British Geological Survey

Mineral Reconnaissance Programme

Mineral exploration for gold and base metals in the Lewisian and associated rocks of the Glenelg area north-west Scotland

Department of Trade and Industry

MRP Report 140

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BRITISH GEOLOGICAL SURVEY

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SUMMARY

An exploration programme for gold and base metals in the Glenelg area of the north-west Highlands of Scotland is described. Regional drainage sampling of the area between Loch Carron and the Strathconon fault was conducted and 212 samples of both stream sediments and panned concentrates were analysed for base metals, gold and a variety of indicator elements. The area covered by the reconnaissance drainage survey is underlain by Lewisian rocks of both the Eastern and Western facies and, also, Moinian rocks in the Caledonian orogenic belt of the Northern Highlands. The Ratagain igneous complex of late Caledonian age is also covered by the drainage survey.

Detailed investigations, involving geophysics, shallow overburden sampling and geological mapping, were carried out over one area underlain by iron-rich rocks, called eulysites in the literature, at Carr Brae near Loch Duich. Iron-rich rocks of a similar character are associated with the copper-gold deposit at Gairloch hosted by the supracrustal Loch Maree Series, which may be of the same age as the Eastern Lewisian. Eulysites within the Eastern Lewisian were traced along strike from Carr Brae for 14 km to the south-west but, despite chemical evidence that the rocks are metamorphosed chemical exhalites, no significant gold or base metal mineralisation was found associated with them. Calc-silicate gneisses within the Eastern Lewisian assemblage of metamorphosed sediments and volcanics do show some copper enrichment but the high gold values found in them in the earlier records of mining trials at Loch Duich could not be repeated.

Graphitic gneisses in the same assemblage do show some potential as a source of crystalline graphite with the carbon content of the rocks reaching 16 %. Further work is needed to assess the economic potential of this occurrence.

The Ratagain igneous complex, despite the recorded occurrence of veins carrying electrum, is not considered to be a good target for further mineral exploration as the complex is well exposed and the mineralisation is widely scattered and of relatively low grade. Veins within the Strathconon fault system are a more favourable target given its long, 100 km, strike length and the occurrence of gold at two localities within this area and at Scardroy 40 km to the north-east.

INTRODUCTION

The discovery by Consolidated Goldfields Ltd (Jones et al., 1987) of the sub-economic copper-gold deposit at Gairloch (Figure 1) was one of the major successes of mineral exploration in Scotland in the past twenty years. Whilst mineral showings and old trials have been known in the Lewisian rocks of the north-west Highlands of Scotland for a long period of time, the discovery of significant tonnages of potentially economic mineralisation was a major breakthrough in exploration. The malachite-stained outcrop that led to the discovery is mentioned in the Survey memoir on the north-west Highlands (Peach et al., 1907) and modern geochemical and geophysical methods followed by a large drilling programme resulted in the discovery of the strongly deformed orebody at Gairloch. The deposit is, however, too small and deformed to be economic and the company abandoned the prospect.

The primary aim of the MRP is to encourage further commercial exploration in the UK and it was decided to investigate other areas in the Lewisian that had potential for economic base metal and gold mineralisation. The Gairloch mineralisation is hosted by the supracrustal Loch Maree Group of metasedimentary and metavolcanic rocks, and three areas of the Lewisian looked prospective because of similar host rocks, possible correlation with the Loch Maree Group and the occurrence of mineral showings. These three areas were Scardroy, Glenelg and Loch Maree (Figure 1). The results of exploration in the first of these areas has been presented in an Open File MRP Data Release (Coats et al., 1993) and this MRP Report describes the results of work completed in the Glenelg area. Work in the Loch Maree area will be described in a subsequent report. Little previous exploration is known to have been carried out in the project area, and Berridge (1969) provides the only recent summary of the mineral resources of the Lewisian.

Work in the Glenelg area was carried out in two phases, the first being a regional geochemical drainage survey of Lewisian rocks from Loch Carron to Glenelg. Concurrently with this reconnaissance survey, detailed orientation work involving rock and shallow overburden sampling, geophysical surveying and geological mapping was carried out over the Carr Brae area, which contains the type locality for the rock called eulysite by Tilley (1936) and would now be generally described as a banded iron formation or BIF. This orientation work showed that an assemblage of metasedimentary rocks containing sulphide and oxide bearing exhalative rocks was present and could be traced along strike. In the second phase the drainage survey was extended to the Strathconon fault and further lithogeochemical sampling completed of the outcrops of the banded iron formation and associated lithologies discovered during the earlier phase. The report is therefore contains a general introduction to the geology of the Glenelg area, the results of the reconnaissance drainage survey, the detailed investigations at Carr Brae and the lithogeochemical sampling. A small section is also included on the Ratagain igneous complex, which intrudes the Lewisian rocks and is known to host gold and base metal mineralisation (Alderton, 1988). The economic potential of the Glenelg area is discussed in the concluding chapter.

Physiography

The area covered by this report is situated on the west coast of the mainland of Scotland opposite the Isle of Skye (Figures 1 and 2) and extends from Loch Carron to Loch Hourn. Kyle of Lochalsh lies about 220 km from Edinburgh and 180 km from Glasgow. Communications are relatively good for the north-west Highlands of Scotland, with the A87 major trunk road bisecting the area on its way to Kyle of Lochalsh, and the railway following a coastal route from Kyle of Lochalsh north-eastwards along Loch Carron to Inverness. The sea lochs of Loch Kishorn, Loch Carron, Loch Alsh, Loch Duich and Loch Hourn break up the area into a series of isolated peninsulas and this can make north - south travel difficult.

Most of the project area is upland with strong relief, ranging from 400 to 850 m in elevation. There is little land suitable for cultivation, except along the coastal strip and in some of the larger valleys. Because of the relief and the cold wet climate, land use is mostly restricted to grazing and forestry. Because of the steepness of the terrain and limited land use there are few tracks, and access to the interior is difficult except on foot. Human settlement is concentrated along the coastal strips, with the settlements of Kyle of Lochalsh, Stromeferry, Dornie, Shiel Bridge and Glenelg being the main centres. The main activities of the area were traditionally crofting and small-scale sheep farming, but recently there has been diversification into tourism and forestry. Kyle of Lochalsh is a major tourist centre on the way to Skye and also has a small fishing fleet. A bridge has recently been constructed across the narrow waterway separating Kyle of Lochalsh from Skye.

