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A geochemical study of Lewisian metasedimentary granulites and gneisses in the Scourie–Laxford area of the north-west Scotland

P. O. OKEKE

Department of Geology, University of Benin, Private Bag 1154, Benin City, Nigeria

AND

G. D. BORLEY AND J. WATSON

Department of Geology, Imperial College, Prince Consort Road, London SW7

ABSTRACT. Major element, trace element, and *REE* data for metasedimentary granulites and their retrogressed derivatives formed from Archaean parent-rocks at two localities in the Lewisian complex of north-west Scotland are presented.

The metasedimentary rocks are enclosed in and intruded by metatonalites and related calc-alkaline rocks and have been highly deformed and metamorphosed along with these rocks. They are geochemically distinct from this meta-igneous suite and range from highly aluminous to highly siliceous types. Comparisons of major and trace element data with those for unmetamorphosed Archaean and post-Archaean sediments suggest that they are derived from a detrital shale–greywacke assemblage, which may have included a volcaniclastic component. High $\sum REE$ and $\sum LREE$ suggest that the source-rocks included fractionated felsic igneous rocks.

Evidence that depletion in the large ion lithophile elements K, Rb, Th accompanied high-pressure granulite metamorphism supports the view, based on data derived from the associated meta-igneous rocks, that depletion was effected by active fluids rather than by abstraction of a partial melt and suggests that removal of K and Th began only when a considerable reduction of Rb had taken place.

THE Lewisian complex of north-west Scotland consists largely of gneisses and high-pressure granulites formed from Archaean protoliths by ductile deformation and metamorphism during late Archaean and early Proterozoic times (*c.* 2800–1700Ma). The general geochemical and isotopic characteristics of these rocks are well established and, consequently, the Lewisian complex is often referred to in discussions concerning the Archaean lower crust. The Lewisian rocks believed to be of metasedimentary origin, which form only a small percentage of the complex (cf. Jehu and Craig, 1927; Coward *et al.*, 1969), have hitherto received little attention in comparison with the much more abundant meta-igneous rocks. The study recorded below was undertaken, first, as a contribution to the filling of this gap, secondly, in order to provide a basis for comparison with possible sedimentary protoliths and, lastly, to examine the effects of deep-seated metamorphism on rocks differing in bulk composition from the average Lewisian granulites and gneisses.

The Scourie–Laxford region of north-west Scotland (fig. 1) straddles the boundary between a southern area in which Archaean granulites have suffered little modification during later tectonothermal events (the Scourian complex) and a northern area in which Archaean granulites and gneisses have been extensively modified by later deformation and high-grade metamorphism (the Laxfordian complex, Peach *et al.*, 1907, Sutton and Watson, 1951). The first well-defined metamorphic

