MINERALOGICAL MAGAZINE, JUNE 1983, VOL. 47, PP. 123-137

The geology and geochemistry of the Strathy complex of north-east Sutherland, Scotland

VALERIE E. MOORHOUSE AND STEVEN J. MOORHOUSE

Geological Sciences, School of Natural Sciences, The Hatfield Polytechnic, Hatfield, Hertfordshire AL10 9AB

ABSTRACT. The Strathy complex is a fault-bounded block of the sub-Moine succession basement characterized by a marked aeromagnetic anomaly. XRF analyses of 94 rocks for 26 elements are used to illustrate the geochemistry of the complex. It comprises siliceous grey gneisses (50 analyses), subordinate amphibolite (13 analyses), hornblende gneiss (13 analyses), and ultramafites (1 analysis), with scapolite-diopside marble and calc-silicate rocks (3 analyses from Strathy, 14 analyses of other calc-silicates). Geochemically the Strathy gneisses are quite distinct from the adjacent Moine lithologies, being unusually low in K, Rb, La, and Ce, and high in SiO_2 and Na_2O, whilst differences in immobile elements such as Ti and Zr preclude their derivation from a Moine source. The Strathy complex is unlike other high-grade gneiss terrains and apparently acquired its characteristic geochemical features by the removal of an anatectic melt under amphibolite-facies conditions leaving a refractory residue of quartz, plagioclase, Ca-poor amphibole, and garnet ± staurolite in siliceous gneisses. Subsequent influx of water, retrogression to biotite-bearing assemblages, production of sillimanite, and anatectic trondhjemitic melts took place during the maximum metamorphism of the surrounding Moine. The complex is considered to have originated as a dacitic supracrustal sequence with minor sediments and mafic-ultramafic intrusives. *REE* and Y abundances suggest a Proterozoic age, possibly as part of the Laxfordian cycle.

Introduction and geological setting of the Strathy complex

The Strathy complex occurs as a fault-bounded block of sub-Moine basement (Harrison and Moorhouse, 1976) within the migmatitic gneisses and granites of the east Sutherland Moine. This eastern Moine is separated from the west Sutherland 'A' Mhoine-type' feldspathic psammites by a central belt (some 11 km wide) bounded by two complex tectonic discontinuities, the Naver and Meadie 'slide' zones (fig. 1). This belt comprises psammite and subordinate pelitic rocks and is dominated by six major tectonic inliers and numerous minor slices believed to be derived from the sub-Moine basement (Read, 1931; Winchester and Lambert, 1970; Moorhouse, 1976; Moorhouse and Harrison, 1976; Moorhouse and Moorhouse, 1977). As distinct from the Strathy complex, these tectonic inliers are folded sheets concordant with the regional foliation, and rocks adjacent to their boundaries commonly contain mineral fabrics characteristic of extremely high strain, taken to indicate their emplacement by a mechanism of low-angle ductile thrusting (sliding) quite different from the vertical shear-zones bounding the Strathy complex.

In the north, along the well-exposed coastal strip, the east Sutherland belt is divisible on lithological and structural grounds into four assemblages. (*a*) The Bettyhill assemblage of variably migmatized quartzitic and pelitic gneiss, amphibolite and several suites of concordant, and cross-cutting, often foliated granite, with thin, strongly reworked strips of the sub-Moine basement (fig. 1). (*b*) The Kirtomy assemblage of banded, migmatitic biotite gneisses with rarely foliated granites and subordinate amphibolite lies structurally above the Bettyhill assemblage and is separated from it by the Swordly slide which brings up slivers of sub-Moine basement. (*c*) The Strathy complex which apparently occurs faulted into the Kirtomy assemblage, the two being juxtaposed east of Ardmore Point (fig. 1), with the eastern boundary on the north coast obscured by the Strathy Bay Old Red Sandstone which is possibly infilling a fault valley. (*d*) The Portskerra assemblage of quartzitic gneiss, abundant granite, and occasional amphibolites which is reminiscent of the Bettyhill assemblage.

The Strathy complex

The Strathy complex (Harrison and Moorhouse, 1976) comprises mainly K-feldspar-free siliceous grey gneisses, subordinate hornblende gneiss, amphibolite, very rare ultramafites, and marble with calc-silicates, intimately associated with later strings, sheets, veins, and larger bodies of concordant and cross-cutting, largely unfoliated trondhjemite.

These rocks are conspicuously different, both lithologically and geochemically (see later), from

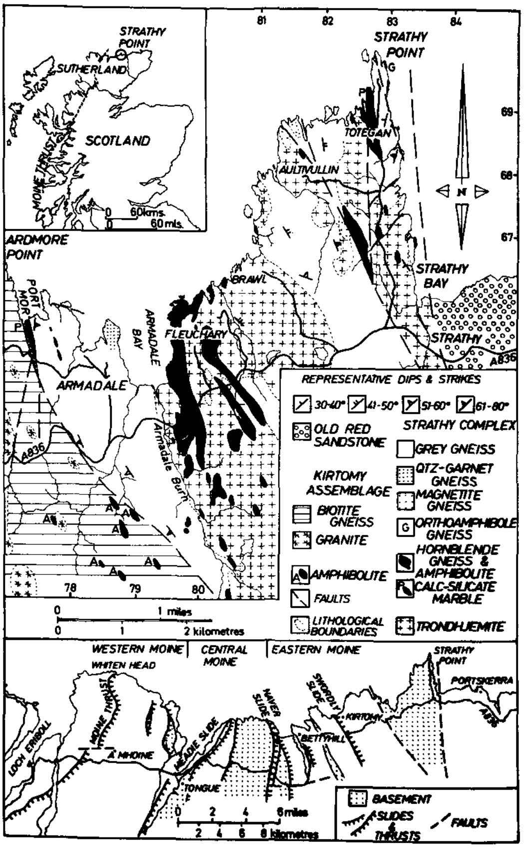

FIG. 1. Geological map of the Strathy complex and its tectonic setting within the north Sutherland Moine.

the undoubted Moine of north Sutherland. That this difference is of a fundamental nature is confirmed by a study of the aeromagnetic map of Great Britain (IGS, 1972) where the Strathy complex is clearly defined by a strong positive anomaly which closely follows the mapped boundaries of the complex. Furthermore the anomaly suggests an off-shore extension of the complex approximately equal in area to that mapped onshore. The magnetic anomaly is abruptly terminated some 9 km offshore, possibly by an ENE-trending fault. The close spacing of anomaly contours along the boundaries of the complex is taken as further confirmation of an origin as a fault-bounded block of lower crustal material.

Structure of the complex

The Strathy complex is characterized by an apparent simplicity of structure, as distinct from the involved sequence of at least five phases of folding recognized in the Bettyhill and Kirtomy assemblages (Moorhouse, 1979; Moorhouse and Moorhouse, 1979*b*, and in prep.) and minor folds and refolds are only sparingly developed in the poorly banded rocks within the complex. The regional foliation of the complex outlines large, rather open NNW-trending folds (fig. 1) believed to be equivalent to late folds elsewhere in north-east Sutherland.

The western boundary of the complex is well exposed on the coast at Port Mor (fig. 1), and a marked escarpment can be traced south-eastwards for 8 km before running into extensive peat bog. At Port Mor the boundary is marked by a vertical shear zone (12 m wide) characterized by the development of abundant white mica and chlorite, folded by late, minor, brittle monoclinal and conjugate folds. Along the centre of the shear zone is a largely undeformed, concordant, virtually unfoliated 4 m wide pink granite sheet. The location of the boundary may well be controlled by the presence of an extensive marble calc-silicate horizon in the Strathy complex between the shear zone and a massive finely crystalline amphibolite sheet (fig. 1). On neither side of the shear zone is there any development of a 'platy fabric' such as is commonly found associated with basement sheets further west in Sutherland, nor have any such fabrics been found elsewhere in or near the complex. In particular it should be noted that where basic orthogneisses and amphibolites occur within the complex they appear to be integral to the complex as a whole, there are no signs of them having been tectonically emplaced into the grey gneisses.

Field relations and petrography

The siliceous grey gneiss lithologies. These quartz-rich rocks are all variations of the dominant grey gneiss lithology of quartz, sodic plagioclase, biotite ± garnet, and amphibole with accessory magnetite, apatite, epidote, and sphene. They are characterized by the absence of K-feldspar and are granoblastic, usually weakly banded or foliated. The plagioclase is frequently a sodic oligoclase, ranging to andesine in varieties containing hornblende. Garnet and amphiboles, both hornblendic and Ca-poor varieties are common in small quantities.

Quartz-garnet 'gneiss'. Where garnet is an important constituent, the lithology is a distinctive, white-weathering, virtually unfoliated quartz-garnet rock, usually with only minor amounts of biotite. This distinctive lithology is well displayed north of Armadale (fig. 1).

Orthoamphibole gneiss. In addition to hornblendic types, accessory amphiboles in the grey gneisses include both monoclinic and orthorhombic Ca-poor types (cummingtonite–grunerite, gedrite–anthophyllite, as originally noted by Collins, 1941). Further optical work, and an XRD study by Dr A. G. Fraser of Hull University, have redefined the orthopyroxene reported by Harrison and Moorhouse (1976) as orthoamphibole. Garnet–orthoamphibole gneiss is well displayed near Strathy lighthouse as a large lens or boudin, with a conspicuous rotated internal 'Z' schistosity, within normal grey gneiss. In this lithology garnet is abundant and biotite, which progressively replaces the amphibole, is more common towards the margins of the lens. In addition to a quartz-oligoclase granoblastic matrix, garnet, orthamphibole, and staurolite appear to form an early paragenesis whilst biotite, sillimanite, and large blebby quartz postdates this. The early paragenesis is believed to represent the state of much of the complex after the first high-grade metamorphic episode (see later).

