginnings of mobility shown by the parautochthonous granitic rocks and of considerable mobility shown by the intrusive granitic rocks suggests that the autochthonous–parautochthonous–intrusive compositional trend (fig. 5) may be significant in the development of igneous material (cf. King, 1965, p. 233).

The closeness of the compositions of some of the autochthonous granitic rocks to compositions of the minimum melting point at moderate to high water-vapour pressures in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2 suggests that selective melting of water-rich (sedimentary) rocks may have been operative, if only to a limited extent. However, the majority of the autochthonous granite rocks were formed under conditions of amphibolite-facies metamorphism, many in epidote-amphibolite facies (cf. Bhattacharjee, 1963*a*; Park, 1964). This represents conditions of temperature below which anataxis of sediments begins—'between 665° C and 740° C at 2000 bars gas pressure' (von Platen, 1965, p. 216) —but at which albite and quartz are the most soluble of the major mineral constituents. The operation of extraction and redeposition of the most soluble substances (Eskola, 1932, pp. 75–77) and of differentiation due to heterogeneous pressure (Ramberg, 1952, pp. 215–220; cf. Bowes and Park, 1966) would result in the development of banded rocks, with metamorphic fabric, rich in normative Q and Ab (cf. figs. 2*a*, 3*a*). Variations in pressure and temperature would result in the varying proportions of Q and Ab shown. Below depths of 5 Km at 300° C, where albite is more soluble than quartz, the trend would be towards trondhjemitic compositions in the felsic bands in both quartzo-feldspathic gneisses and in hornblende-schists–amphibolites. Original proportions of Or and An appear to have had no major effect on the final products, which are commonly associated in the field with bands, lenses, and pods rich in hornblende or biotite or both (fig. 1*b*) containing comparatively low silicon and sodium proportions (cf. Bowes and Park, 1966).

Some of the parautochthonous granitic rocks have compositions which plot within the field of the autochthonous types (fig. 5), indicating a continuity of processes of formation. However, in the case of other parautochthonous granitic rocks, the closeness of the normative Q, Or, Ab proportions to the minimum-melting-point compositions at low water-vapour pressures in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O (fig. 4*a*) indicates genesis by selective melting followed by crystallization at low water-vapour pressures. Weight is added to this conclusion by the plots of Or, Ab, An proportions in relation to the thermal trough in the system $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 (fig. 4*b*) and the field evidence indicating the development of parautochthonous types from felsic bands of banded gneisses, which have low water contents (cf. table I, nos. 1–44), with the gradual loss of foliation and the development of some cross-cutting relations (fig. 1*c*, *d*).

The closeness of the normative Q, Or, Ab, An proportions of a few of the intrusive granitic rocks to the minimum-melting-point and thermal-trough compositions in the experimental systems (fig. 4*a*, *b*) indicates that selective melting at low water-vapour pressure was operative during their formation, as in the case of some of the parautochthonous granitic rocks. The dominance of normative Or in most of the intrusive granitic rocks corresponds with the abundance of microcline replacement of oligoclase (cf. Bhattacharjee, 1963*a*) and appears to be the result of potassium metasomatism (cf. Eskola, 1956). The very coarse grain-size of some of the pegmatitic sheets occupying axial zones of folds (fig. 1*f*) indicates the accession of fluids and the field of composition of these sheets (fig. 4*a*, *b*) represents an Or-rich extension of the field of composition of the more granitic types. The genesis of the Or-rich parautochthonous granitic rock is explained as the result of the accession of potassium (with water) into a rock with a composition comparable to the minimum-melting-point composition. It should also be noted that some of the more potassium-rich autochthonous granitic rocks in the Loch Tollie district show evidence of microcline replacing oligoclase (Bhattacharjee, 1963*a*).

Conclusions

The evidence of the petrochemistry of Lewisian granitic rocks suggests that the sodium-dominant nature of autochthonous granitic rocks and the potassium-dominant nature of granitic rocks formed later in the same cycle, as noted by many workers (cf. Read, 1957, p. 333), results from the varying role of different granite-forming processes in the development of the Granite Series. The effects of mineral solubility under stress conditions appear to be dominant in the development of autochthonous granitic rocks; selective melting at moderate to high water-vapour pressure may also be significant in some environments. With the formation of parautochthonous granitic rocks at the expense of autochthonous types, selective melting, at low water-vapour pressures, becomes dominant. This process continues in the formation of intrusive granitic rocks but the resultant products are modified by potassium metasomatism. This metasomatic alteration also affects some of both the autochthonous and parautochthonous types.

Banded autochthonous granitic rocks, which comprise a considerable proportion of the Lewisian complex, have compositions indicating that they were not formed by the metamorphism of pre-existing granitic rocks and are not orthogneisses.

The field of composition of the Lewisian granitic rocks moves from Ab–Q-rich to Ab = Or = Q (approximately) to Or-rich, this trend being transverse to the compositional variations postulated on the basis of some experimental studies.

The field of composition taken by Tuttle and Bowen (1958, Fig. 42) as typical of granitic rocks is not representative of all the various members of the Granite Series (found in various geological situations) and the conclusion (p. 77) 'that magmatic liquids are involved in the genesis of granitic rocks' is not applicable to all granitic rocks.

This study also shows that the geological relevance of studies of experimental systems with compositions corresponding to those of granitic rocks depends upon the extent to which these studies 'are based on a structural, petrographic and chemical appreciation of the phenomena they are designed to explain' (King, 1965, pp. 232–233).

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