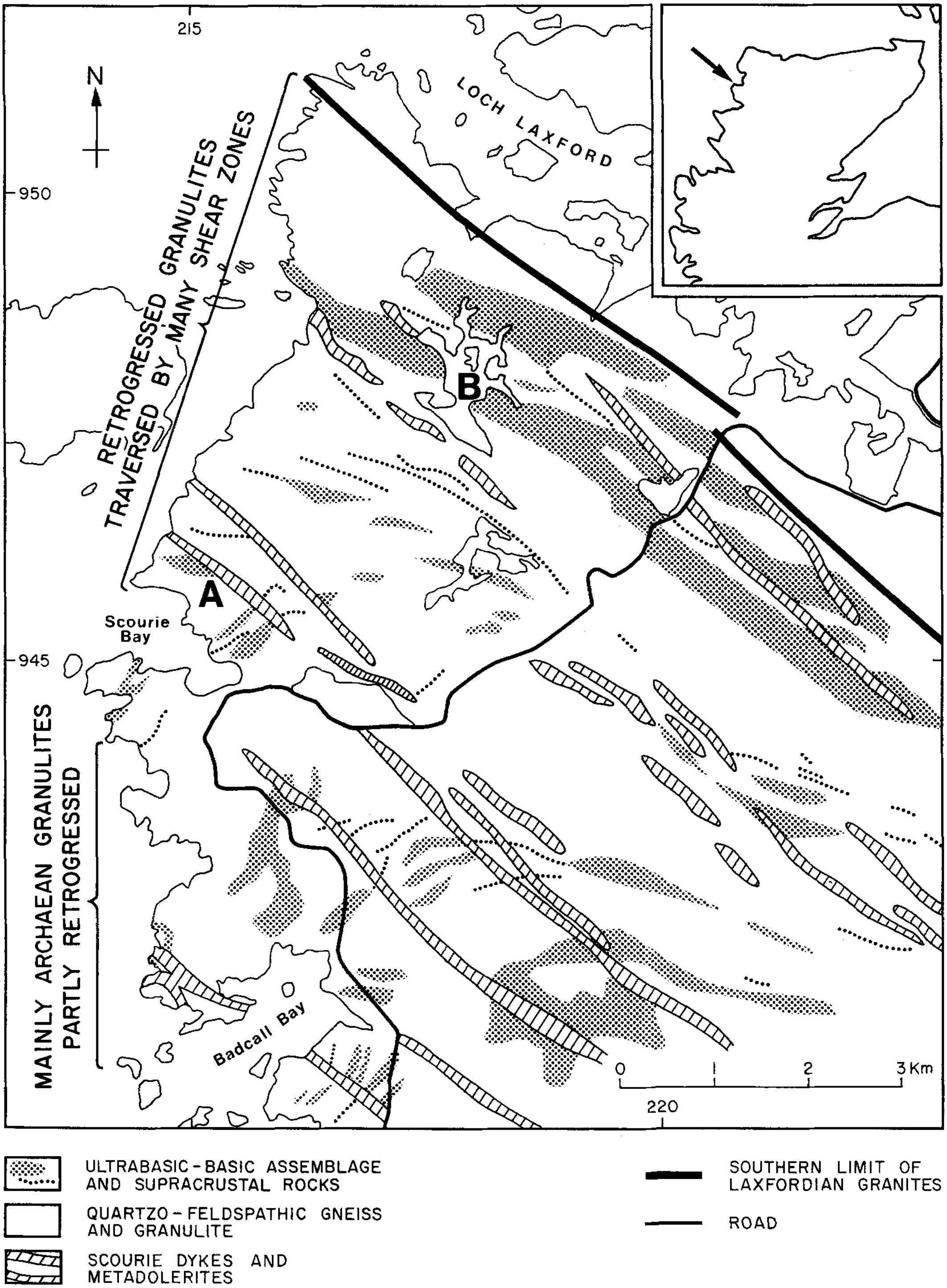

FIG. 1. Sketch-map showing the distribution of Archaean assemblages of mafic rocks with associated metasediments and the location of sample areas on the north side of Scourie Bay (A) and in the vicinity of Foindle (Loch nam Brac, B).

event, known in local terminology as the Badcallian event (Park, 1970), was a granulite- and gneiss-forming event dated at 2900–2700Ma (e.g. Moorbath *et al.*, 1969). The rocks which predate this event include the metasedimentary rocks described below, a number of layered mafic–ultramafic complexes, and a very large volume of metamorphosed tonalitic, granodioritic, and other calc-alkaline plutonic rocks in the form of innumerable sheets and veins enclosing all the other rock-types.

As the original relationships and primary structures have been largely obliterated by strong ductile deformation during the Badcallian event, the identification of rocks derived from sedimentary protoliths has rested mainly on the occurrence of unusual mineral assemblages indicating bulk compositions comparable with those of sedimentary rocks. Aluminous, siliceous, carbonate, and calc-silicate varieties, with rare magnetite-rich layers are the principal types found in the Scourian complex. These distinctive types are always interleaved with mafic and felsic rocks of uncertain origin. In this paper, attention is concentrated on an aluminous to siliceous assemblage.

The predominant tonalitic to granodioritic granulites and retrogressed granulites which form the bulk of the Scourian complex in the type area are characterized by unusually low levels of K, Rb, Th, and U, the LIL (large ion lithophile) elements, and by high K/Rb ratios. These features are generally ascribed to the abstraction of LIL elements by an active fluid phase during deep-seated metamorphism (e.g. Moorbath *et al.*, 1969; Sheraton *et al.*, 1973; Lambert and Holland, 1974; Tarney and Windley, 1977; Rollinson and Windley, 1980*a*). The effects of chemical modifications during the Badcallian events or during later retrogressive phases must therefore be taken into account when the origins of the metasedimentary rocks are considered.

Field relations and petrography. Rocks possibly of metasedimentary origin are sparsely distributed in the Scourie–Laxford region, forming small lenticular or irregular bodies on both sides of Scourie Bay and a larger NW–SE tract interfolded with a layered mafic–ultramafic complex about 1 km south of Loch Laxford (fig. 1). Although the occurrence of these rocks was recorded by Peach *et al.* (1907) and Sutton and Watson (1951), a metasedimentary origin was not proposed until comparatively recently (Davies, 1974; Beach *et al.*, 1974; Davies and Watson, 1977). Sampling during the present study was concentrated on two localities where aluminous and siliceous granulites and their retrogressed derivatives are well exposed.