Cordierite gneiss. Only one occurrence of cordierite-bearing gneiss is known, this was discovered by Collins (1941) on the northern tip of Strathy Point. It is interesting that the only grey gneisses to contain K-feldspar also occur in this area, possibly due to metasomatism, which may also have produced the cordierite, 'pinite' and sillimanite which occur in narrow zones in a quartz–plagioclase–staurolite gneiss.

Magnetite gneiss. Magnetite, which is a common accessory in all the siliceous lithologies, forms conspicuous large euhedral crystals with a surrounding mafic-free halo in the quartz–magnetite gneiss, best seen north-east of Aultivullin (NC 814688, fig. 1). This was originally mapped by the Geological Survey as 'quartz–magnetite schist of Strathy' (Horne and Greenly, 1896).

'Granites'. All the above lithologies are cross-cut by large and small bodies of coarse-grained, weakly foliated sodic trondhjemite and by later, usually EW-trending, unfoliated pink microgranite sheets.

Mafic lithologies, hornblende gneiss. These are subordinate components of the complex and petrographically are grey gneisses with less quartz and more hornblende. Plagioclase tends to be andesine, reflecting the more calcic nature of the rocks. Often associated with the more massive amphibolite sheets, they were collectively termed 'Durcha-type Moine' by Collins (1941).

Amphibolites occur as large, apparently concordant sheets of hard, massive, quite fine-grained, hornblende–plagioclase–quartz rock frequently containing accessory clinopyroxene, e.g. at Port Mor (fig. 1). A spectacular net-veining of amphibolite by trondhjemite occurs on the east side of Armadale Bay (fig. 1). Possibly younger smaller sheets of amphibolite, more or less schistose, still with some cross-cutting relationships to the grey gneiss, occur near A'Ghualann (NC 832668) on the west coast of Strathy Bay.

Armadale ultramafic body. This small body consists almost entirely of hornblende and opaque ore. It is distinct mineralogically from amphibolites and ultramafites found in the Sutherland Moine and in terms of its Ni and Cr values (Table VII), it is similar to pyroxene-rich ultramafics from the foreland Lewisian and analogous bodies from the orthogneissic basement sheets in central Sutherland (Moorhouse and Moorhouse, 1979*a*).

Marble and calc-silicate lithologies are best developed at Port Mor (fig. 1) and on Strathy Point. They vary from calcite-rich to scapolite-diopside calc-silicates; at Port Mor both types occur interbanded. The most characteristic paragenesis is scapolite, diopside, ±calcite, ±orange spinel with prominent accessory sphene, apatite, ore, and quartz, occasionally with acicular actinolite rimming the large pyroxenes.

Rock types in the Moine adjacent to the Strathy complex. The most striking feature on traversing from the complex into the adjacent rocks is the immediate incoming of abundant K-feldspar. To the west, the adjacent Kirtomy migmatitic biotite gneisses are well exposed and show a typical assemblage of varying proportions of oligoclase–andesine, K-feldspar, biotite, quartz, with some muscovite ± accessory garnet, sillimanite, chlorite, zircon, apatite, and ore. Amphiboles are never found in these Moine biotite gneisses.

To the east, the adjacent Moine rocks are not well exposed, being variably obscured by the Old Red Sandstone cover near the coast and inland by extensive peat bog. However, lithologies similar to Kirtomy biotite gneiss occur in the vicinity of Bowside Lodge (NC 830610) and in Strath Halladale (NC 896577) whereas around Portskerra (NC 874644) and the northern end of Strath Halladale the rocks are more siliceous, reminiscent of those to the west around Bettyhill.

All these Moine gneisses are distinct from the Strathy complex rocks in that they are more commonly strongly foliated and contain abundant K-feldspar and bodies of granite (s.s.), but no amphiboles, although sheets of meta-igneous amphibolite do occur (Moorhouse and Moorhouse, 1979*a*).

GEOCHEMISTRY

Geochemical comparison of the Strathy complex with other gneiss groups

From the tables of analyses (Tables IV–VIII; for analytical technique see Moorhouse and Moor-

Table I. Mean analyses of the Strathy complex siliceous gneiss and other gneiss terrains.

	A	B	C	D	E	F
SiO_2	72.80	67.36	63.80	68.35	71.64	72.60
TiO_2	0.25	0.64	0.31	0.53	0.82	0.68
Al_2O_3	12.46	14.61	15.09	13.83	11.80	11.85
Fe_2O_3	3.46	6.12	6.62	6.01	5.04	4.16
MnO	0.03	0.06	0.07	0.09	0.03	0.01
MgO	1.62	2.86	2.81	1.90	2.04	1.54
CaO	1.74	3.20	4.67	3.64	1.69	1.34
Na_2O	5.27	2.52	3.09	4.67	2.90	2.79
K_2O	1.09	2.75	1.94	0.47	2.64	3.59
P_2O_5	0.07	0.13	0.15	0.09	0.16	0.14
S	824	800	1120	359	516	482
Ga	7	-	-	20	12	12
Cr	28	120	88	31	60	54
Ni	7	36	40	20	41	29
Cu	24	-	-	40	13	12
Zn	62	-	-	79	77	55
Rb	20	59	42	9	91	113
Sr	200	405	424	149	365	353
Y	26	19	13	-	31	28
Zr	140	288	218	133	430	455
Nb	4	11	7	-	14	14
Ba	273	1100	802	206	758	828
La	7	-	31	-	40	37
Ce	37	51	56	-	108	107
Pb	11	20	16	19	21	27
Th	3	7	7	8	16	18
K/Rb	452	387	383	433	241	264
K/Rb*	528	-	-	-	247	283
Rb/Sr	0.100	0.146	0.099	0.060	0.249	0.320
Rb/Sr*	0.123	-	-	-	0.344	0.380
Ca/Y	479	1204	2569	-	390	342
Ca/Y*	626	-	-	-	551	409

Fe_2O_3 is total Fe as Fe_2O_3. K/Rb is mean K/mean Rb, K/Rb* is mean K/Rb.

A. Strathy complex siliceous gneisses, 50 analyses, Table IV.
B. Leverburgh belt metasediments, 21 analyses, Sheraton et al. (1973).
C. East Greenland metasediments, 48 analyses, Sheraton et al. (1973).
D. Acid-intermediate gneisses, Tromøy, 79 analyses, Cooper and Field (1977).
E. Kirtomy assemblage biotite gneisses, 39 analyses, Moorhouse and Moorhouse (unpublished data).
F. Bettyhill assemblage quartzitic gneisses, 33 analyses, Moorhouse and Moorhouse (unpublished data).

Table II. Mean analyses of various granulite terrains, weighted averages for the Strathy complex, and the mean analysis of the Strathy trondhjemites.

	A	B	C	D	E	F	G
SiO_2	64.56	69.35	65.58	60.70	60.60	71.54	69.66
TiO_2	0.47	0.37	0.65	0.95	0.90	0.24	0.23
Al_2O_3	15.75	12.89	14.18	15.83	15.40	13.79	15.79
Fe_2O_3	4.69	4.67	7.11	7.82	7.20	2.89	1.98
MnO	0.06	0.04	0.11	0.11	0.20	0.02	0.00
MgO	2.23	2.55	2.50	3.02	3.90	1.54	1.42
CaO	4.50	2.66	4.16	5.28	5.70	1.89	2.11
Na_2O	4.60	5.04	4.59	3.55	2.80	5.63	6.16
K_2O	1.15	1.08	0.47	2.28	2.60	1.23	1.45
P_2O_5	0.16	0.09	0.15	--	0.20	0.10	0.14
S	-	826	514	-	-	736	604
Ga	-	9	21	-	-	9	13
Cr	48	62	29	71	-	30	34
Ni	37	29	19	-	-	8	10
Cu	-	26	46	-	-	17	7
Zn	-	70	94	-	-	54	43
Rb	13	19	8	46	70	23	28
Sr	565	221	160	543	340	442	804
Y	8	25	-	-	-	17	4
Zr	197	146	123	222	310	173	222
Nb	5	4	-	-	-	4	4
Ba	779	262	290	1217	1090	438	685
La	-	8	-	-	-	10	14
Ce	42	42	-	-	-	39	41
Pb	12	11	19	-	20	16	23
Th	1	3	7	-	2	4	5
K/Rb	734	471	487	411	308	444	430
K/Ba	12.25	34.21	18.58	15.56	19.80	23.30	17.57
Rb/Sr	0.023	0.086	0.050	0.080	0.206	0.052	0.035
K/Sr	16.90	40.57	24.38	34.86	63.48	23.10	14.97
Ca/Y	4022	761	-	-	-	795	3772

A. Scourian gneisses from Assynt, 154 analyses, Sheraton et al. (1973).
B. Strathy complex weighted average, 85% siliceous gneiss, 12% amphibolite, 3% hornblende gneiss.
C. Tromøy granulites, 95 analyses, Cooper and Field (1977).
D. Brazilian granulites, 62 analyses, Sighinolfi (1971).
E. Musgrave Range granulites, 23 analyses, Lambert and Heier (1968).
F. Strathy complex, weighted average, 60% siliceous gneiss, 40% trondhjemite.
G. Trondhjemites in Strathy complex, 22 analyses, Moorhouse and Moorhouse (in preparation).

house, 1979*a*) and a comparison of the mean analysis of the Strathy siliceous gneisses with averages from other terrains (Table I), it is evident that these Strathy rocks are SiO_2-rich; concomitantly TiO_2, Al_2O_3, total Fe_2O_3, MnO, CaO tend to be lower, but Na_2O is higher than other high-grade metamorphic rock groups. Potassium is even lower than the average for the Scourian rocks of Assynt but not as low as the Tromøy acid-intermediate gneiss (Tables I-II). In Table II average analyses of various granulite terrains are compared with a weighted average of Strathy grey gneiss, amphibolite, and hornblende gneiss, representing a crude mean of the 'non-granitic' part of the complex.