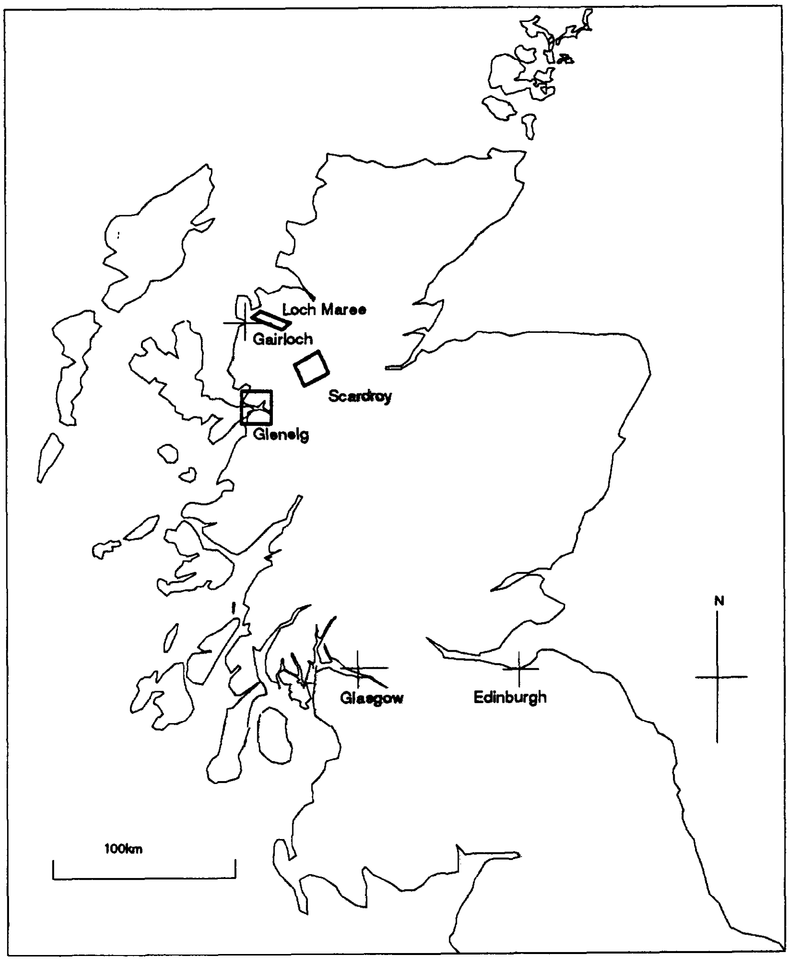

Figure 1 Location map of Scotland showing the Glenelg, Scardroy and Loch Maree project areas

General geology

The Lewisian rocks of the Glenelg area form part of the Glenelg-Attadale inlier, which is the largest outcrop of basement gneiss in the Caledonian orogenic belt of the northern Highlands, extending as it does for 30 km from Loch Hourn to Loch Carron (Figure 2). Rocks of the inlier are divided into two parts, the Western and Eastern Lewisian, separated by a zone of strongly deformed rocks which includes units of both Lewisian and Moinian aspect and which intersects the north-east coast of Loch Duich, 1 km south-west of Eilean Donan Castle. The Western Lewisian consists of migmatitic and granodioritic acid gneisses, together with metabasic rocks such as pyroxene-hornblende granulite, amphibolite, hornblende schist and rare ultrabasic rocks. The Eastern Lewisian comprises a much wider variety of rock types, including some of undoubted sedimentary origin as well as hornblende and biotite gneiss and eclogite derived from igneous rocks. Distinctive iron-rich rocks, called eulysites by Tilley (1936) also occur within the metasediments. Rocks of the Eastern Lewisian were strongly deformed after the deposition of the Moine, as evidenced by the occurrence of blastomylonite. On the eastern side of the inlier the Lewisian passes beneath the main outcrop of the Moine. The relationship between the Eastern and Western Lewisian is obscure but it is possible that the former, with its undoubted metasedimentary rocks, forms a cover sequence to the migmatite complex of the Western Lewisian (May et al., 1993). The area to the north of Loch Alsh has been mapped by Barber and May (1975), from Loch Alsh to Glen More by Sutton and Watson (1958) and between Glen More and the Strathconon fault by Ramsay (1957).

Eastern Lewisian

Bounded to the east by the Moine and to the west by the narrow strip of deformed Moine and Lewisian, the outcrop of the Eastern Lewisian can be readily followed on the 1:50 000 geological map from just north of Loch Hourn to where it wedges out 4 km north-east of Dornie. South of Glen More the outcrop strikes just east of north and is 1.5 - 2.5 km broad, though in upper Glen Beag, possibly as a result of folding, a tongue of Lewisian extends eastwards for 4 km. Approximately 1 km north of Glen More the strike swings round to NE-SW. On the south-west shore of Loch Duich, as a result of folding which also affects the Moine rocks, the trend of the outcrop changes to NW-SE before resuming its NE-SW alignment on the north-east side of the loch. As a result of this folding the Eastern Lewisian extends along the southern shore of Loch Duich to where it is truncated by the Ratagan igneous complex.

The following description of the Eastern Lewisian is based largely on that of the outcrop north-east of Loch Duich (Figure 3) contained in May et al. (1993). The major part of the outcrop consists of hornblende and biotite gneisses and their blastomylonitic derivatives. In places the gneiss is characterised by a coarse-banded texture resulting from the alternation of quartzofeldspathic and ferromagnesian layers, which resembles the migmatitic gneiss of the Western Lewisian. Within the gneisses are streaks, bands and lenticles of basic and ultrabasic rock, including eclogite and its derivatives, pyroxenite and non-eclogitic amphibolite. The eclogite is of particular interest, mainly because it occurs only rarely in Britain, but also because it gives some indication of the metamorphic conditions which prevailed. It forms bands within the gneisses ranging up to several metres in thickness. The larger bodies tend to form isolated exposures so that their shape and relationship to the surrounding rocks is not always obvious. Some show alternating bands rich in garnet and rich in pyroxene, and where the relationship is apparent the bands are parallel to the margins of the eclogite and also to the banding in the adjacent gneiss.

Metamorphic rocks of sedimentary origin occur in the centre of the Eastern Lewisian outcrop, in a broad belt which tapers to the north (Figure 2), possibly indicating that it represents the core of a pre-