At the more southerly locality, alongside a lochan 250 m north of Scourie Bay (fig. 1, locality A) the predominant rocks are banded granulites and gneisses of tonalitic to granodioritic composition enclosing narrow mafic bands. In these meta-igneous rocks, the early mineral assemblages of high-pressure granulite facies (including ortho- and clinopyroxene in felsic and pyroxene–garnet in mafic types) are partially replaced by assemblages in which hornblende and biotite are the principal ferromagnesian minerals. The younger assemblages commonly define planar and linear fabrics related to one or more phase of post-Badcallian deformation; these fabrics are most prominent in ductile shear-zones which thin and distort the banding of the granulites. Details of mineral compositions and reactions recorded in the vicinity of Scourie Bay are given by Peach *et al.* (1907), O'Hara and Yarwood (1978), and Rollinson (1981), and are not repeated here.

At the sides of the lochan, felsic and mafic pyroxene–granulites are interleaved with coarse brown-weathering granulites studded with dark red garnets up to 1 cm in diameter which pass, in shear zones, into strongly foliated striped biotite schists and gneisses. In the least-modified granulites, the principal minerals (Table I) are quartz (showing the opalescence and swarms of minute needles characteristic of quartz in the associated meta-igneous rocks), antiperthitic andesine, garnet, and magnetite ± pyrite and orthopyroxene. Magnetite locally becomes the principal ferromagnesian mineral. Clusters of minute biotites around garnet, orthopyroxene, and magnetite indicate incipient retrogression. In the vicinity of shear-zones, biotite increases and a planar fabric is defined by the alignment of flattened quartz and feldspar blebs and by biotite. Within the shear-zones, close partings are plastered with biotite, the grain-size is reduced, and garnet remnants are broken up. Beach (1973) has recorded kyanite, sillimanite, staurolite, and corundum from retrogressed granulites in a shear zone at this locality.

The more northerly sample locality, which lies around Loch nam Brac northwest of Foindle within the metasedimentary assemblage identified by Davies (1974) and Beach *et al.* (1974), is situated in the transition zone between the Scourian and Laxfordian complexes (fig. 1, locality B). Garnetiferous granulites similar to those of the southern site survive only as remnants enclosed in coarse biotite–garnet gneisses which Sutton and Watson (1951) termed 'brown gneisses'. The range of initial compositions is greater than that at Scourie Bay, the highly garnetiferous or micaceous varieties being associated with gneisses containing more than 50% quartz. The characteristic minerals (Table I) are red garnet (usually partly replaced by biotite), plagioclase, quartz, biotite ± muscovite.

TABLE I. *Principal minerals of the granulites and gneisses*

	Scourie Bay				Foindle				
	1	2	3	4	5	6	7	8	9
Quartz	×	—	×	×	×	×	×	×	×
Plagioclase	×	×	×	×	×	×	×	×	—
K-feldspar	—	—	×	×	×	×	×	×	—
Garnet	×	×	×	×	—	×	×	×	×
Iron oxide	×	×	—	×	×	×	×	×	×
Sillimanite	(×)	—	(×)	—	—	—	—	—	—
Kyanite	—	—	—	—	—	(×)	—	—	—
Hornblende	—	×	×	×	—	(×)	—	—	—
Biotite	—	×	×	—	×	×	×	×	×
Muscovite	—	—	—	—	×	×	×	—	—
Zircon	×	×	—	—	×	×	—	—	—
Apatite	—	—	—	—	—	×	—	×	—
Sphene	—	—	—	×	×	×	—	×	—
Epidote/clinozoisite	×	×	—	—	×	—	×	—	—
Chlorite	—	—	—	—	×	×	—	×	—
Calcite	—	×	—	—	—	—	×	—	—

1 Garnet granulite
2 Garnet–biotite granulite.
3 Quartz–garnet–biotite granulite.
4 Quartz-feldspar-garnet granulite.
5 Quartzitic gneiss.
6 Garnet–mica gneiss.
7 Biotite–muscovite gneiss.
8 Biotite schist.
9 Quartz-magnetite gneiss.

Pyrite is a widespread accessory responsible for a characteristic yellow-brown weathering. Sillimanite is recorded by Davies (1974) from other localities and orthoamphibole is locally associated with biotite.

The foliated micaceous gneisses formed by retrogression of garnetiferous granulites in the Foindle area contain a variety of lenses and boudins of more massive rocks some of which were sampled for sectioning and analysis. Some of these proved to be little-retrogressed kernels rich in garnet. Others turned out to be chemically akin to mafic or felsic meta-igneous rocks of types well known in the Lewisian complex. These latter bodies are regarded as tectonic inclusions of rocks originally interleaved with the metasedimentary gneisses which were disrupted because they acted as competent units in the more ductile micaceous gneisses; they are dealt with only incidentally below.