Several interesting points emerge from this comparison of the mean analyses which are probably significant, in spite of the obvious inherent disadvantages of such comparisons. First, the Strathy complex as a whole, with or without the trondhjemites, is more siliceous than the other high-grade terrains. Secondly, the complex is low in K_2O, Rb, and Ba, especially compared with the Brazilian and Musgrave granulites. The Strathy siliceous gneisses are also quite different from the average Leverburgh belt and East Greenland metasediments (Table I). In particular K_2O, t·Fe_2O_3, TiO_2, MgO, CaO and P_2O_5, Cr, Ni, Rb, Sr, Zr, Ba, Ce, Pb, and Th are considerably lower, both in absolute values and relative to SiO_2 content, whereas SiO_2, Na_2O and (mean K/mean Rb) are higher. The Tromøy acid-intermediate gneisses are more akin to the Strathy siliceous gneisses in that Ni, Cr, Sr, Zr, and Ba are similar, SiO_2 and Na_2O

Table III. Mean analyses of basic hornblendic rocks from the Strathy complex and the Bettyhill and Kirtomy Moine assemblages.

	A	B	C
SiO_2	51.48	49.40	49.31
TiO_2	1.04	1.02	2.03
Al_2O_3	15.33	15.33	12.94
Fe_2O_3	9.81	11.92	14.55
MnO	0.12	0.12	0.05
MgO	6.70	8.10	6.57
CaO	8.23	7.82	8.84
Na_2O	4.18	3.67	2.10
K_2O	1.03	1.00	1.40
P_2O_5	0.19	0.24	0.25
S	944	809	1063
Ga	19	20	26
Cr	159	276	193
Ni	102	170	144
Cu	55	30	43
Zn	101	123	131
Rb	15	13	42
Sr	283	355	176
Y	22	20	51
Zr	152	191	232
Nb	6	7	10
Ba	218	197	340
La	9	11	9
Ce	62	70	75
Pb	8	8	10
Th	3	1	4

A. Strathy complex hornblende gneiss, 13 analyses, Table VI.
B. Strathy complex amphibolites, 13 analyses, Table VII.
C. Amphibolites from the Bettyhill and Kirtomy Moine assemblages, 13 analyses, Moorhouse and Moorhouse (1979; Table VI, BS277- BS195 Bettyhill, BS 69-BS100 Kirtomy).

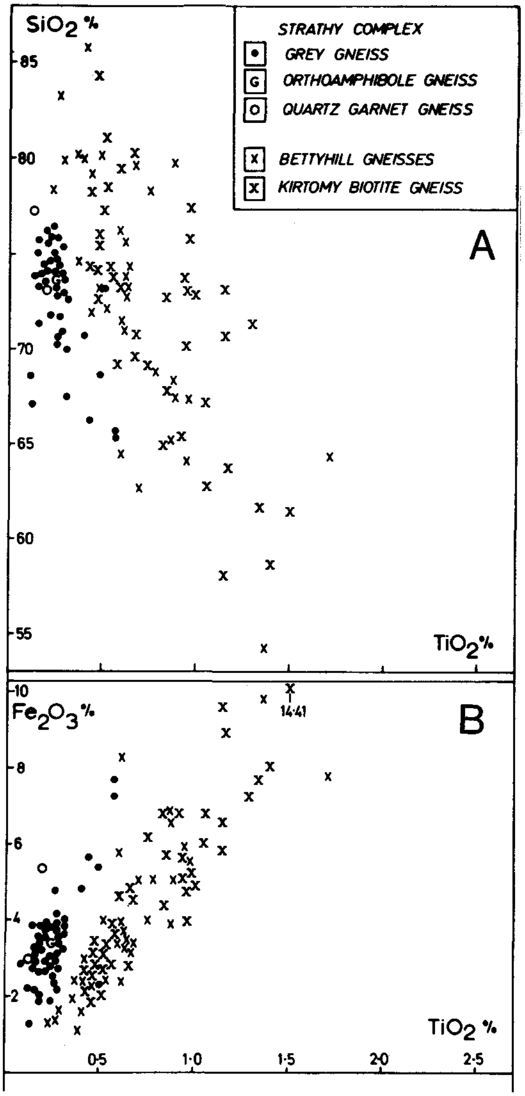

FIG. 2. (A) SiO_2 *vs.* TiO_2. (B) Total Fe_2O_3 *vs.* TiO_2.

are almost as high, but t·Fe_2O_3 and CaO are much higher, whilst K_2O and Rb are considerably lower (compare columns A and D Table I, columns B and C Table II).

Geochemical comparison of the Strathy complex with the local Moine rocks

The Strathy complex siliceous gneisses have an SiO_2 content equivalent to the local Moine gneisses but have higher average Na_2O, lower TiO_2, t·Fe_2O_3, K_2O, Cr, Ni, Sr, Zr, Nb, Pb, and Th, notably lower Rb, Ba, La, and Ce, whilst the Strathy K/Rb ratios are considerably higher and Rb/Sr much lower (Table I).

The SiO_2-TiO_2 and t·Fe_2O_3-TiO_2 plots (fig. 2) illustrate some of these differences. On the SiO_2-TiO_2 plot the Strathy gneisses occupy a low-TiO_2 field comparable with that of Lewisian lithologies from basement sheets within the Moine further west in Sutherland (Moorhouse, 1976; Moorhouse and Moorhouse, 1977, and in prep.). The Moine gneisses exhibit a much greater range of SiO_2, t·Fe_2O_3 and TiO_2 values with a more pronounced negative SiO_2-TiO_2 correlation and positive t·Fe_2O_3-TiO_2 correlation than those of the Strathy gneisses.

The K_2O *vs.* Na_2O diagram (fig. 3A) emphasizes the low-K_2O, high-Na_2O nature of the Strathy gneisses which is quite distinct from the lower-Na_2O, higher-K_2O of the Moine gneisses. In a similar manner the Moine rocks occupy a separate high Rb and Sr field on fig. 3B.

Table IV. The Strathy complex siliceous gneisses.

	BS 31	BS 26	BS 43	BS131	BS 50	BS 4	BS 63	BS117	BS128	BS137	BS 82	BS121	BS 48	BS127	
SiO_2	78.10	77.26	76.47	76.47	76.26	76.10	75.86	75.86	75.70	75.66	75.37	75.18	75.06	74.97	SiO_2
TiO_2	0.14	0.13	0.24	0.24	0.19	0.21	0.22	0.26	0.16	0.21	0.29	0.18	0.15	0.24	TiO_2
Al_2O_3	10.20	9.89	10.94	11.75	11.65	10.63	11.33	11.46	12.03	12.02	11.47	12.12	11.49	12.92	Al_2O_3
Fe_2O_3	2.16	2.92	2.66	2.85	2.66	3.79	3.72	2.35	2.74	2.65	3.30	1.98	2.22	2.97	Fe_2O_3
MnO	0.05	0.05	0.04	0.00	0.04	0.00	0.03	0.00	0.00	0.00	0.00	0.08	0.00	0.03	MnO
MgO	1.30	2.08	1.39	1.00	1.50	1.76	1.59	1.10	1.05	0.78	0.88	1.30	1.26	1.33	MgO
CaO	0.90	0.58	0.98	0.98	2.42	0.98	1.36	1.35	2.42	1.51	1.59	1.24	1.83	1.78	CaO
Na_2O	5.80	5.40	5.10	5.70	5.00	4.70	5.00	4.60	4.60	5.40	5.40	5.90	4.50	5.80	Na_2O
K_2O	0.51	0.56	1.22	1.10	1.01	1.02	1.20	1.46	0.55	0.91	0.72	0.77	1.75	0.98	K_2O
P_2O_5	0.02	0.01	0.02	0.09	0.03	0.05	0.04	0.09	0.04	0.08	0.07	0.03	0.06	0.09	P_2O_5
Loss	0.75	0.86	0.80	1.72	0.94	0.73	1.10	1.51	0.58	0.69	0.91	1.02	1.45	0.75	Loss
Total	99.93	99.74	99.86	101.90	101.70	99.97	101.45	100.04	99.87	99.91	100.00	99.80	99.77	101.86	Total
S	410	910	630	290	530	820	30	440	570	350	280	1070	1060	210	S
Ga	4	4	0	0	6	6	7	1	0	6	5	2	3	8	Ga
Cr	33	27	28	26	29	29	30	33	30	26	29	27	31	32	Cr
Ni	15	1	3	4	5	8	1	4	4	3	9	4	0	8	Ni
Cu	58	18	7	0	21	4	6	15	0	48	15	58	7	3	Cu
Zn	28	10	57	0	52	36	68	85	0	58	52	60	51	34	Zn
Rb	5	7	13	23	12	18	30	32	9	15	11	6	25	16	Rb
Sr	87	56	251	111	266	230	232	180	188	263	325	124	84	264	Sr
Y	28	27	14	31	30	34	6	31	31	27	21	28	24	26	Y
Zr	114	108	201	111	123	156	134	172	117	118	122	118	87	132	Zr
Nb	3	4	2	1	1	1	6	3	2	3	4	3	4	2	Nb
Ba	142	187	293	240	219	284	396	382	178	296	244	204	220	284	Ba
La	7	8	2	7	7	7	6	10	7	9	4	7	7	7	La
Ce	34	40	23	28	33	30	31	39	39	30	25	33	35	39	Ce
Pb	9	8	12	8	9	8	12	14	9	11	12	6	8	7	Pb
Th	2	2	0	1	2	0	3	3	4	2	2	2	4	3	Th
NC	804661	801656	829695	818682	876694	785655	812685	831675	813671	812687	804643	832671	828697	816662	NC

NC Initial letters of National Grid Reference.