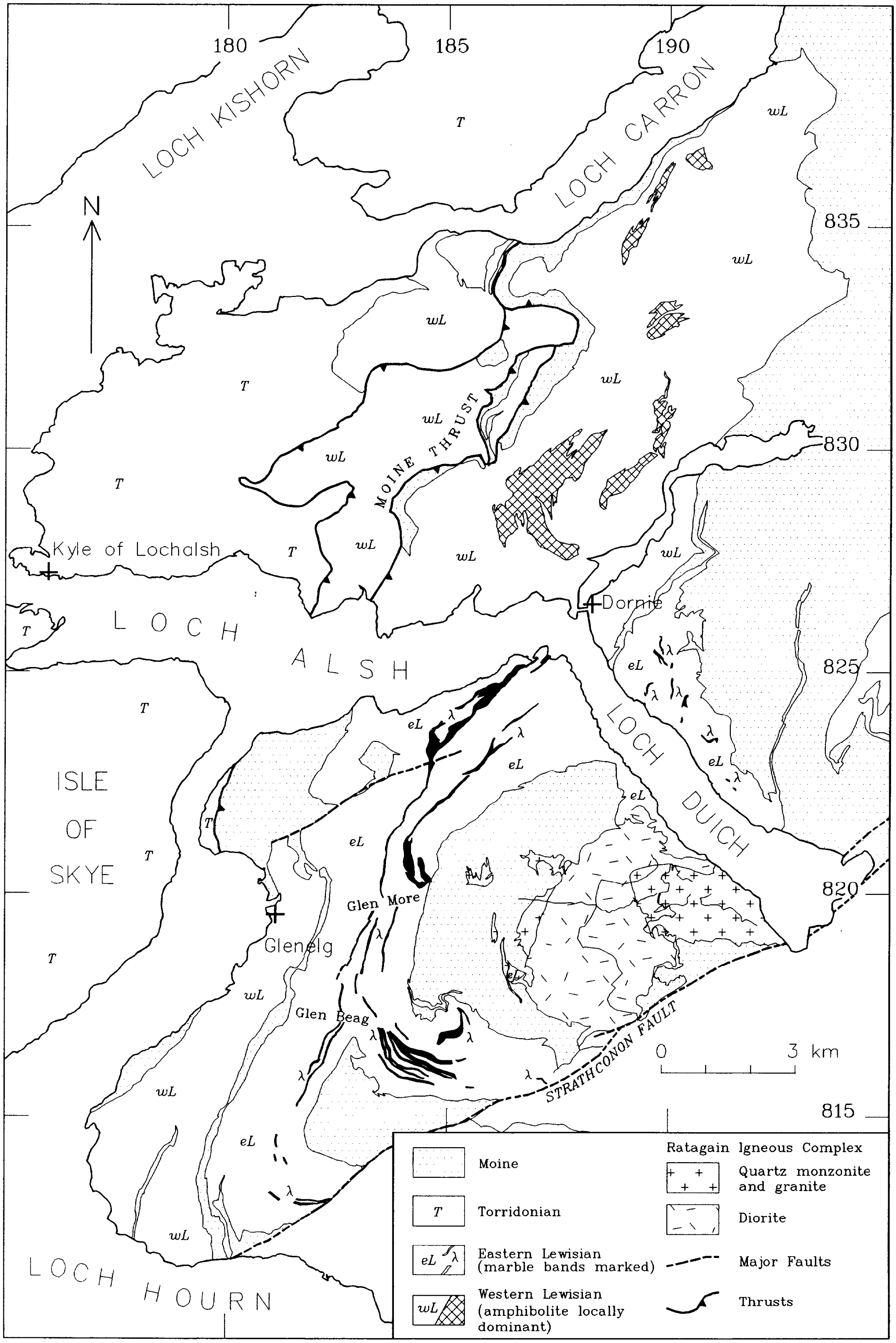

Figure 2 Schematic geology of the Glenelg project area (rocks south of the Strathconon fault and north of Loch Carron are left blank)

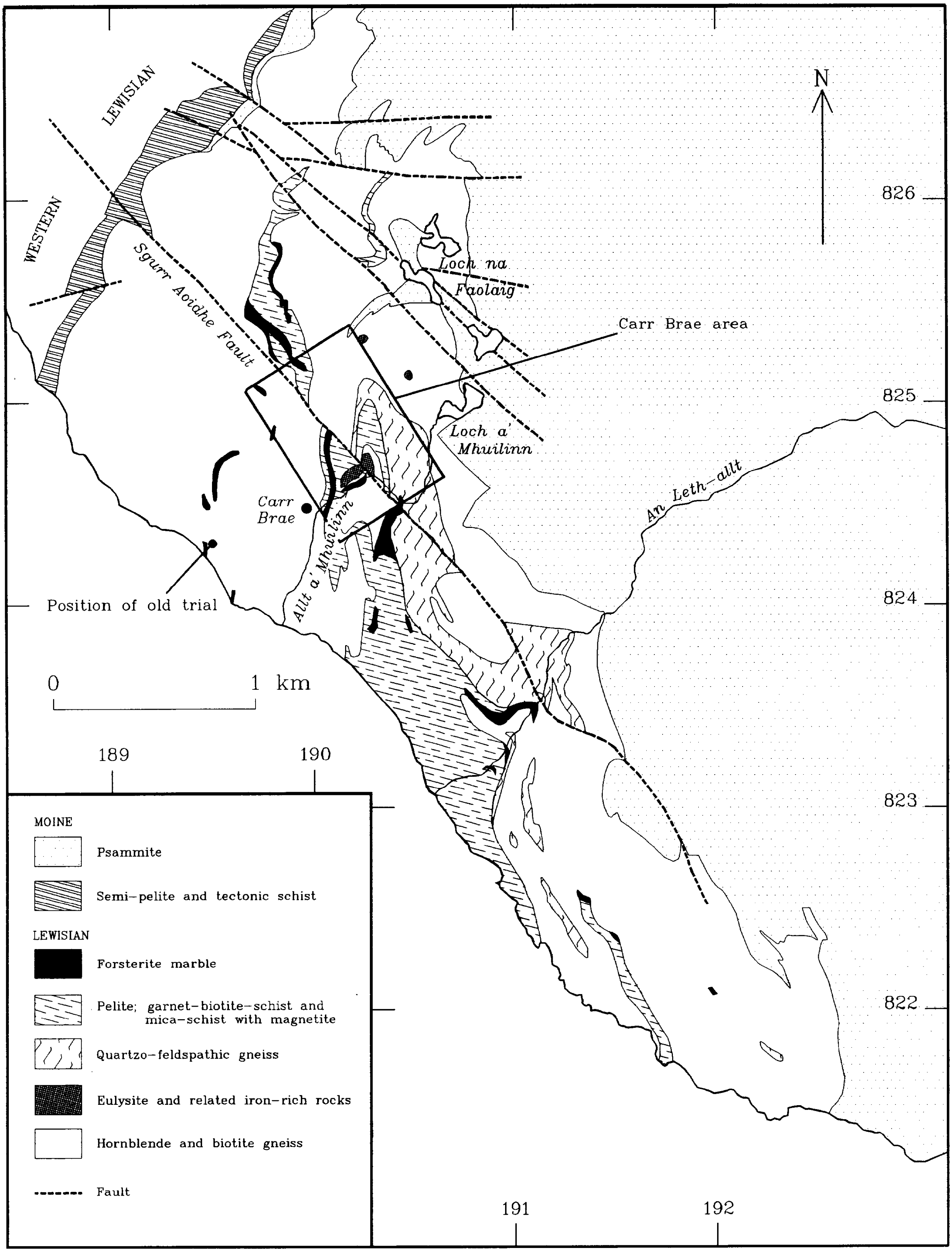

Figure 3 Geological map of the Eastern Lewisian north-east of Loch Duich (after May et al., 1993)

Moine fold. The metasedimentary succession consists largely of garnet-biotite pelite, but also includes magnetite-bearing mica schist and quartz-feldspar gneiss. Bands and lenses of forsterite marble occur sporadically through the hornblende-biotite gneiss, but are more common, as are the eulysites within the pelites.

Ratagain igneous complex

Intruded into the Lewisian and Moinian metamorphic rocks is a suite of Caledonian igneous rocks forming the Ratagain igneous complex. A recent account of the geology of the complex has been given by May et al. (1993) and only a brief description of the major features is presented here. The complex comprises principally diorites and quartz monzonites but there are also minor components of appinites, syenites and granites. The pluton was emplaced at 425 +/-3 Ma, making it of similar age to the Assynt alkaline suite. The complex has several similarities to that suite , such as the high Ba, Sr and rare-earth element contents. The emplacement of the pluton may be related to the adjacent Strathconon fault, and the fault was probably active throughout the history of the pluton as evidenced by the late-stage quartz-fluorite-calcite veins and crush breccias.

Mineralisation

The geological memoir for Sheet 71 (Peach et al., 1910) gives a description of exploratory work carried out in 1904 and 1905 near Dornie not far from the shore of Loch Duich [1895 8243]. A trial level was dug into a five foot thick, pyrite- and pyrrhotite-rich band in the Eastern Lewisian, and analyses of material collected by the Survey gave 1.8 ppm Au, 0.25 % Cu and 0.8 % Ni. Earlier hand-picked material from the same site had yielded 5.4 ppm Au and 16.8 ppm Ag.

Carbonate veins with galena and chalcopyrite in the bed of Allt Srath a'Chomair [187100 815870] are also recorded in the memoir. A sample of this vein was found to contain 65.5 ozs. of silver per ton of lead (Peach et al., 1910).

Further veins associated within the Strathconon fault complex are briefly described in the recent geological memoir for Sheet 72W (May et al., 1993). These contain pyrite, chalcopyrite, galena, sphalerite, and minor amounts of hessite and gold-bearing electrum (Alderton, 1986, 1988). The Ratagain igneous complex hosts quartz-fluorite-calcite veins which contain galena, pyrite and magnetite (Nicholls, 1951 and May et al., 1993), and these may be part of the same suite.

Clifford (1959) described an ankerite-quartz-pyrite rock with the chromium mica, fuchsite, from a fault zone in the upper reaches of the An Leth Allt, but the locality is not accurately defined and is believed to lie outside the area covered by this report. He also pointed out the occurrence of similar rocks associated with gold deposits in Canada, Kalgoorlie and California.