Analytical procedures. The compositions of the metasedimentary suites at the localities mentioned above are discussed on the basis of eight major and trace-element analyses of samples from Scourie Bay and thirty-five from Foindle (Tables II and III). The analyses are presented as averages of three groups, the more pelitic (low SiO_2) and siliceous (high SiO_2) being separated from the more abundant transitional types. To facilitate comparison with the better-known calc–alkaline felsic granulites, average compositions cited from Weaver and Tarney (1981) and Rollinson and Windley (1980*a*) are tabulated in columns A and B. Full analyses and details of procedures are given in Okeke (1978).

Major element oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO_2, MgO, K_2O, P_2O_5 in wt. %) and trace element (Cr, Ni, Rb, Sr, Y, Zr, Ba, Th, Zn, Cu concentrations in ppm) were determined by X-ray fluorescence spectrography at the Department of Geology, Imperial College of Science and Technology, London. Details of the procedure are given in Parker (1980). A Philips PW 1212 X-ray spectrometer was used. G-1, W-1, NIM-S, NIM-G, GSP, AGV, DTS, PCC, NIM-N, NIM-N, NIM-L, NIM-P, BCR-1, and NIM-D were used as external standards for analyses based on the values of Flanagan (1973) and Abbey (1973). Na_2O and FeO determinations were done by flame photometry and by titration against potassium dichromate respectively.

Rare-earth elements were analysed by Instrumental Neutron Activation Analysis (INAA) using the facilities of the University of London Nuclear Reactor Centre. Eleven elements (La, Ce, Nd, Sm, Eu, Gd, Tb, Ho, Tm, Yb, and Lu) were determined, using two detectors for counting (Ge(Li) for La and Germanium for other elements). Corrections were made to the raw count data for flux changes and decay. For estimates of accuracy of this method, international standard rock BCR-1 was analysed; the *REE* results as shown in Table V compare well with the results produced by other workers. Nakamura's (1974) and other accepted chondrite values have been used for normalization of the *REE* data.

TABLE II. *Metasedimentary rocks, Scourie Bay; major elements (wt. %), trace elements (ppm), element ratios*

	1(2)*	2(6)	A(110)	B(18)
SiO_2	54.31	68.22	60.6	62.32
TiO_2	1.15	0.48	0.67	0.61
Al_2O_3	20.33	15.98	15.1	16.09
Fe_2O_3	0.10	0.18	7.6	5.86
FeO	9.12	3.45		
MnO	0.18	0.08	0.13	0.09
MgO	2.53	1.74	4.5	2.80
CaO	2.99	2.61	7.2	6.68
Na_2O	4.13	3.78	3.3	4.38
K_2O	2.61	2.48	0.9	0.69
P_2O_5	0.10	0.07	—	0.19
Oxidation ratio	0.92	4.0	—	—
$FeO_T/(FeO_T+MgO)$	0.79	0.68	—	—
CaO/Al_2O_3	0.15	0.15	—	—
Na/K	1.29	1.93	—	—
Cr	303	77	318	—
Ni	185	55	98	46.3
Rb	37	36	7	3.0
Sr	394	473	334	436.0
Y	31	20	16	10.5
Zr	206	263	120	158.0
Ba	891	1993	521	365.0
Th	15	4	—	0.9
Zn	157	49	—	63.0
Cu	178	49	—	—
V	264	68	—	—
K/Rb	578.0	902.2	1067	1903.0
K/Sr	73.0	46.0	—	—
K/Ba	21.9	19.5	—	—
Rb/Sr	0.12	0.09	0.021	—
Ba/Rb	25.1	100.6	—	—
Ba/Sr	2.18	3.9	1.6	—
Ca/Y	702	267.2	—	—

* Numbers of samples in brackets.

1. Average pelitic analysis.
2. Average semi-pelitic (metagreywacke?) analysis.

A. Average granulite of Scourie–Lochinver area Weaver and Tarney, 1981).
B. Average tonalitic gneiss, Scourie–Badcall area (Rollinson and Windley, 1980*a*).