Fe_2O_3 is total Fe as Fe_2O_3. Loss is loss on ignition of dried samples.

BS 26 is a quartz-garnet gneiss.

	BS122	BS130	BS 51	BS 37	BS191	BS 28	BS125	BS 39	BS 40	BS 97	BS 96	BS 22	BS 64	BS 3	
SiO_2	74.64	74.63	74.52	74.48	74.45	74.05	73.92	73.90	73.80	73.80	73.68	73.62	73.36	73.35	SiO_2
TiO_2	0.25	0.22	0.23	0.26	0.19	0.19	0.28	0.18	0.16	0.28	0.22	0.25	0.19	0.19	TiO_2
Al_2O_3	13.10	12.05	12.16	12.72	11.58	11.78	11.92	12.79	12.09	12.84	12.65	11.81	12.41	12.05	Al_2O_3
Fe_2O_3	2.46	2.93	3.75	2.90	3.38	3.33	3.10	1.91	3.01	3.41	3.78	3.58	3.38	5.36	Fe_2O_3
MnO	0.00	0.08	0.06	0.00	0.00	0.08	0.01	0.00	0.00	0.07	0.00	0.00	0.15	0.08	MnO
MgO	2.04	0.79	2.05	1.03	1.16	1.34	1.78	1.02	1.15	2.14	1.37	2.64	1.49	1.16	MgO
CaO	1.31	0.96	1.40	1.82	1.44	2.03	0.94	1.48	1.91	1.72	0.81	3.17	1.05	0.72	CaO
Na_2O	5.90	5.80	5.40	5.30	6.00	4.20	5.40	6.30	5.30	4.40	6.10	3.10	6.00	6.10	Na_2O
K_2O	1.34	1.13	0.74	1.22	0.70	1.19	1.58	0.86	1.02	1.83	1.30	0.53	0.78	0.21	K_2O
P_2O_5	0.04	0.03	0.05	0.06	0.04	0.03	0.05	0.03	0.05	0.11	0.08	0.08	0.03	0.06	P_2O_5
Loss	0.33	0.84	0.43	0.84	0.49	1.74	0.58	1.58	1.31	1.24	1.47	1.02	1.18	0.40	Loss
Total	101.41	99.46	100.79	100.66	99.43	99.96	99.56	100.05	99.80	101.84	101.46	99.80	100.02	101.68	Total
S	550	600	290	670	560	140	620	400	1100	470	1020	1040	110	310	S
Ga	0	7	8	8	5	6	8	8	5	7	16	11	2	6	Ga
Cr	35	28	29	29	26	29	30	38	29	46	31	26	27	22	Cr
Ni	8	24	2	25	5	3	6	9	3	16	4	2	3	3	Ni
Cu	0	14	11	14	12	12	18	10	9	5	6	3	43	21	Cu
Zn	0	64	62	57	28	52	84	33	57	116	84	80	274	84	Zn
Rb	28	25	8	30	9	22	19	16	22	43	32	5	13	1	Rb
Sr	213	158	84	423	171	298	135	316	244	286	71	216	121	87	Sr
Y	8	31	28	5	33	26	25	4	25	25	41	29	45	36	Y
Zr	184	150	113	129	125	107	202	151	151	116	171	102	130	116	Zr
Nb	6	0	3	4	1	3	6	4	1	3	8	2	1	1	Nb
Ba	423	392	155	513	267	193	252	431	339	242	238	134	180	131	Ba
La	5	6	6	11	8	5	10	13	8	7	7	9	11	10	La
Ce	33	29	38	52	37	33	46	38	31	27	48	38	37	44	Ce
Pb	18	11	8	16	6	7	12	17	10	9	14	7	5	6	Pb
Th	4	1	2	4	2	2	5	8	2	2	5	2	1	2	Th
NC	831669	821663	831687	822649	775655	799653	833668	813686	812687	831683	830683	828695	812687	787653	NC

BS 22 is an orthoamphibole gneiss. BS 3 is a quartz-garnet gneiss.

Table IV (continued). The Strathy complex siliceous gneisses.

	BS 42	BS 65	BS115	BS221	BS 58	BS 46	BS 35	BS 66	BS120	BS 61	BS 45	BS222	BS 41	BS133	
SiO_2	73.34	73.25	73.18	72.87	72.81	72.70	71.76	71.68	71.28	70.89	70.70	70.61	70.29	69.92	SiO_2
TiO_2	0.24	0.16	0.50	0.28	0.27	0.31	0.22	0.27	0.16	0.28	0.40	0.27	0.26	0.31	TiO_2
Al_2O_3	12.78	12.38	12.79	13..5	12.34	12.10	11.75	12.45	13.19	12.34	11.28	14.45	12.93	13.20	Al_2O_3
Fe_2O_3	2.74	3.16	2.31	2.72	4.14	3.62	3.73	3.82	3.00	3.56	4.80	3.78	4.75	3.98	Fe_2O_3
MnO	0.00	0.00	0.03	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	MnO
MgO	1.03	1.45	1.84	0.99	2.69	1.49	1.23	1.63	3.72	1.42	3.82	0.72	2.25	1.83	MgO
CaO	2.09	1.74	1.90	1.87	1.15	2.70	3.01	1.30	1.42	1.20	1.42	2.05	1.04	1.76	CaO
Na_2O	4.90	5.20	4.60	5.70	5.70	4.40	4.20	6.10	3.80	6.20	3.60	6.40	5.50	5.60	Na_2O
K_2O	1.26	0.97	2.13	0.59	1.00	1.35	0.97	1.14	2.28	0.96	2.30	0.92	1.64	1.36	K_2O
P_2O_5	0.06	0.04	0.03	0.11	0.05	0.08	0.05	0.05	0.03	0.10	0.02	0.08	0.06	0.13	P_2O_5
Loss	1.48	1.45	0.51	1.03	1.53	1.17	1.49	1.37	0.80	3.01	1.45	0.81	1.05	1.30	Loss
Total	99.92	99.80	99.82	99.31	101.77	99.92	98.41	99.81	99.68	99.96	99.79	100.09	99.94	99.39	Total
S	850	1010	960	200	170	940	4840	990	450	840	1310	140	370	240	S
Ga	8	5	0	8	6	11	9	9	9	12	11	10	9	12	Ga
Cr	35	28	27	28	33	28	29	30	27	27	30	25	25	27	Cr
Ni	13	2	5	7	4	4	9	2	5	4	2	5	2	4	Ni
Cu	18	3	40	58	6	36	182	10	2	18	124	8	17	7	Cu
Zn	51	55	144	44	54	70	20	60	74	41	121	56	56	61	Zn
Rb	18	16	34	11	13	23	27	23	30	21	38	22	27	32	Rb
Sr	228	191	234	128	63	314	194	186	136	82	195	178	66	129	Sr
Y	26	30	26	18	34	25	27	19	41	33	22	34	34	29	Y.
Zr	106	93	232	127	104	122	100	80	163	108	157	127	126	107	Zr
Nb	0	0	5	3	3	3	3	3	4	2	2	5	3	0	Nb
Ba	348	232	543	141	161	314	251	280	163	233	390	277	177	216	Ba
La	8	5	9	8	7	14	8	5	8	6	4	9	5	5	La
Ce	41	31	25	42	41	68	34	25	42	32	23	47	31	38	Ce
Pb	14	10	35	9	5	10	8	9	10	11	11	9	6	7	Pb
Th	4	4	2	4	1	8	4	0	3	1	2	2	3	1	Th
NC	829698	818687	831675	802660	823689	827698	806664	820671	831675	821688	828699	823650	815687	816688	NC

Table IV (continued). The Strathy complex siliceous gneisses.

	BS126	BS 23	BS 10	BS 79	BS 56	BS157	BS129	BS132
SiO_2	68.61	68.57	67.47	67.14	66.14	65.65	65.41	65.30
TiO_2	0.49	0.12	0.31	0.13	0.43	0.57	0.57	0.14
Al_2O_3	13.58	10.64	12.29	20.08	12.75	14.18	14.27	15.72
Fe_2O_3	5.39	2.90	3.88	1.29	5.57	7.24	7.68	3.85
MnO	0.15	0.03	0.03	0.00	0.02	0.08	0.18	0.08
MgO	1.64	1.48	1.84	1.23	2.12	2.13	1.89	3.34
CaO	3.35	0.77	1.39	2.92	3.79	3.35	2.19	3.69
Na_2O	5.10	6.10	5.80	4.60	3.70	5.80	5.40	6.60
K_2O	0.66	0.96	1.38	1.26	0.83	0.94	1.75	0.33
P_2O_5	0.15	0.02	0.08	0.00	0.25	0.23	0.25	0.03
Loss	0.88	8.26	4.75	1.31	3.50	0.61	0.37	0.72
Total	100.00	99.85	99.87	99.96	99.10	100.78	99.96	99.80
S	30	200	350	180	9999	620	100	940
Ga	13	5	9	11	9	17	16	15
Cr	26	30	25	26	25	17	17	30
Ni	28	17	4	5	10	0	0	16
Cu	22	6	17	19	157	0	1	2
Zn	43	51	87	60	53	67	125	52
Rb	9	16	30	35	18	17	54	3
Sr	395	86	361	400	321	218	192	247
Y	35	16	6	13	19	32	42	35
Zr	100	629	120	146	84	94	124	179
Nb	3	23	3	6	7	2	8	3
Ba	253	256	380	511	307	235	390	120
La	6	4	8	5	5	5	6	12
Ce	30	22	48	26	39	47	48	50
Pb	13	9	14	11	12	8	21	11
Th	0	3	5	5	2	2	6	4
NC	819657	812685	795640	803647	826692	793633	822666	816687

Table V. Calc-silicates from the Bettyhill assemblage (BS224A, BS224B) and the Kirtomy assemblage (BS 88, BS 89).