The geological mapping carried out by Peach et al. (1910) identified several localities of magnetite-rich rocks which are marked on the original 1:10,560 maps. Tilley described in 1936 the mineralogy of these iron-rich rocks, some containing abundant fayalite and therefore classified by him as "eulysite", from the Eastern Lewisian near Totaig on Loch Duich [1878 8243]. Other localities were identified by Tilley (1937) in Gleann Beag [1852 8158] and by Barber (1968) north-east of Loch Duich on Creag Reidh Raineach [1902 8253]. The eulysites are banded with magnetite-rich layers alternating with silicate-rich layers. These unusual iron-rich rocks are associated with marble and pelite and are thought by May et al. (1993) to be metasedimentary ironstones. Some of the outcrops of iron-rich rocks show evidence of trial excavations and it is possible that they have been investigated as sources of iron ore. As described later in this report, the main eulysite locality forms a rocky knoll at [1902 8246] overlooking Carr Brae and also contains pyrite-bearing rocks.

REGIONAL GEOCHEMISTRY

The area covered by the reconnaissance drainage sampling between Loch Carron and the Strathconon Fault is shown in Figure 2. Standard BGS techniques for sampling drainage sediments were employed (Plant 1971), wet sieving in the field through 150 micron aperture nylon sieves. Heavy-mineral concentrates were collected from the same sites by panning about 4 kg of the -2 mm fraction of the stream-sediment down to 100ml (Gunn 1989). In total 212 stream-sediments and 211 panned concentrates were collected. The stream-sediment samples were analysed by XRF spectrometry in the BGS laboratories for Ti, Mn, Fe, Ni, Cu, Zn, As, Ba, and Pb and an initial batch of 98 samples in the orientation phase analysed additionally for Ca, V, Cr, Co, Zr, Nb, Mo, Ag, Sn, Sb, La, Ce, Bi, Th and U. This group of samples was also analysed for Au by Acme Laboratories of Canada, using an aqua regia attack followed by solvent extraction and AAS spectrometry. The panned concentrate samples were analysed for a similar range of elements using XRF by BGS and Au using AAS by Acme Laboratories.

Stream sediments

The geochemical results for the stream sediment samples are summarised in Table 1, and the median values are compared with those for the Great Glen Geochemical Atlas (British Geological Survey, 1987) in Table 2.

Calcium

Calcium was only determined on the batch of stream sediment samples collected in the first year of work and thus only in the northern part of the area. The element ranges from 0.59 % to 4.89 % and shows little correlation with the occurrence of metalimestones in the Eastern Lewisian north of Loch Duich. The median calcium content is 2.96 % Ca, which is comparable to the mean content of 3.2 % Ca over the Lewisian foreland given in the Great Glen Geochemical Atlas (British Geological Survey, 1987). Higher calcium values are related to the occurrence of metabasic rocks in the Western Lewisian, and this is confirmed by the correlations with V, Co, Ni and Fe. The main calcium-bearing minerals are hornblende and plagioclase feldspar. The Geochemical Atlas also shows that the Western Lewisian has higher values of calcium west of the Moine thrust, presumably because of the higher percentage of metabasic rocks.

Titanium

The distribution of titanium in the Glenelg area reflects that of metabasic rocks in the Lewisian and the basic portion of the Ratagain complex (Figure 4). The south-west portion of the Ratagain complex is composed of hornblende diorite, monzodiorite, syenite and appinite containing elevated levels of titanium, up to 1.89 % Ti in the appinite phase (May et al., 1993). The highest titanium content (1.03 %) in stream sediments is found in sample KLC 4339 at [18764 81725] draining the main appinite body. Titanium in the intrusive rocks is present in the mineral sphene and is not of economic importance.