TABLE III. *Metasedimentary rocks, Foindle; major elements (wt. %), trace elements (ppm), element ratios*

	1(2)*	2(28)	3(4)
SiO_2	55.93	67.69	80.85
TiO_2	0.73	0.50	0.11
Al_2O_3	15.83	15.35	9.80
Fe_2O_3	0.45	0.23	0.04
FeO	8.79	3.62	1.38
MnO	0.19	0.07	0.11
MgO	5.24	1.84	0.49
CaO	4.76	3.29	1.89
Na_2O	1.54	3.40	1.60
K_2O	3.25	2.52	1.94
P_2O_5	0.27	0.20	0.03
Oxidation ratio	4.11	5.86	2.28
$FeO_T/(FeO_T+MgO)$	0.63	0.65	0.73
CaO/Al_2O_3	0.31	0.21	0.20
Na/K	0.50	2.42	0.81
Cr	180	45	7
Ni	64	24	10
Rb	77	42	43
Sr	385	407	89
Y	46	28	80
Zr	200	230	229
Ba	1133	1138	902
Th	6	9	10
Zn	208	60	402
Cu	48	25	10
V	153	65	6
K/Rb	388.5	580.0	379
K/Sr	103.0	99.0	259
K/Ba	23.6	23.0	18
Rb/Sr	0.34	0.23	0.5
Ba/Rb	18.4	43.0	22
Ba/Sr	4.05	3.0	11
Ca/Y	1224.5	4208	235

* Numbers of samples in brackets.

1. Average pelitic.
2. Average semi-pelitic (metagreywacke?) analysis.
3. Average siliceous analysis.

Major and trace element data. The analysed garnetiferous granulites and their retrogressed derivatives differ from the metamorphosed tonalites, granodiorites and granites with which they are associated in several important respects (Tables II and III*). The spread of silica percentages (55–81 %) is not very different from that of the calc–alkaline suite, although rocks with $SiO_2 > 75\,\%$ are rare in the latter. Al_2O_3 reaches values $> 17\,\%$ in almost half of the analysed samples and rises to $> 19\,\%$ where garnet or mica are abundant. All but one of the samples are corundum-normative. CaO remains generally below 4 % even at low silica percentages and the ratio CaO/Al_2O_3 averages 0.19 as against 0.48 in the meta-igneous granulites.

The Fe/Mg ratio remains almost constant (fig. 2) and total alkalis, though variable, show only a very small increase with SiO_2. K_2O is significantly

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* The full analytical data are available in Okeke (1978).

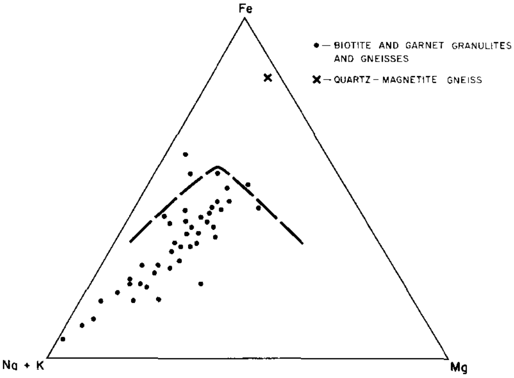

FIG. 2. FMA (atomic fractions) plot of all supracrustal samples. Broken line separates tholeiitic and calc-alkaline fields in igneous rocks.

TABLE IV. *Average trace-element data (ppm)*

—	1	2	B tonalite	C trondhjemite
Ni	40	51	46	13
Zn	110	74	63	14
Cu	52	21	—	—
V+Cr	206	101	83	12
Ba	1027	1036	365	393
Sr	427	330	436	448
Ba/Sr	2.4	3.1	0.83	0.88

1. $Al_2O_3 > 17\%$ (19).
2. $Al_2O_3 < 17\%$, $SiO_2 < 75\%$.

B, C, from Rollinson and Windley (1980*a*).

above the levels in the calc-alkaline granulites of similar silica content—at $SiO_2 < 65\%$, K_2O averages 2.0, as against 0.69 in metatonalites and at $SiO_2 > 65\%$, the average is 3.3 as against 0.85 for metatrondhjemites (cf. Rollinson and Windley, 1980*a*). The ratio K_2O/total alkalis (0.3-0.86) is also well above that in meta-igneous granulites other than the rare granites.

These contrasts confirm the distinction drawn in the field between the garnet-granulite assemblage and the enclosing calc-alkaline felsic granulites. The major-element compositions do not suggest affinities with any other type of igneous suite but are, as is indicated below, compatible with derivation from pelitic to psammitic sedimentary parent rocks.

Trace element data reveal further distinctive features (Tables II, III, and IV). Sr levels are similar to those of the calc-alkaline suite but Ba, and Ba/Sr ratios are notably high. Rb levels are high but, as K_2O is also above that of the calc-alkaline suite, K/Rb ratios are high (see later). The metals Ni, Zn, V, and Cr, together with Th, are on average higher than in the metatonalites and metatrondhjemites and are comparable with levels cited for pelitic sediments (Table IV). Zn, in particular, reaches 250 ppm in several samples, a level which is associated with the local occurrence of a zinc-chrome spinel (Beach, 1973).