	BS224A	BS224B	BS 88	BS 89
SiO_2	69.64	77.25	64.67	67.41
TiO_2	0.65	0.31	0.67	0.28
Al_2O_3	11.40	9.66	15.73	13.96
Fe_2O_3	3.18	3.04	4.98	2.93
MnO	0.03	0.13	0.25	0.10
MgO	1.21	1.82	2.34	0.56
CaO	4.22	2.52	6.31	7.22
Na_2O	1.50	1.30	0.60	0.90
K_2O	2.30	2.23	2.62	1.56
P_2O_5	0.17	0.18	0.23	0.30
Loss	5.52	1.72	1.62	4.67
Total	99.82	100.16	100.02	99.89
S	240	770	1150	270
Ga	15	7	22	34
Cr	53	40	53	33
Ni	26	21	27	10
Cu	5	11	5	0
Zn	34	28	97	15
Rb	98	109	82	54
Sr	415	260	314	280
Y	39	21	42	17
Zr	349	137	369	194
Nb	17	10	17	9
Ba	787	631	199	232
La	44	38	0	17
Ce	122	124	73	61
Pb	15	18	19	22
Th	13	7	19	8
NC	710620	710620	773617	772613

Table VI. The Strathy complex hornblende gneisses.

	BS123	BS 21	BS113	BS293	BS256A	BS 54	BS 47	BS 15	BS 25	BS 36	BS119	BS 81	BS 53	
SiO_2	57.04	56.39	55.17	54.88	52.74	52.09	51.83	51.73	48.73	48.20	47.62	46.52	46.28	SiO_2
TiO_2	0.88	0.38	1.57	1.39	0.60	0.42	0.49	0.94	0.65	2.00	1.50	0.65	1.99	TiO_2
Al_2O_3	15.25	15.99	17.18	14.00	16.24	14.89	14.29	15.19	15.57	13.32	17.18	14.51	15.72	Al_2O_3
Fe_2O_3	8.93	6.39	8.41	11.06	9.25	10.21	9.35	10.23	7.64	13.61	9.61	11.67	11.22	Fe_2O_3
MnO	0.19	0.23	0.09	0.00	0.01	0.01	0.14	0.16	0.17	0.12	0.11	0.13	0.14	MnO
MgO	4.85	5.20	3.83	5.28	7.99	7.29	7.74	5.88	7.16	7.14	8.35	8.66	7.74	MgO
CaO	5.78	7.01	4.59	8.13	5.81	7.55	9.92	6.50	6.80	10.12	12.23	11.69	10.92	CaO
Na_2O	4.90	4.80	5.10	2.80	4.80	4.50	4.50	5.50	5.10	3.30	2.90	2.90	3.20	Na_2O
K_2O	0.75	0.62	2.17	1.37	0.35	1.32	1.26	0.63	0.78	0.87	0.77	1.22	1.30	K_2O
P_2O_5	0.21	0.07	0.63	0.17	0.12	0.02	0.09	0.15	0.10	0.24	0.20	0.16	0.32	P_2O_5
Loss	0.95	2.23	0.49	0.72	1.55	1.47	1.77	2.68	7.51	0.89	0.66	1.73	0.97	Loss
Total	99.73	99.31	99.83	99.80	99.46	99.77	101.38	99.59	100.21	99.81	101.13	99.84	99.80	Total
S	1250	3030	970	280	250	1020	350	1640	240	880	810	750	800	S
Ga	19	17	24	24	0	18	15	16	19	23	21	19	27	Ga
Cr	30	41	22	139	222	32	233	99	152	191	296	361	248	Cr
Ni	7	35	19	104	154	46	93	69	137	94	128	285	152	Ni
Cu	38	253	15	11	0	8	79	63	3	56	137	6	42	Cu
Zn	116	69	107	103	0	107	90	126	56	119	74	229	114	Zn
Rb	8	9	43	22	6	16	18	7	11	10	7	21	16	Rb
Sr	250	225	89	221	216	181	353	305	228	315	474	257	561	Sr
Y	29	14	30	43	16	12	7	21	19	39	20	13	29	Y
Zr	109	67	393	220	79	43	50	77	86	238	213	88	308	Zr
Nb	2	0	37	6	0	2	4	2	1	6	7	2	7	Nb
Ba	155	137	619	305	146	139	152	185	209	183	134	281	186	Ba
La	6	2	59	18	2	5	4	5	4	3	6	6	8	La
Ce	47	40	165	88	42	37	41	46	39	60	71	50	81	Ce
Pb	8	9	16	8	8	6	9	7	7	8	5	7	8	Pb
Th	0	1	22	6	1	0	1	3	3	1	3	0	3	Th
NC	834669	789649	831678	790621	797650	827689	827698	774654	801654	823648	831674	802642	829694	NC

Table VII. The Strathy complex amphibolites and the Armadale ultra-mafic body.

	BS289	BS257	BS 62	BS124	BS 20	BS116	BS219	BS 9	BS 55	BS 32	BS134	BS 44	BS110	BS 49	
SiO_2	55.77	52.63	51.55	50.85	50.59	50.50	50.09	49.68	49.54	48.91	48.21	48.01	46.23	45.37	SiO_2
TiO_2	0.11	0.61	0.55	1.17	0.27	0.67	0.59	0.52	1.48	0.66	2.01	0.58	2.52	1.64	TiO_2
Al_2O_3	2.46	16.09	16.67	14.75	15.66	15.46	14.70	13.95	18.54	13.80	14.64	16.23	15.08	13.72	Al_2O_3
Fe_2O_3	5.72	10.40	9.85	10.78	8.08	13.21	9.53	24.04	10.13	10.35	13.21	11.42	12.88	10.44	Fe_2O_3
MnO	0.00	0.01	0.17	0.00	0.17	0.16	0.00	0.13	0.04	0.35	0.16	0.15	0.21	0.01	MnO
MgO	20.25	7.45	6.79	8.33	9.32	8.43	10.29	7.08	3.56	10.33	7.12	7.87	7.36	11.41	MgO
CaO	13.39	4.89	7.69	8.80	9.00	5.40	8.26	2.59	5.45	9.16	10.72	9.04	9.68	10.99	CaO
Na_2O	0.90	5.10	4.70	3.30	4.20	4.00	3.80	1.90	6.00	3.30	2.80	3.40	3.30	1.90	Na_2O
K_2O	0.20	1.09	0.88	0.49	0.74	1.85	0.52	0.36	1.82	0.65	0.76	1.53	1.24	1.10	K_2O
P_2O_5	0.03	0.14	0.05	0.19	0.04	0.10	0.11	0.08	1.12	0.09	0.22	0.08	0.35	0.58	P_2O_5
Loss	1.21	1.52	2.01	0.95	1.82	1.05	2.23	1.02	1.74	2.27	0.78	1.55	0.93	2.39	Loss
Total	100.04	99.93	100.91	99.61	99.90	100.92	100.12	101.35	99.42	99.87	100.61	99.86	99.78	99.55	Total
S	170	160	170	1000	400	740	300	770	2620	460	340	590	990	1980	S
Ga	0	22	16	21	14	18	17	27	27	15	24	17	27	18	Ga
Cr	2168	172	68	266	540	295	540	654	19	476	205	88	176	578	Cr
Ni	1784	106	70	57	298	123	336	210	3	356	102	53	100	394	Ni
Cu	0	0	0	31	18	144	2	0	41	0	37	0	111	16	Cu
Zn	0	102	270	101	94	77	135	61	115	223	100	97	122	108	Zn
Rb	1	21	10	4	8	7	6	7	41	12	16	16	15	12	Rb
Sr	187	124	283	314	297	474	144	17	1310	243	233	291	369	517	Sr
Y	2	14	18	23	7	19	13	13	32	15	34	11	33	28	Y
Zr	26	67	83	153	45	214	65	58	860	98	217	35	318	276	Zr
Nb	2	2	4	3	2	6	0	1	31	0	5	7	13	17	Nb
Ba	68	126	285	230	180	131	112	86	541	117	205	157	158	237	Ba
La	4	4	4	10	4	2	4	1	55	1	3	1	5	45	La
Ce	49	46	44	66	37	69	49	35	174	55	52	49	75	155	Ce
Pb	4	5	11	8	10	6	8	7	12	14	7	9	8	4	Pb
Th	1	0	0	5	0	0	0	0	4	1	2	0	0	7	Th
NC	778651	796658	623687	833668	795649	830678	802661	796636	824691	805662	815688	829695	831681	827697	NC

BS289 is the Armadale ultra-mafic body.

Table VIII. Marbles from Port Mor (BS), Glenelg (GL), Shin (LS), Urquhart (UQ) and along the Sgurr Beag slide near Dornie (W).