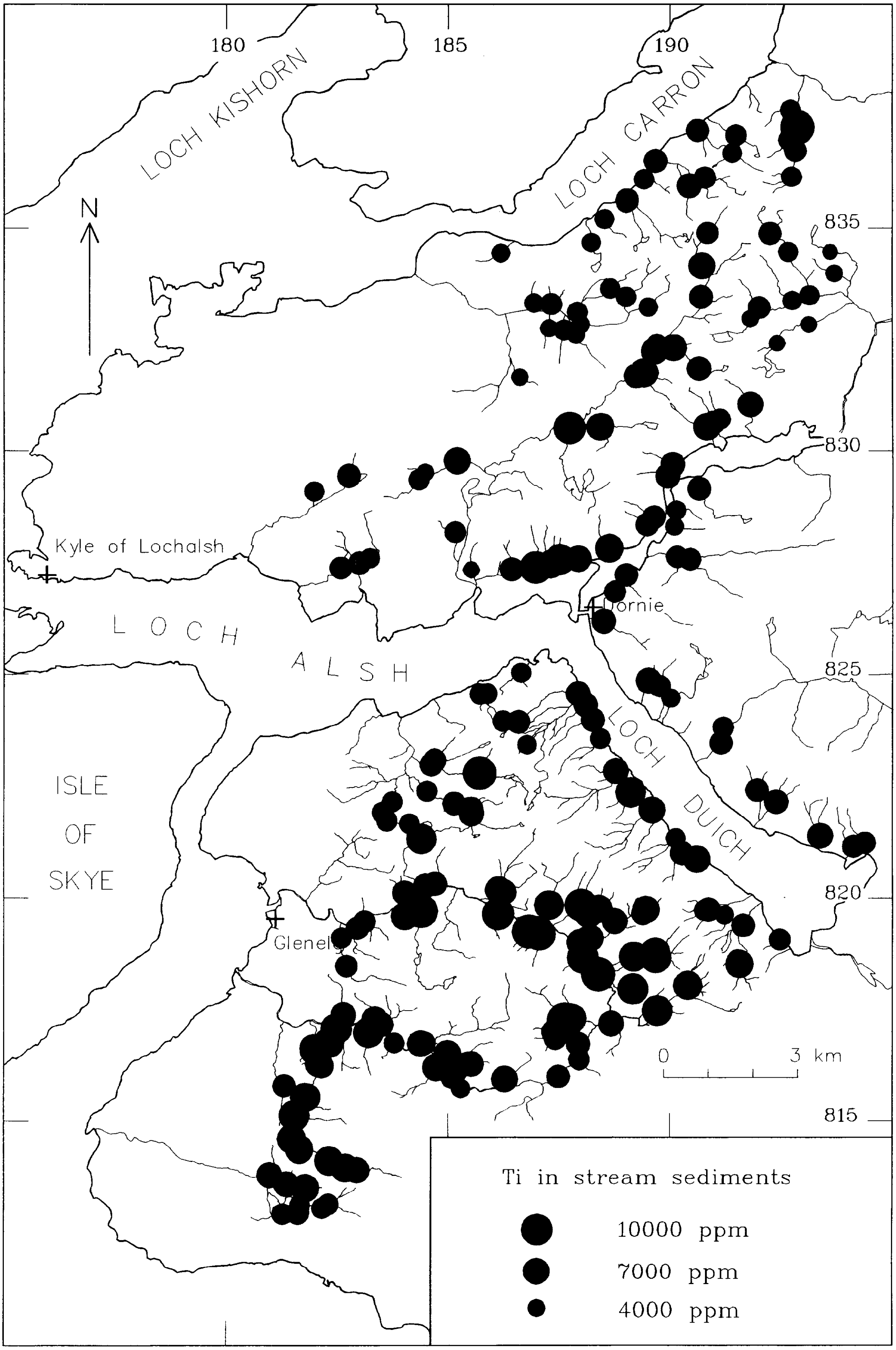

Figure 4 Distribution of titanium in stream sediments

Table 1 Summary statistics for stream sediment samples from the Glenelg area								
	N	Median	25 th percentile	75 th percentile	Mean	Standard deviation	Maximum	Minimum
Ca	98	29550	20900	34300	27908	9752	48900	5900
Ti	212	6005	5235	7160	6231	1320	10030	3400
V	98	149	124	170	147	39	254	46
Mn	212	2340	1800	4705	3725	3564	32010	630
Fe	212	75950	66550	87800	77606	19504	206600	32100
Co	98	34	29	39	35	11	65	11
Ni	212	75	58	100	82	42	363	12
Cu	212	42	27	61	46	26	147	6
Zn	212	122	102	147	128	38	333	36
As	211	5	2	7	5	5	54	0
Zr	98	378	272	461	434	305	2169	168
Nb	98	9	7	10	9	3	17	5
Mo	98	5	3	7	5	3	20	0
Ag	98	2	1	3	2	1	5	0
Sn	98	2	1	3	2	2	15	0
Sb	98	1	0	2	1	1	6	0
Ba	212	587	463	733	648	298	2623	198
Au	98	0.003	0.001	0.005	0.004	0.005	0.041	0.001
La	98	32	27	40	35	13	98	14
Ce	98	70	61	89	76	27	220	36
Pb	212	17	12	23	23	41	576	0
Bi	98	0	0	0	0.2	0.4	1	0
Th	98	5	3	6	5	3	14	0
U	98	1	0	2	2	5	28	0

All values in ppm

The eclogites and amphibolites that form a major proportion of the Eastern Lewisian are also enriched in titanium. Analysed eclogites range from 0.40 to 2.15 % Ti (Mercy and O'Hara, 1968 and Sanders, 1972). At the high metamorphic grades shown by the eclogites, titanium is present as rutile (TiO_2) and this mineral has industrial uses as a pigment. However, at the rutile grades indicated by the above analyses they are probably uneconomic (G E Norton, personal communication). Over the whole area the median content of 0.60 % Ti is very closely comparable to the 0.61 % Ti median for the Great Glen Geochemical Atlas area (British Geological Survey, 1987).

Vanadium

Vanadium is positively correlated with Ti, Fe, Co, Ni, Cu, Zn and Nb and occurs chiefly in basic igneous rocks. The median value of 149 ppm V is much higher than that for the Great Glen Atlas (Table 2) and this reflects the greater proportion of basic rocks in the Lewisian of the project area. Both the Eastern and Western Lewisian have elevated values, with the highest value of 254 ppm being recorded in Gleann Udalain [18751 82620] in the Western Lewisian.

Table 2 Comparison of stream sediment compositions with the Great Glen Geochemical Atlas (British Geological Survey, 1987)		
	Median (this survey)	Median (Great Glen)
Ca	29550	15650
Ti	6005	10100
V	149	66
Mn	2340	1611
Fe	75950	63300
Co	34	15
Ni	75	29
Cu	42	8
Zn	122	88
Zr	378	1060
Mo	5	0
Sn	2	0
Ba	587	830
La	32	47
Pb	17	20
U	1	3

All values in ppm

Manganese

The distribution of manganese in stream sediments is partly controlled by bedrock composition but levels are very variable because of precipitation of manganese oxides in the surface environment. All of the sediments with more than 1 % Mn were collected from streams that showing secondary enrichment, with marked black staining on the clasts. It is considered that most of the element variation is the result of such processes.

Iron

Iron levels recorded in this survey are higher than the average for the Great Glen Atlas (Table 2) because of the higher percentage of basic rocks in the Lewisian and the Ratagain complex compared to the Moine metasediments that form a large part of the Atlas area. Secondary precipitation of hydrous iron oxides affects the iron distribution in stream sediments and iron values greater than 10 % are the result of this rather than bedrock composition. The eulysite rocks at Loch Duich were not detected in the stream sediments that drain the outcrops, probably because their outcrops are too small.

Cobalt

Cobalt levels are high compared to the median for the Great Glen Atlas (Table 2) because of the presence of a greater proportion of basic rocks in the Lewisian and in the Ratagain complex. High correlations with Ca, Ti, V, Mn, Fe, Ni, Cu and Zn confirm this interpretation. The three highest cobalt values above 60 ppm are found in the northern part of the area (Figure 5), where three streams drain the Carn nan Iomairean ridge [ca. 1912 8355]. All these samples have slightly elevated levels of Ca, Ni and Zn, and pyrite is recorded in the panned concentrate or noted in grey gneiss upstream at site KLC 3899 [19148 83707]. Cobalt analyses were not completed on the samples from the southern

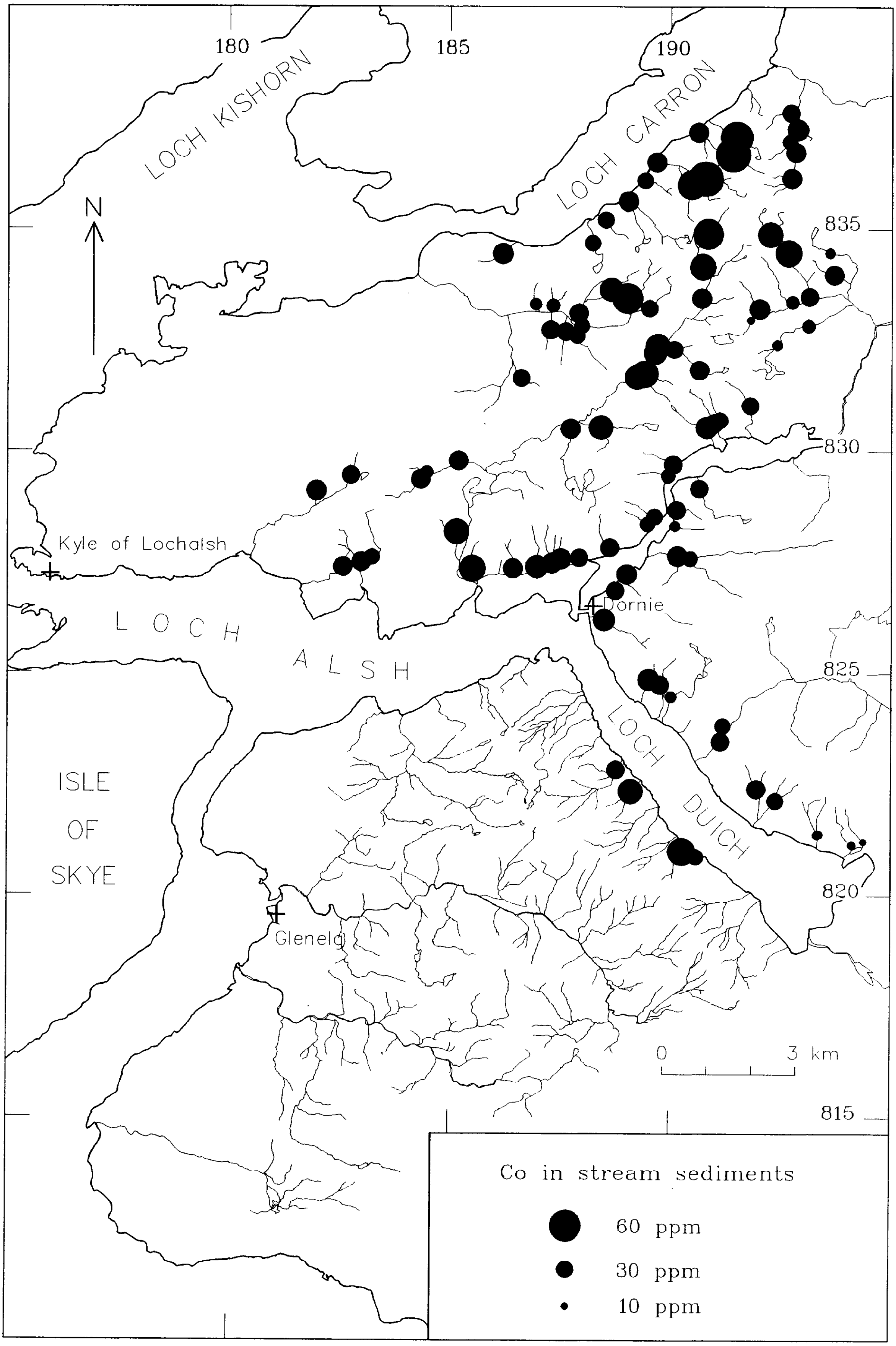

Figure 5 Distribution of cobalt in stream sediments

part of the area, which covers most of the Eastern Lewisian. Low values of cobalt are found in the easternmost samples, collected from streams draining the Moine succession.