Rare earth elements. Analyses of *REE* and plots normalized against chondrite values (Table V, fig. 3) are presented as averages for aluminous, transitional and siliceous metasediments from the two localities discussed above; an additional analysis of a garnetiferous granulite from Scourie More, south of Scourie Bay has been kindly provided by Dr D. Savage. Total *REE* are 100-259 ppm and the ratio $\sum LREE/\sum HREE$ ranges from 9.3-25.9. The chondrite-normalized curves have a consistent form characterized by a steep slope for the light elements and almost flat *HREE*. Eu is remarkably constant and (with the exception of the Scourie More sample) a small negative Eu anomaly or no anomaly is recorded. When compared with the calc-alkaline Lewisian granulites and gneisses (Weaver and Tarney, 1981) the principal distinctive features are (i) the absence of a pronounced positive Eu anomaly at high silica percentages, (ii) the relatively high *HREE* values, and (iii) the flat *HREE* curve. *LREE* values are broadly similar in the metasedimentary and meta-igneous suites. Comparisons with pelitic and psammitic rocks, facilitated by curves for a North American shale composite (Haskin *et al.*, 1966) and for Archaean greywackes from Wyoming (Condie, 1976) shown on fig. 3 are discussed in the next section.

Discussion: origins and influence of metamorphism. The evidence outlined above seems to provide a basis for separating the garnet-granulites from the enclosing calc-alkaline granulites. Some general resemblances to pelitic to psammitic sedimentary assemblages already noted provide the starting point for a further discussion. Two complicating factors—the possible contribution of volcanic or hydrothermal processes and the extent to which metamorphism has modified original compositions—are taken up in later paragraphs.

The highly garnetiferous granulites and their micaceous retrogressed derivatives can with some confidence be regarded as metapelites. The fact that these types are linked by a continuous transition with quartz-rich varieties containing up to 81% SiO_2 suggests that the assemblage is detrital, including pelitic, semi-pelitic and psammitic types. A single magnetite-rich granulite ($FeO+Fe_2O_3$ *c.* 20%) could perhaps represent a banded iron-

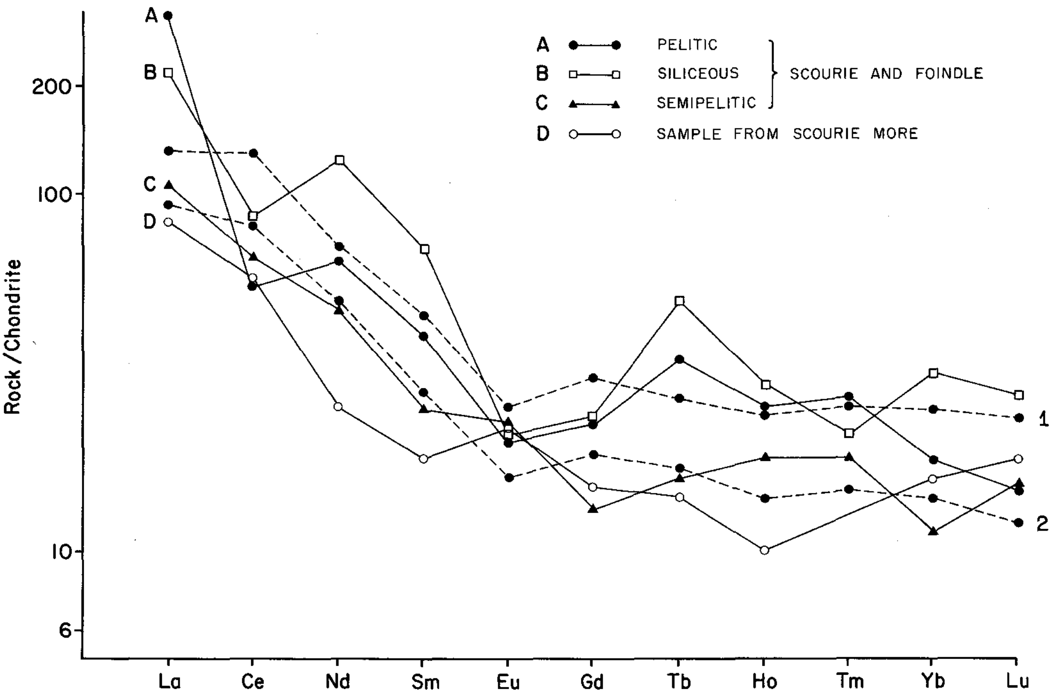

FIG. 3. Average rare earth element analyses normalized against chondrite values (Nakamura, 1974). The broken lines represent (1) average Archaean greywacke from Wyoming (Condie, 1976) and (2) a North American shale composite (Haskin *et al.*, 1966).

formation comparable to the Algoma jaspilitic type. Calc-silicate gneisses rich in diopside which, though not present at the localities sampled, form occasional lenses in the Foindle tract, may be derived from impure carbonate rocks (cf. Barooah, 1970). These very subordinate ferruginous and calcareous types could equally well be regarded as products of exhalative or hydrothermal activity related to volcanism.