	BS 17	BS 24	BS 16	GL 8	GL 7	GL 3	GL 4	LS 5	LS 4	UQ 4B	UQ 4C	W 9A	W 9B	
SiO_2	59.06	50.86	37.03	13.42	12.59	12.46	12.03	40.80	23.45	51.60	40.04	14.03	11.14	SiO_2
TiO_2	0.53	0.77	0.88	0.12	0.14	0.05	0.04	0.02	0.02	0.38	0.31	0.01	0.01	TiO_2
Al_2O_3	15.06	14.02	16.91	2.18	2.13	0.76	0.75	0.45	0.39	7.88	8.71	0.16	0.12	Al_2O_3
Fe_2O_3	3.73	6.29	8.16	2.57	2.58	1.36	1.20	1.08	1.16	0.97	2.01	0.46	1.18	Fe_2O_3
MnO	0.00	0.00	0.09	0.06	0.07	0.05	0.04	0.00	0.01	0.00	0.00	0.00	0.00	MnO
MgO	2.84	4.68	4.37	20.08	18.31	19.72	20.89	14.08	9.07	2.97	9.76	20.83	20.98	MgO
CaO	14.32	16.61	18.89	30.81	30.96	30.13	31.81	31.84	43.62	19.18	26.16	32.19	32.48	CaO
Na_2O	2.90	3.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70	0.70	0.00	0.00	Na_2O
K_2O	0.41	0.72	1.40	0.09	0.03	0.25	0.17	0.03	0.03	1.65	0.16	0.01	0.01	K_2O
P_2O_5	0.15	0.14	0.29	0.03	0.04	0.02	0.02	0.02	0.08	0.07	0.10	0.03	0.02	P_2O_5
Loss	1.76	2.69	10.43	30.80	33.25	34.00	32.95	11.78	22.20	11.84	11.64	32.18	33.00	Loss
Total	100.77	99.78	99.45	100.31	100.10	98.80	100.90	100.10	100.03	98.24	99.59	99.90	98.94	Total
S	1710	1670	2140	210	330	0	310	120	260	600	80	610	5390	S
Ga	19	23	46	5	5	2	3	4	4	10	12	2	2	Ga
Cr	60	93	56	36	37	24	27	26	20	39	37	21	22	Cr
Ni	47	66	21	17	20	2	7	7	1	13	12	0	2	Ni
Cu	24	36	4	4	41	28	28	0	0	0	0	3	132	Cu
Zn	81	109	67	27	27	13	7	55	42	14	32	5	8	Zn
Rb	6	11	49	2	1	8	5	1	0	27	3	0	1	Rb
Sr	976	1119	1696	98	111	97	82	112	198	907	1248	138	145	Sr
Y	20	23	34	7	9	1	1	3	2	9	7	0	0	Y
Zr	168	306	342	22	31	22	15	10	16	580	383	9	15	Zr
Nb	13	13	13	3	5	0	2	0	2	6	9	3	6	Nb
Ba	279	906	278	54	31	116	67	38	3	463	88	38	35	Ba
La	41	34	34	11	11	5	7	4	4	10	10	2	3	La
Ce	135	111	143	94	107	77	73	58	99	54	75	67	72	Ce
Pb	20	21	34	3	2	3	2	20	37	9	12	8	9	Pb
Th	24	16	16	2	1	0	0	2	1	5	5	0	1	Th
NC	774655	774654	775656	NG875254	875254	875254	875254	NC526137	526137	NH491304	491304	008137	008137	NH

The high K/Rb ratios and low Ba values of the Strathy rocks differentiate them from the Moine gneisses in a remarkable manner. On fig. 4, the Strathy gneisses occupy a low-Ba, high-K/Rb field with a marked negative correlation, whereas the Moine gneisses fall in a high-Ba, low-K/Rb field with a positive correlation (see later).

Many of the geochemical features of the Strathy rocks considered so far have been analogous to those of Lewisian basement orthogneisses from elsewhere in the Sutherland Moine (Moorhouse, 1976; Moorhouse and Moorhouse, 1977, and in prep.) and the foreland Lewisian (Sheraton *et al.*, 1973; Holland and Lambert, 1975). One of the best geochemical discriminants between Moine cover and Lewisian basement rocks is a CaO *vs.* Y diagram (Moorhouse, 1976; Moorhouse and Moorhouse, 1977, and in prep.). However, the Strathy siliceous gneisses are quite dissimilar from most of the Lewisian gneisses in having low CaO and quite high Y. Therefore, in terms of CaO and Y there is a complete overlap between the Strathy complex gneisses and the Moine gneisses. Although the Strathy gneiss Y levels are approximately equivalent to the Moine gneisses and higher than the Leverburgh and east Greenland metasediments (Table I), their La and Ce contents are much lower than these rock groups. Ce is equal to the average Scourian from Assynt (Table I) and La is even lower than the average for the Scourian assemblage (26 ppm, Holland and Lambert, 1975). Thus, on a CaO *vs.* La diagram (fig. 5) the Strathy gneisses fall in a similar field to Lewisian basement orthogneisses from elsewhere (cf. fig. 5 and Moorhouse and Moorhouse, 1977, fig. 4).

On a Y–Ce–La triangular plot (fig. 6) most of the Strathy gneisses fall in a completely separate field from the Moine gneisses. Thus the Strathy gneisses are fundamentally different from the local Moine gneisses and quite dissimilar from normal Archaean gneisses which tend to be Y-poor and La-Ce rich (Tarney, 1976). However, these latter rocks are often considerably more mafic than the Strathy gneisses and as Wright *et al.* (1973) show there is a tendency for the most mafic Archaean granulites to have the highest Ce and La values. Therefore, the differences in Ce and La values could be ascribed to differences in the gross geochemistry

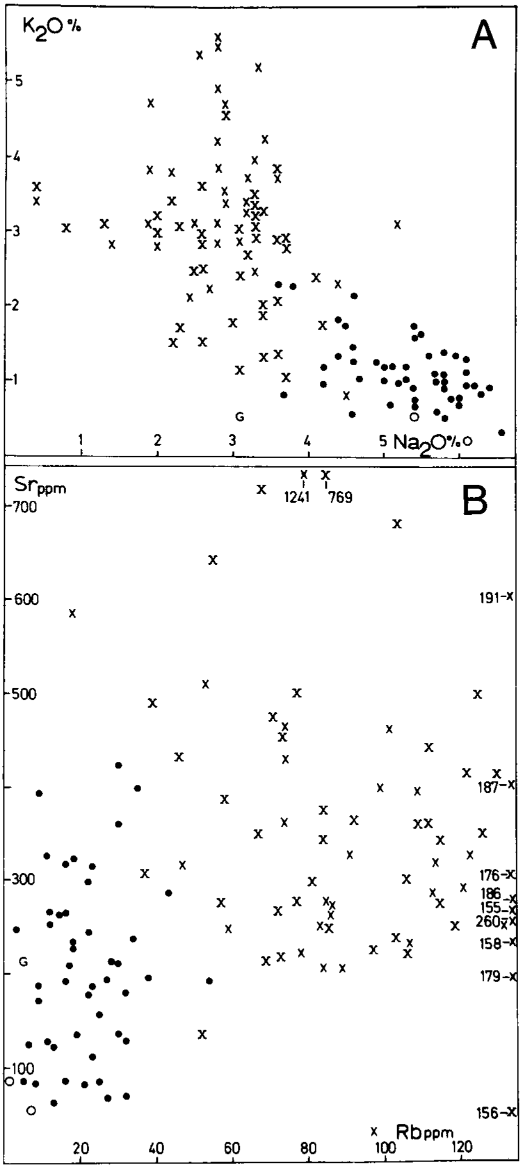

FIG. 3. (A) K$_2$O *vs.* Na$_2$O. (B) Sr *vs.* Rb. Key as fig. 2.

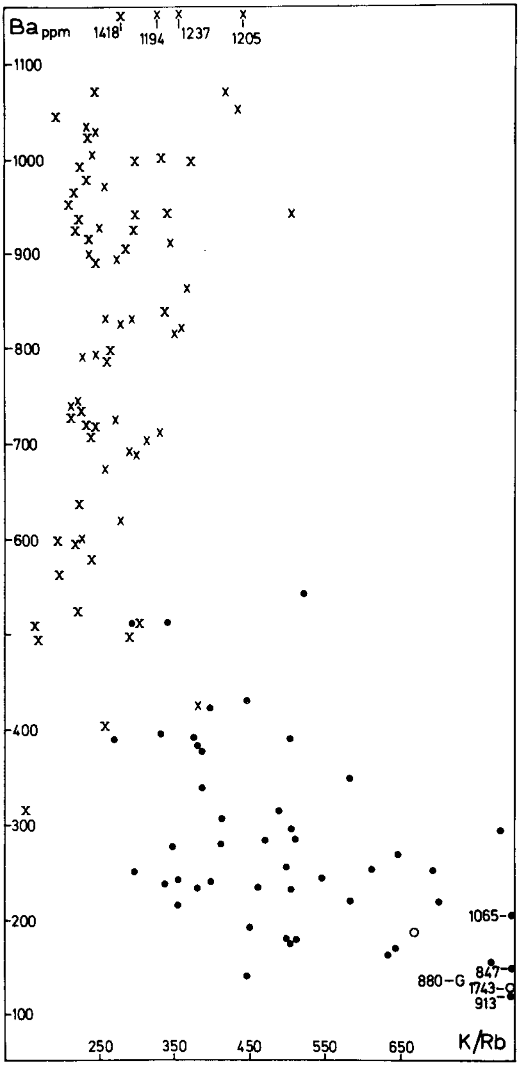

FIG. 4. BA *vs.* K/Rb ratio. Key as fig. 2.

of the rock groups. However, the most silicic Archaean gneisses have much lower Y contents than the Strathy gneisses (Tarney and Windley, 1977) as do many Archaean acid igneous rocks (Arth and Hanson, 1975). In terms of Y level the Strathy rocks appear to be more comparable with younger central European granulites (Tarney and Windley, 1977) than with Archaean rocks.

The Strathy complex hornblende gneisses and amphibolites. Whilst discriminatory diagrams using SiO$_2$, Fe$_2$O$_3$ and TiO$_2$ cannot completely separate these basic rocks from the Bettyhill and Kirtomy Moine amphibolites there are significant differences. A comparison of the analyses of the Strathy hornblendic rocks (Tables VI and VII) with Moine amphibolites from the Bettyhill and Kirtomy assemblages (Moorhouse and Moorhouse, 1979*a*, Table VI, analyses BS277–BS195 Bettyhill, BS69–BS100 Kirtomy amphibolites), and a comparison of the average analyses (Table III) indicate that the Strathy rocks are poorer in TiO$_2$, t·Fe$_2$O$_3$, K$_2$O, Rb, Y, Zr, Ba, and richer in Na$_2$O.