Nickel

The variation of nickel over the area reflects the distribution of basic rocks, and the median value is about twice that given in the Great Glen Geochemical Atlas (Table 2). Two groupings of high values in the stream sediments are evident, over the south-west portion of the Ratagain complex and over the Western Lewisian south-west of Loch Carron (Figure 6). The earlier phases of the Ratagain complex contain basic diorites, which show elevated levels of nickel, and May et al. (1993) give representative values of 144, 192 and 208 ppm Ni for the three phases that occupy the south-west part of the complex. Aucott and Collingborn (1971) also record pyrite-bearing quartz veins in this area with 0.9 % Ni in the margins of the pyrite grains. The second group, to the south-east of Loch Carron, occurs over the Western Lewisian and is related to the hornblende geisses which form a major component in this area. The highest nickel value of 363 ppm was determined in a sample from [18552 82735]. The sample is recorded as having a high content of magnetite in the panned concentrate, and hornblende gneiss with a high content of magnetite or, perhaps, pyrite may be the reason for the high nickel. A few samples to the west of Loch Duich associated with the eclogites and magnetite-rich rocks are slightly anomalous in nickel.

Copper

Copper levels are high over the area,and the median content is five times that given for the Great Glen Atlas. This enrichment is again due to the greater proportion of basic rocks, and nearly all the area of Lewisian is anomalous on a regional scale (Figure 7). The highest values occur south-west of Loch Duich and mark the outcrop of the sulphide-bearing graphitic gneiss and calc-silicate rocks (Figure 34), which are enriched in copper and associated with the Lewisian marble bands. Other anomalous sites include KLC 3923 and 3927 on the southern shore of Loch Duich. These contain 82 and 122 ppm Cu respectively and both drain a small sliver of Eastern Lewisian on the edge of the Ratagain complex. Quartz veins containing chalcopyrite cut the igneous complex but none are recorded from these catchments and an origin in the Lewisian may be indicated. Three samples on the north side of Loch Duich are slightly anomalous, with 84, 67 and 67 ppm Cu. These samples were collected from streams draining the eulysite outcrops and are significant because of the close association with the old Cu-Au trial which occurs downhill and closer to the loch side. This part of the area is discussed in more detail later. The anomalous sample (KLC 3909) collected on the south side of Loch Carron at [186194 83444] contains 116 ppm Cu but also has a high tin content in the panned concentrate, indicating contamination. A copper coin was discovered in the sample during panning, confirming this identification.

Zinc

Zinc shows strong correlations with Co, V, Mn, Ba, Pb, Fe, Ca and Ni. This reflects its association with elements in mafic silicates and oxides. Zinc is moderately enriched in the area compared to the regional median given in the Great Glen Geochemical Atlas. The spatial pattern (Figure 8) shows high values over the Western Lewisian in the north of the area from Glen Udalain [ca. 1890 8315] to Loch Carron. Closer examination of the high values shows that zinc is also affected by secondary oxide precipitation and the sample with highest value of 333 ppm Zn, north of Loch Alsh, contains 3.2 % Mn and 11.9 % Fe. This sample also has elevated barium (2623 ppm), another element concentrated by secondary manganese oxide precipitates. However, some mineralisation may also be present in the catchment because pyrite was recorded in the panned concentrate. The only samples that may indicate mineralisation rather than the mafic association are samples KLC 4819 and 4820