The rocks assigned to a detrital series compare best in terms of bulk composition with greywacke assemblages. The absence of pure quartzites and the broad spread of compositions seem to rule out an affinity with a mature orthoquartzite facies, the low lime content restricts the possible proportion of a carbonate component (fig. 4) and the (K_2O/total alkalis) ratio and persistence of ferromagnesian minerals even at high SiO_2 levels exclude all but a few samples from consideration as possible meta-arkoses.

The wide distribution of pyrite and moderate to high levels of Cu, Zn, Ni, V, and Cr, especially in pelitic samples (Table IV), could be attributed to adsorption of metals on clay particles. Metal abundances are close to those of Wedepohl's (1971) shale composite and below those of many black shales, a feature consistent with the absence of graphite. Ni levels in metagreywackes are close to that of a Phanerozoic greywacke composite (Condie, 1976) but below that of Archaean greywackes cited by Condie and by Nance and Taylor (1977). Metal levels in greywackes may depend largely on the scale and character of any volcaniclastic component.

The rare earth element patterns of sediments are of interest because *REE* are thought to be more resistant to fractionation during both weathering and metamorphism than many other trace elements. *REE* patterns in many greywackes appear to mimic those of calc-alkaline andesitic suites, a relationship which would be in keeping with the derivation of such sediments from island-arc volcanics or from similar plutonic terrains (e.g. Taylor, 1977; Nance and Taylor, 1977). Analyses of low-grade Archaean greywackes indicate that these rocks differ from their post-Archaean analogues in that (i) $\sum REE$ are lower (ii) $\sum LREE/\sum HREE$ are lower and (iii) Eu is commonly enriched relative to chondritic patterns (cf. Nance and Taylor, 1977). The Lewisian samples shown in fig. 3 resemble both Archaean and post-Archaean shales and greywackes in their general concave-up pattern and

TABLE V. *Rare Earth element data (ppm) for the rocks in the Scourie–Foindle region*

	A	B	C	D
La	43.0	35.0	72.7	27.2
Ce	46.9	57.2	74.0	47.2
Nd	40.4	29.3	78.5	15.9
Sm	8.0	5.1	14.2	3.6
Eu	1.5	1.8	1.6	1.7
Gd	6.2	3.7	6.5	4.2
Tb	1.7	0.8	2.5	0.7
Ho	1.8	1.3	2.1	0.7
Tm	0.9	0.6	0.7	—
Yb	3.9	2.4	7.1	3.4
Lu	0.5	0.5	0.9	0.6
$\sum REE$	152.6	139.2	259.1	100.1
Y	35.1	26.4	79.3	—
$\sum(REE+Y)$	187.8	161.7	338.4	—
Eu/Eu*	0.7	—	0.5	1.6
La/Yb	10.8	14.3	11.7	6.4
La/Ce	1.0	0.6	1.0	0.5
$\sum LREE/\sum HREE$	11.7	25.9	14.7	9.3

Eu/Eu* is europium enrichment factor.

A = Average of five metapelites, Scourie–Foindle.
B = Average of thirty-four metagreywackes, Scourie–Foindle.
C = Average of four siliceous metasediments, Foindle.
D = Meta-pelite?, Scourie More. (anal. D. Savage).

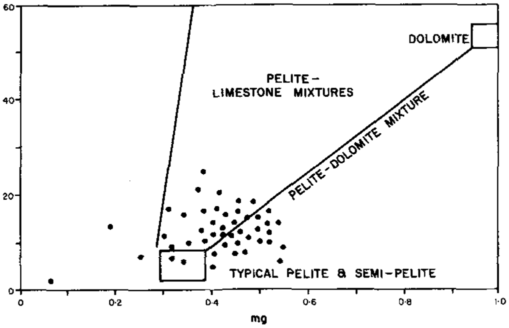

FIG. 4. Niggli mg–c plot slightly modified from Leake (1964) showing the distribution of metasediments relative to the fields of pelitic, semi-pelitic and calcareous sediments.