Even allowing for the fact that Moorhouse and Moorhouse (1979*a*) demonstrated that the amphi-

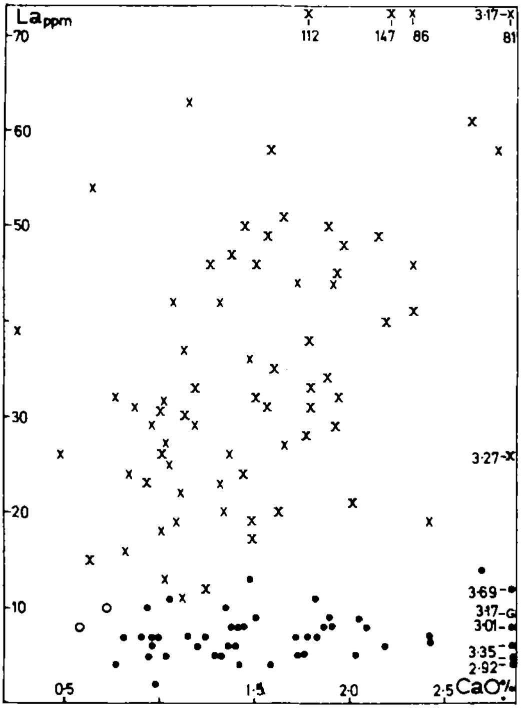

FIG. 5. La *vs.* CaO. Key as fig. 2.

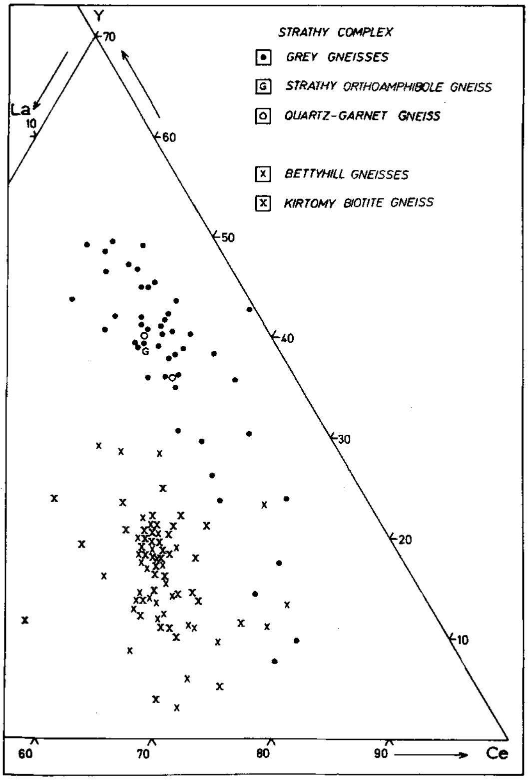

FIG. 6. Y–La–Ce plot.

bolites in the Sutherland Moine are geochemically quite varied, the Strathy basic rocks as a whole fall outside this variation and appear to have a different origin. For example the Moine amphibolites fall into two groups on an AFM plot (Moorhouse and Moorhouse 1979*a*, fig. 14) one with a tholeiitic trend, the other with a mild alkaline trend. However the Strathy basic rocks show a quite different calc-alkaline trend (fig. 7).

The Port Mor marble and calc-silicate rocks. Three examples of Port Mor diopside–scapolite marble with minor amounts of calcite have been analysed (Table VIII). Two quartz-plagioclase-clinozoisite mica, and two quartz-plagioclase diopside-garnet calc-silicates, from the Bettyhill and Kirtomy Moine respectively, have been analysed for comparison (Table V), as have two calc-silicate rich clinopyroxene marbles from Glen Urquhart, four calcite-rich forsteritic marbles from the Glenelg Lewisian, two calcite-rich forsteritic-marbles from a Lewisian slice along the Sgurr Beag slide, and two calcite-rich clinopyroxene marbles from the Lewisian slice at the Aird of Shin (Table VIII).

It is evident that the gross geochemistry of these rocks (see Tables V and VIII) is controlled by their calcite/silicate ratio. Obviously the geochemical discrimination of marbles/calc-silicates with different origins using diagrams such as CaO *vs.* MgO (Winchester and Lambert, 1970) is unlikely to be satisfactory, especially as these rocks are prone to metasomatic interactions. Here the mineralogy of

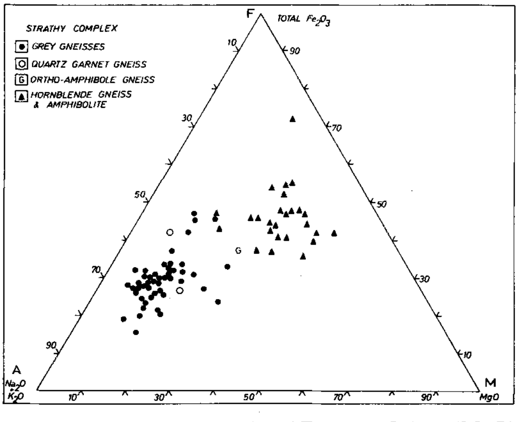

FIG. 7. A (Na_2O+K_2O)–*F* (total Fe as Fe_2O_3)–*M* (MgO) plot for Strathy gneisses and amphibolites.

the Port Mor marbles is quite different from the silicate-rich Moine calc-silicates, which are therefore geochemically distinct from the marbles. The Port Mor diopside–scapolite marble geochemistry is most closely paralleled by the calcite-poor, pyroxene-bearing Glen Urquhart rocks.

Discussion of the evolution of the Strathy complex

Mineralogical considerations. Sheraton *et al.* (1973) concluded that the Scourian rocks of Assynt acquired their low K_2O and Rb geochemical character by a process of 'charnockitization' of substantially diopside-normative rocks, producing granulite-facies calcic-plagioclase hypersthenic gneisses. This process cannot be responsible for the geochemical peculiarities of the Strathy complex (Tables I and II) as here 25 % of the gneisses are corundum-normative and 50 % of the gneisses which show diopside in the norm have only extremely small proportions, commonly less than 1 %. In addition, the plagioclase in the Strathy rocks is Na-rich, quite unlike that of the Assynt rocks, and there is no unequivocal evidence of granulite-facies mineral parageneses.

The earliest mineral parageneses still recognizable in the Strathy complex contain, in addition to dominant quartz and oligoclase, low-Ca amphibole (or hornblende in the most calcic gneisses), garnet, and occasional staurolite; this assemblage would be stable in the upper amphibolite facies (Turner, 1968) and may have been produced by reactions such as:

1. chlorite + muscovite → staurolite + biotite + garnet + H_2O.

Ca-poor amphibole by a reaction such as

2. biotite + quartz → K-feldspar + orthoamphibole + H_2O.

Hornblende in the hornblende-bearing gneisses:

3. biotite + plagioclase + quartz → K-feldspar + albite + hornblende.

These last two reactions are known to take place under the highest amphibolite-facies conditions (Knabe, 1966), but the fact that, in the Strathy complex, staurolite was apparently stable in the presence of quartz may indicate very high pressure, i.e. lower crustal conditions (Schreyer and Seifert, 1969). Thus it is quite possible that any original K-feldspar component produced in reactions such as 2 and 3 was removed during a period of early anatexis. Following this was lower grade, but probably still amphibolite-facies, retrogression producing biotite-bearing assemblages, and 'blebby' quartz (by reversing reactions 2 and 3) which overprints the quartz–plagioclase polygonal groundmass. Then prograde metamorphism to upper amphibolite-facies sillimanite grade, involving the production of garnet, spinel, and sillimanite, which also affected the surrounding Moine, produced trondhjemites in the Strathy complex and granites in the Moine rocks by anatexis of the respective gneisses (Moorhouse, 1979; Moorhouse and Moorhouse, in prep.).

Geochemical considerations. With regard to the above, the evidence of the Ba *vs.* K/Rb ratio diagram (fig. 4) is of great importance. The positive correlation shown by the Moine gneisses on this plot can be explained by the removal of anatectic granite from the biotite-rich (Rb-accepting) Moine gneisses. On average, the relatively biotite-free granite differs from the parent Kirtomy gneisses (Table I, column E), in containing less Rb (average 81 ppm) as this is held in the biotite of the gneiss, much more Ba (average 2480 ppm) and more K_2O (average 4.49 %, Moorhouse, 1979; Moorhouse and Moorhouse, in prep.) as these go into the K-feldspar of the melt (Ba being preferentially accepted relative to Rb). Thus those Moine gneisses which have supplied least anatectic melt will tend to have the highest Ba and K/Rb ratios, whereas those gneisses which have supplied the most anatectic granite have the lowest Ba and K/Rb ratios, having lost proprtionately more of their K_2O and Ba than their Rb. Thus, the Moine gneisses have a positive Ba–K/Rb correlation.

This is quite distinct from the negative correlation shown by the Strathy gneisses, which is simply explained by postulating that anatectic melts have also been extracted from them, probably during two distinct phases of metamorphism but under rather different conditions. During the earliest phase any original K-feldspar in the rock and the K-feldspar component produced by reactions 2 and 3 went into an anatectic melt which was removed from the complex. Rb and to a lesser extent Ba, would also be concentrated in the melt as there is no Rb accepting phase stable in the gneisses once biotite has been replaced by amphibole (reactions 2 and 3), whereas plagioclase may contain significant amounts of Ba (Taylor, 1965). The average gneiss composition after removal of this first anatectic melt but prior to the later anatectic phase is crudely approximated by a weighted average of 60 % siliceous gneiss plus 40 % trondhjemite, these being the approximate proportions seen in the field (Table II, column F). This indicates that prior to the later anatectic phase the Strathy gneisses were depleted in K_2O, Rb, and Ba relative to high-grade terrains such as the Brazilian and Musgrave granulites (Table II) but had similar Sr contents; which is reflected in the higher K/Rb and lower Rb/Sr ratios of this Strathy, 'post-early anatexis' gneiss, mean analysis (Table II, column F).