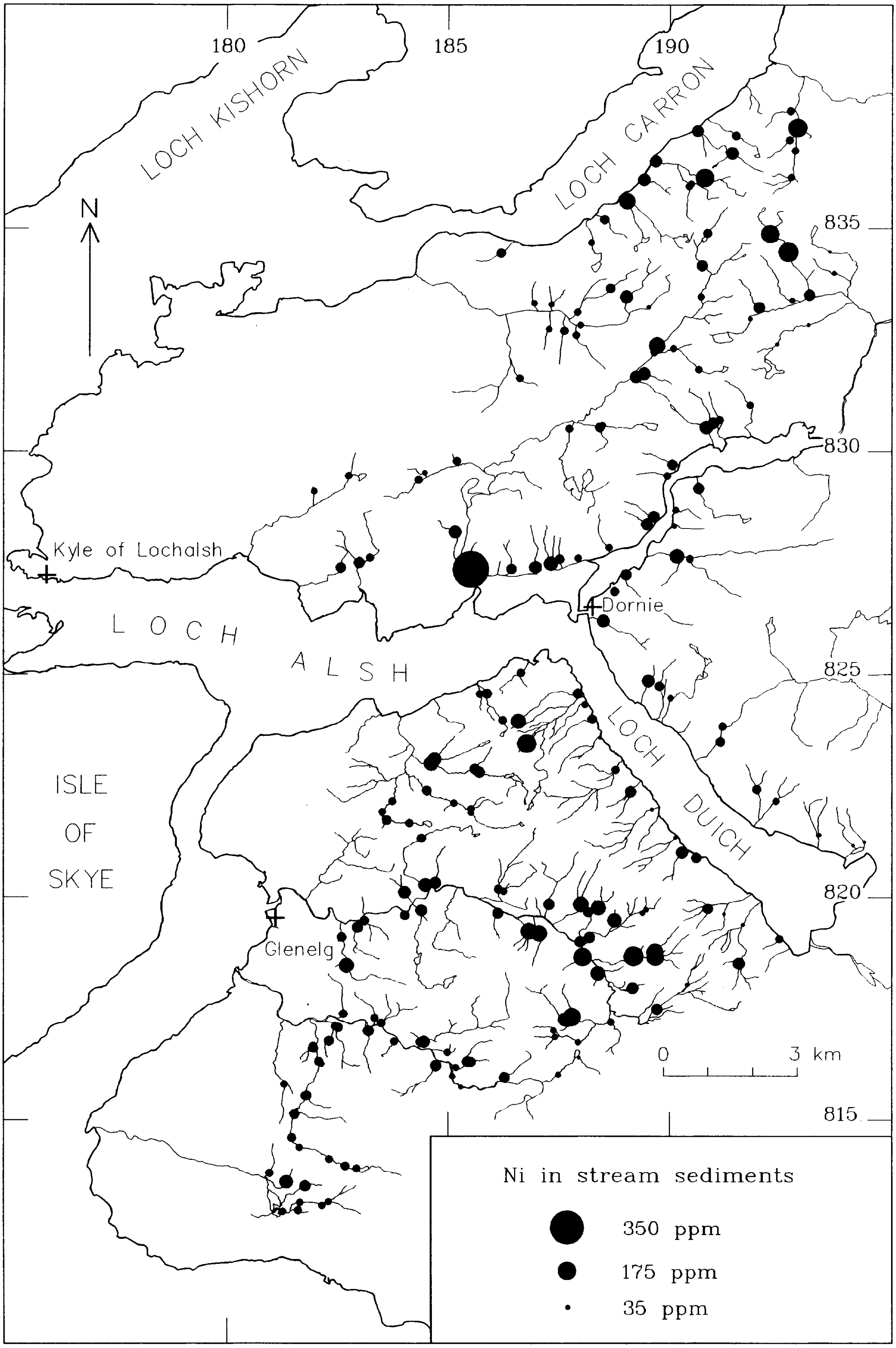

Figure 6 Distribution of nickel in stream sediments

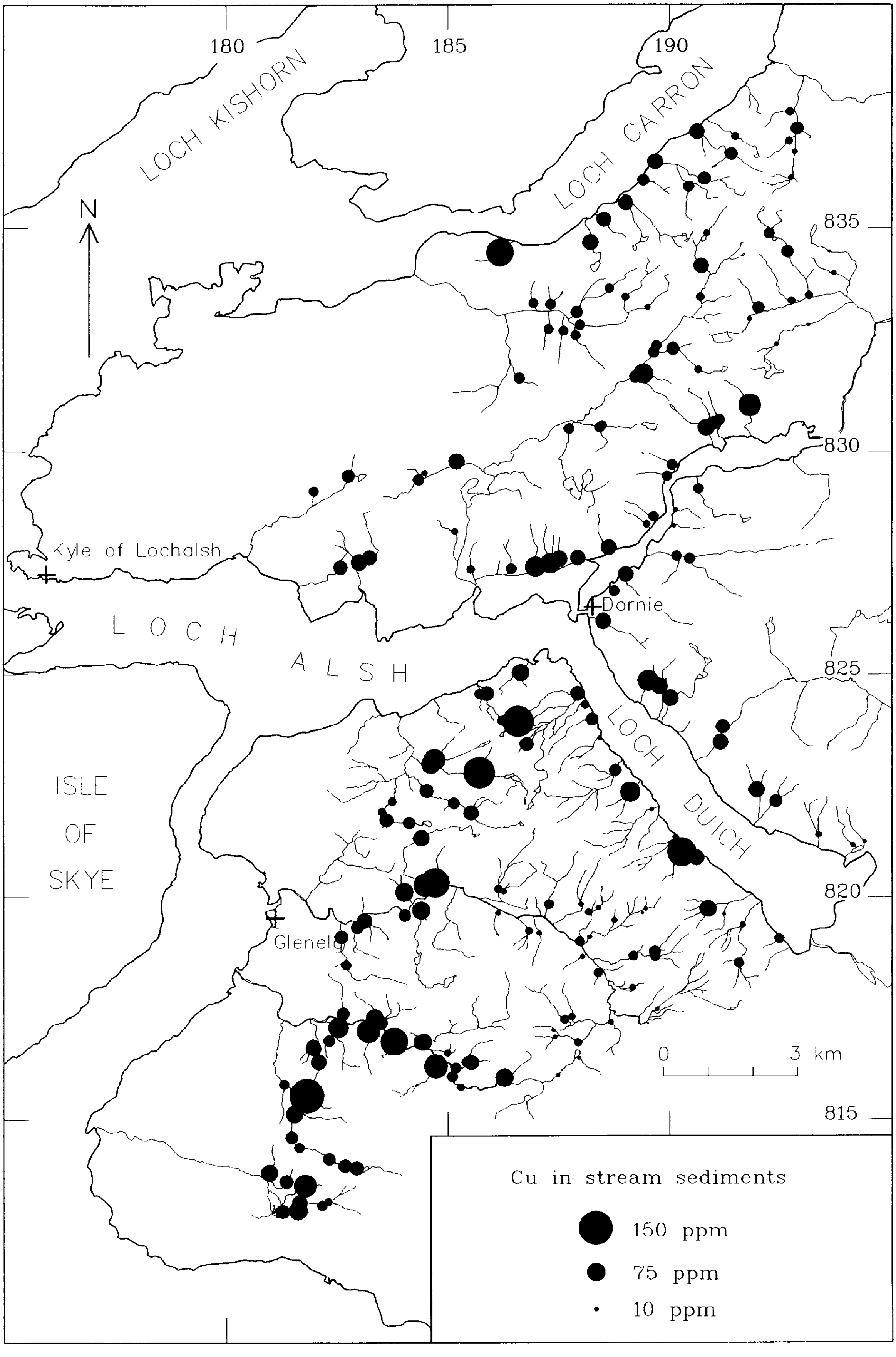

Figure 7 Distribution of copper in stream sediments

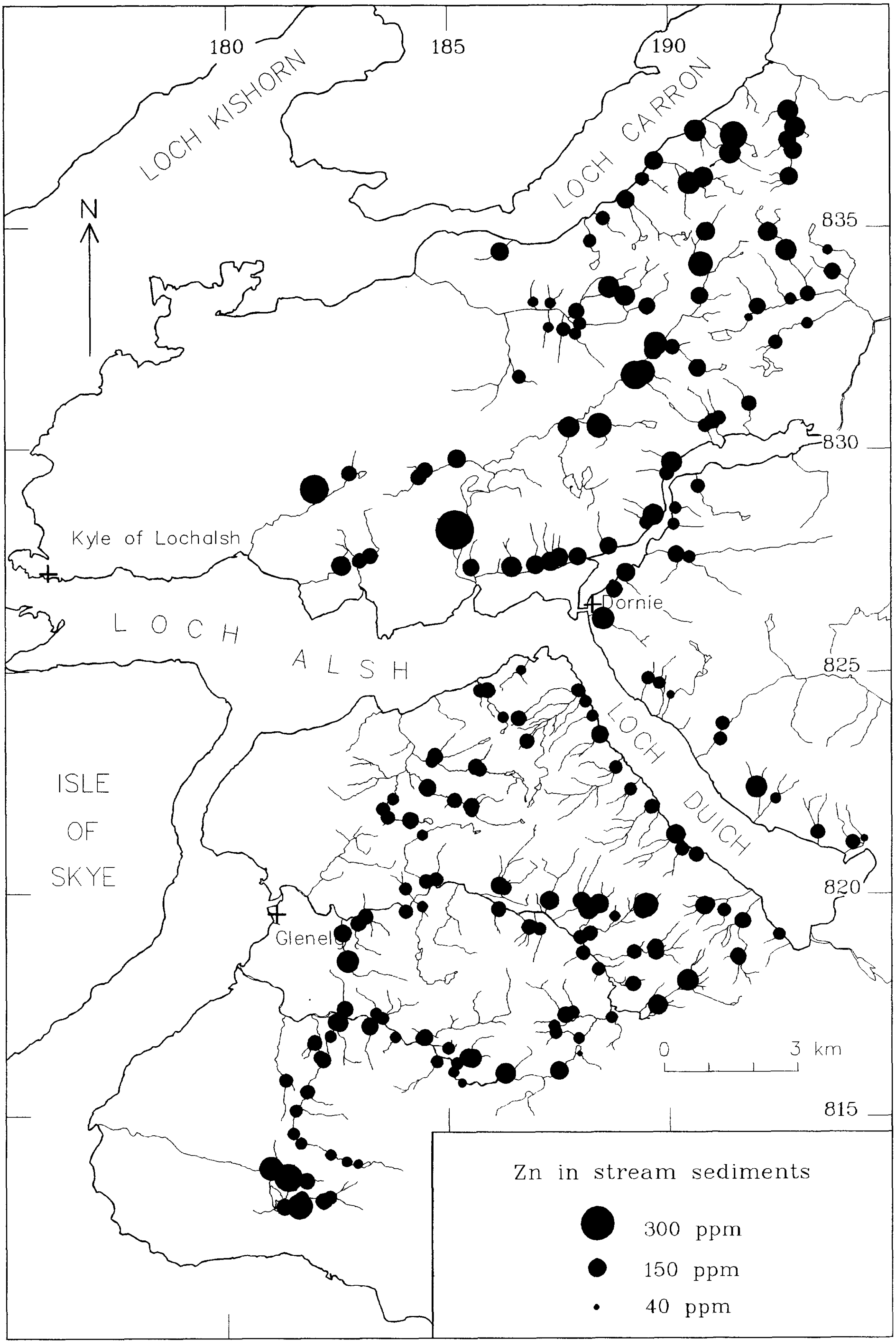

Figure 8 Distribution of zinc in stream sediments

(236 and 202 ppm Zn) from the southernmost samples. These drain the sulphide-rich horizon associated with the Eastern Lewisian marble band and outcropping pyrite-bearing calc-silicate rocks were found in the catchment.