lack of *HREE* depletion. They are closer to post-Archaean examples in the literature in all three characteristics listed above and show exceptionally high levels of *LREE*. Although the presence or absence of a positive Eu anomally may relate to local variations in detrital plagioclase (Nance and Taylor, 1977), the high totals and steep *LREE* slopes may be significant in terms of provenance. If these are inherited features, they suggest that the Lewisian metasediments were derived from source-lands including well-fractionated felsic igneous rocks. An idea of the appropriate composition is given by the fact that $\sum REE$ and *LREE* values are roughly the same as those in the younger Lewisian metatonalites and metatrondjhemites (cf. Weaver and Tarney, 1981). Mafic granulites and amphibolites recorded by Weaver and Tarney show lower totals and flatter slopes and five amphibolites interleaved with metagreywackes at the Foindle locality give $\sum REE$ 80 ppm and $\sum HREE/\sum LREE$ 6.6 (cf. Table V). Although Pb and Sr isotopic data generally suggest that little or no crustal material substantially older than the date of Badcallian metamorphism is incorporated in the Lewisian (e.g. Moorbath *et al.*, 1969), Bowes *et al.* (1976) have inferred that some zircons in quartzitic gneisses are derived from continental sources over 3000Ma in age. The *REE* data given here are consistent with a contribution of detritus from such a source.

No allowance has been made in the preceding paragraphs for possible chemical modifications due to the high-pressure granulite metamorphism or the subsequent retrogressive events. Evidence relating to retrogression is dealt with elsewhere. The evidence of systematic depletion in LIL elements found in the meta-igneous granulites (see earlier) suggests that levels of K, Rb, Th, and U below those in unmetamorphosed sedimentary analogues might be expected at least in samples where granulite mineral assemblages are preserved.

Four samples from Scourie Bay and one from Foindle fulfilling this requirement (LNS 101, 104, 108, and 114, LNB94) give the following averages for LIL elements: K_2O 1.9 Rb 32 ppm Th 7 ppm, K/Rb 646. These levels are less than half those given for Wedepohl's (1971) shale composite. K_2O is below that of Archaean greywackes from Wyoming (Condie 1976) and Kalgoorlie (Nance and Taylor, 1977) but Th (not recorded by Condie) is within the range of Kalgoorlie samples. In conformity with the high K/Rb ratios, Rb values are only $\frac{1}{4}$ of the shale level and $\frac{1}{3}$ Wyoming greywacke. Although the recorded variation in unmetamorphosed Archaean detrital sediments is too large to give great weight to these contrasts, the evidence as regards K and Rb supports the concept of depletion during high-pressure metamorphism. The high values for Ba/Sr and *LREE* are features shared with the calc–alkaline granulites which Weaver and Tarney (1981) regard as inconsistent with a depletion process due to the abstraction of a partial melt. If the geochemical features in the metasedimentary rocks are inherited features pointing to source-lands geochemically similar to the younger calc–alkaline

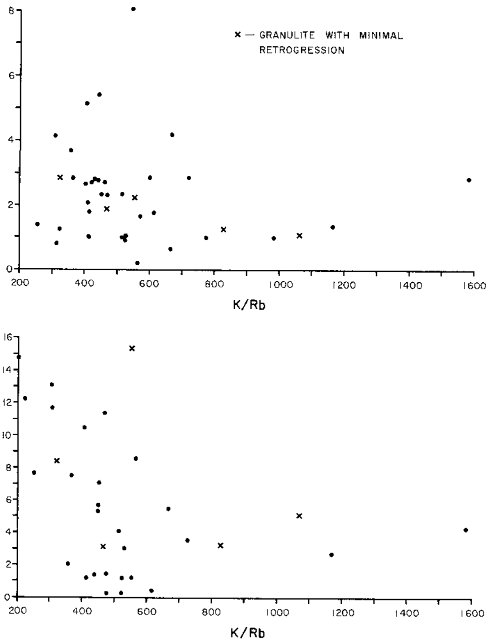

FIG. 5. K_2O and Th plotted against K/Rb, as possible indicators of selective depletion.

suite (cf. discussion of *REE*), they are consistent with depletion by a fluid phase rather than a partial melt. The concept of selective depletion developed by Rollinson and Windley (1980*b*) from comparisons of tonalitic, trondhjemitic and granitic members of the calc-alkaline suite, which leads to the inference that rocks originally richer in LIL elements suffered relatively little depletion, can be tested against data from the metasediments where a broad range of LIL element values is available. Rollinson and Windley note a decrease in K/Rb ratio with increasing K content which, if one assumes depletion of Rb relative to K, points to the abstraction of a smaller LIL contribution from the granites. In fig. 5 where K_2O and Th are plotted against K/Rb, both elements show a wide scatter (perhaps inherited from the protoliths) where the K/Rb ratios are below 600 and a tighter grouping of low values at higher K/Rb ratios. These distributions might imply that significant depletion in K and Th did not take place until loss of Rb had raised K/Rb to levels well above those of the crustal average. They are consistent with, but do not necessarily indicate selective depletion of rocks with lower initial K_2O.

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