Therefore, during the early anatexis of the Strathy gneisses we believe significant proportions of the original K_2O, Rb, and Ba were completely removed from the complex via an anatectic melt, whilst Sr remained relatively immobile in the Ca-bearing plagioclase and amphibole. During the later anatectic phase Sr and Ba are strongly concentrated in the plagioclase-rich trondhjemite (Table II, column G), K_2O and Rb are only slightly enriched as by this stage retrogression of amphibole had produced biotite in the Strathy gneisses which would tend to hold the K_2O and Rb.

The Y–Ce–La distribution. A similar line of reasoning explains the relative abundances of Y, La, and Ce in the Strathy rocks. Of the *RE*-holding minerals those with small lattice sites, such as garnet and apatite, show preferential enrichment in the heavy *RE* (Gd–Lu) and Y (Taylor, 1965; Frey, 1969), whereas the light *RE* tend to follow the large elements Sr, Ba, and K.

Both garnet and apatite are common in the Strathy rocks, and the garnet certainly was stable in the gneisses during both periods of anatexis. Therefore Y would tend to be retained in the Strathy rocks whereas Ce and La would have a tendency to be lost from the complex in the proposed early anatectic phase. Thus this would explain why the Ce and La content of the Strathy complex is low, lower than the Moine gneisses and the Leverburgh and East Greenland metasediments (Table I). It is also worth noting that Moorhouse and Moorhouse (1977) found that Y was immobile, but La and Ce were mobile and concentrated in the felsic fraction, during migmatization of certain Lewisian rocks.

Evolution of the Strathy complex in comparison with other terrains

In contrast to this proposal for the geochemical evolution of the Strathy complex, various authors have considered that anatexis of metavolcanics and metasediments was not primarily responsible for the removal of K_2O etc. from high-grade terrains such as the Assynt gneisses. For example, Sheraton *et al.* (1973) suggest the removal of K_2O and Rb via an aqueous fluid whilst others, notably Holland and Lambert (1975) and Tarney and Windley (1977) appeal to mechanisms involving the direct derivation of material from the mantle.

The high Ba and La content of the Assynt granulites/gneisses (Sheraton *et al.*, 1973) does militate against the formation of anatectic melts as this would be likely to remove substantial Ba and La. Sheraton *et al.* also consider that 'K-feldspar should be a stable phase in rocks which are not diopside normative', this is manifestly not the case in the Strathy complex for the reasons given above.

Cooper and Field (1977), when considering the origin of the Tromøy granulites state that in spite of these rocks having Ba and Sr values lower than many other granulites the Tromøy rocks are 'much too acid for there to have been major amounts of granite removed'. However, it is an observed fact that when an anatectic melt is removed from acid quartz-rich rocks the residue becomes richer in silica, i.e. more acid (Winkler, 1967; and a consideration of the Qz–Ab–An–Or–H_2O system).

The parental material of the Strathy complex. These gneisses were obviously originally rich in silica, whatever processes are considered to have subsequently modified them. Nevertheless, the original parental material was probably not as rich in SiO_2 as the present day siliceous gneiss (Table I, column A) or the gneiss-trondhjemite mean (Table II, column F), whilst it would have been richer in K_2O, Rb, plus Ba, La, and Ce to a lesser extent.

In view of the fact that probable calcareous metasediments occur in the Strathy complex (Port Mor marble and Strathy calc-silicates) plus possible quartz-rich metasediments (quartz–magnetite gneiss, quartz–garnet gneiss) could not a large proportion of the Strathy complex rocks represent paragneiss with inherited geochemical peculiarities? This would appear unlikely because, for example, on the SiO_2–TiO_2 diagram (fig. 2A) the Strathy gneisses occupy a position distinct from typical metasediments (e.g. the Moine gneisses) but fall in a field occupied by calc-alkali igneous rocks and Archaean gneisses (Tarney, 1976). Secondly, when the Strathy gneisses and amphibolites are plotted on an AFM diagram (fig. 7) they display a calc-alkali trend very similar to the trend of Archaean gneisses from Scotland and Greenland (Sheraton *et al.*, 1973). Finally, when plotted on variation diagrams such as MgO *vs.* Ni and Cr (figs. 8A, B) a trend is apparent running from the siliceous gneisses through the hornblende gneisses and the amphibolites, like trends observed in many igneous sequences.

It is possible that whilst the basic rocks are of igneous origin, the more acid are paragneisses or volcano-clastics derived from a calc-alkaline sequence. However, as the mafic minerals containing the bulk of the Cr and Ni are the first to break down in the sedimentary process we would expect the above trends to be less apparent. Therefore we believe that the bulk of the Strathy complex is probably not of metasedimentary derivation and the most likely parent for the siliceous grey gneisses would seem to be an acid volcanic or its plutonic equivalent. In view of the foregoing discussion, use of Winchester and Floyd's (1977) magma-type discrimination which indicates a rhyolitic origin is

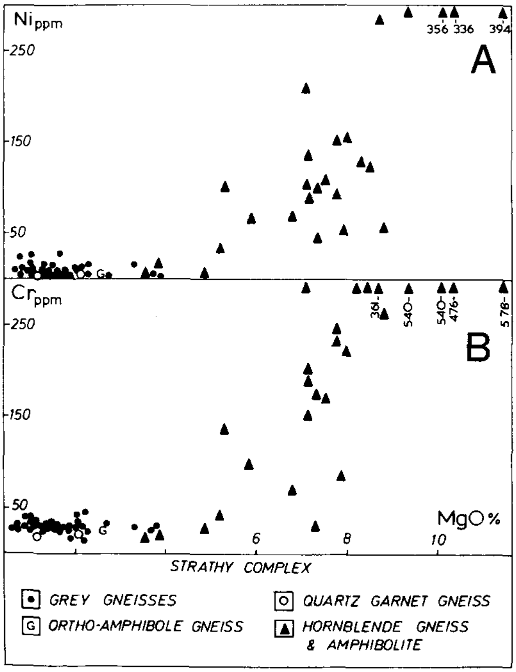

FIG. 8. (A) Na *vs.* MgO. (B) Cr *vs.* MgO. Strathy gneisses and amphibolites.

certainly misleading. The actual parent material was probably less SiO_2-rich but is not likely to have been as basic as andesite, if only because this would probably have resulted in a diopside-normative 'charnockitization' process leading to hypersthene-bearing granulite (Sheraton *et al.*, 1973). Therefore, a low-CaO dacitic, perhaps inclining towards Na-rich or pantelleritic, composition appears to be the most likely parental material.

Minor amounts of metasediments could have become involved with contemporaneous volcanism if the complex was originally formed in an island-arc type environment. If the gneiss precursors were plutonic they may represent a basement upon which the metasediments were deposited unconformably, or an underplating mechanism may have been responsible for the involvement of the sediments in the complex (Tarney and Windley, 1977).

Conclusions

The only geochronological work carried out on the Strathy complex to date (Rb–Sr whole rock; Taylor, Moorhouse, and Moorhouse, unpub.) unfortunately proved inconclusive, yielding unreliable indications of a middle Proterozoic event. Thus, in the absence of any reliable geochronological data, although there are numerous possibilities, we believe the available evidence indicates that the Strathy complex is a block of the sub-Moine basement most probably referable to the Lewisian complex. Although an early Scourian origin cannot be ruled out, the *REE* and Y data suggest a post-Archaean origin. Therefore the complex possibly originated as a Laxfordian, or even early Grenvillian, volcanic supracrustal sequence with minor sediments and intrusives. One of the most notable features of the complex is that although it has not apparently undergone granulite-facies metamorphism it has a geochemistry deficient in 'incompatible' elements. This geochemical imprint could have been acquired by the removal of an anatectic melt during upper amphibolite-facies metamorphism whilst the complex formed part of the lower crust, most probably during the Laxfordian or Grenvillian cycle.

Retrogression during later events has only slightly modified this unusual geochemistry. During the metamorphism of the adjacent Moine cover sequence, H_2O and probably some K_2O and Rb were introduced into the complex, producing trondhjemitic anatectic melts simultaneously with the production of granitic anatectic melts in the local Moine gneisses (Moorhouse, 1979). Therefore, if Strathy complex-type basement is present elsewhere beneath the east Sutherland Moine, it may have contributed significant amounts of sodic melt to the east Sutherland migmatite–granite complexes (Brown, 1967, 1971; Moorhouse, 1979, Moorhouse and Moorhouse, in prep.).

The Strathy complex occurs as a fault-bounded block of basement aspect which is clearly defined by a strong positive aeromagnetic anomaly. It is structurally, lithologically, and geochemically distinct from the tectonic inliers of Lewisian basement found elsewhere in the Moine succession and its geochemistry is incompatible with a derivation from the local Moine gneisses. Further research may enable us to recognize other examples of Strathy complex type basement within the Moine but as far as we know at the present time, the Strathy complex is unique within the Northern Highlands of Scotland.

Acknowledgements. The initial work, including the XRF analyses, was carried out at Hull University whilst we were in receipt of awards from NERC (V.E.M.) and Hull University (S.J.M.). We are particularly grateful for the advice of Drs N. S. Angus and A. G. Fraser, and technical assistance from Mr R. Middleton at this time. Financial assistance towards some of the field-work expenses from the University of Newcastle Staff Research Fund is gratefully acknowledged by S.J.M. Dr A. G. Fraser very kindly confirmed the determination of orthoamphibole by XRD. Especial thanks are due to Professor J. V. Watson for the loan of Dr R. S. Collins's thin sections and for reading and helpfully criticizing an early version of the manuscript. At the Hatfield Polytechnic Mr J. Rice photographically reproduced our diagrams and Mr J. Foster gave technical assistance.

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[*Manuscript received 1 August 1980;
revised 12 August 1982*]