Arsenic

Arsenic shows a distribution which is closely linked to sulphide mineralisation; the element occurs as a separate mineral, arsenopyrite, or as a trace element in pyrite. In the secondary environment As can also occur in iron oxide precipitates. The median abundance of arsenic over the project area is relatively low at 5 ppm, and the maximum value of 54 ppm is also unexceptional. However, most of the samples with greater than 10 ppm As can be related to sulphide mineralisation (Figure 9). The sample with the highest arsenic content was collected from Allt na Dalach Bige at [18659 82394] and this drains the pyrite-bearing graphite gneiss and calc-silicate lithologies associated with the marble bands (Figure 2). Other samples along strike are also anomalous. Two samples from the eastern side of Loch Duich also have elevated arsenic levels. Several samples at the southern end of the marble belt near Loch na Lochain [ca. 1811 8132] have arsenic levels between 11 and 24 ppm. Isolated anomalous values are found in Glen Udalain [18924 83168] and in the Ratagain complex, where the sample, KLC 4324 at [18939 81964] also contains anomalous lead. One of the late veins cutting the Ratagain complex is present at this site (rock sample KLR 4324) and one possible very small grain of gold was observed in the concentrate. Alderton (1988) records electrum and two As-bearing minerals from these veins, tennantite and gersdorffite. Another sample KLC 4336 was collected from a stream draining the Strathconon fault at [19004 81804] and contains 13 ppm As. Pyrite mineralisation was noted in a stream clast of vein quartz from the site and another grain of very fine possible gold observed. From the above observations it is likely that arsenic is a good pathfinder for gold in this metallogenesis.

Zirconium

The variation of zirconium in stream sediments is dominantly controlled by the amount of zircon which, as a resistate mineral, is higher in stream sediments than the crustal average. The median for the project area (378 ppm Zr) is lower than the Great Glen Geochemical Atlas (1060 ppm Zr), because of the lower proportion of Moine rocks, which show higher Zr levels over the psammitic lithologies. Five samples with greater than 900 ppm Zr were collected from streams that drain the Boc Mor Psammite, which occurs at the base of the Moine succession to the east of Loch Duich, and contains zircon-bearing heavy-mineral bands (May et al., 1993). The Ratagain igneous complex, despite its intermediate character, does not appear to be significantly enriched in zirconium, unlike other similar complexes such as Carn Chuinneag (British Geological Survey, 1987).

Niobium

Niobium shows strong correlations with Ti, Zr, Ce, La and V. It occurs dominantly in sphene, which is more abundant in the diorite portions of the Ratagain complex, and in the metabasic rocks in the Lewisian. Niobium also occurs in detrital minerals such as zircon and sphene and has higher levels over the basal Moine rocks.

Molybdenum

This element was only determined in the reconnaissance stage of the investigations. Average levels over the area are relatively high with a median of 5 ppm Mo compared to the Atlas value of 0 ppm. This is partly explained by differing analytical methods but the XRF method employed in this study is generally reliable and free from interference. Similar high values (up to 28 ppm Mo) were found in the Scardroy area (Coats et al., 1993) and it is postulated that the Lewisian is enriched on a regional scale in this element. Molybdenite mineralisation has also been described by Gallagher et al. (1974)

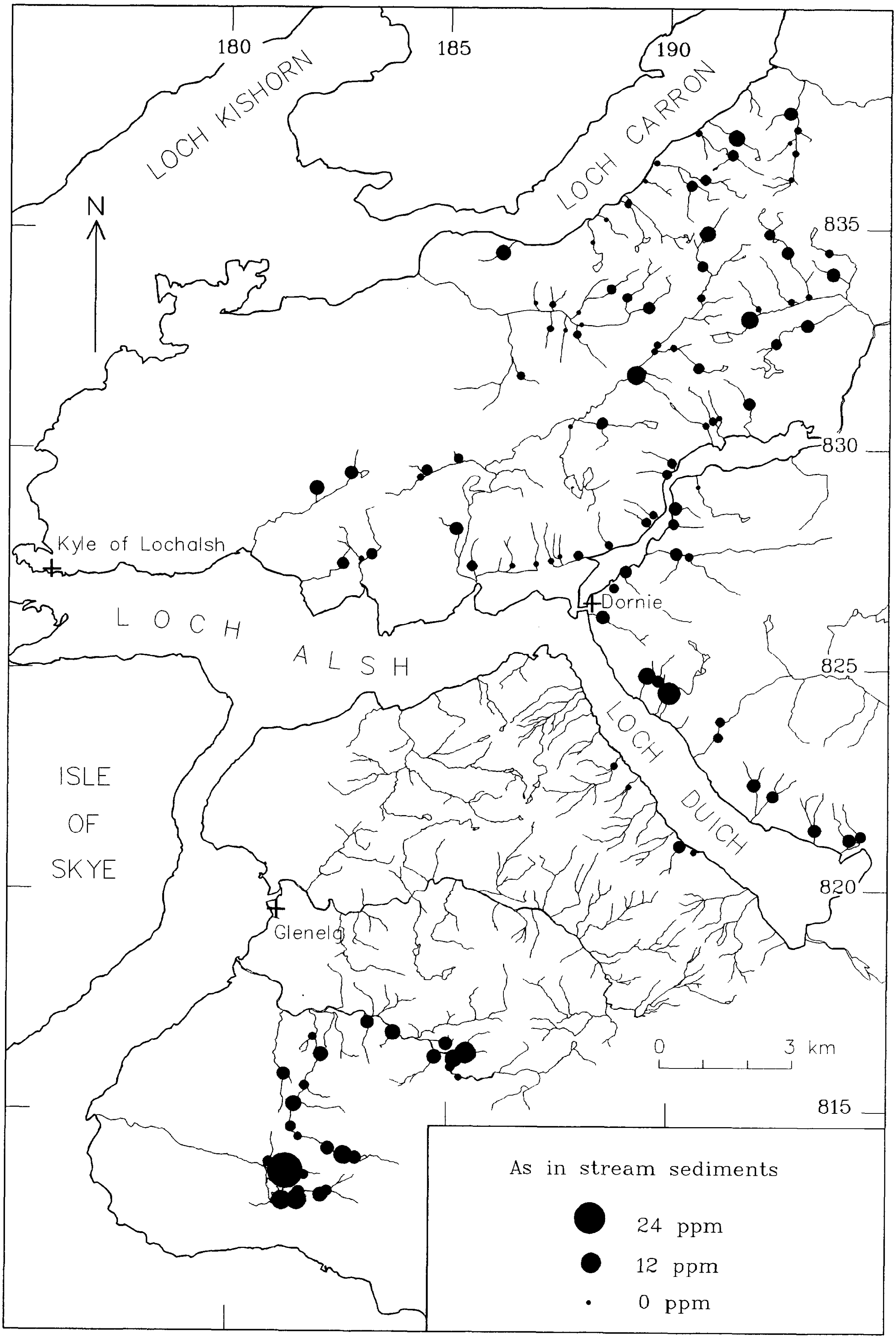

Figure 9 Distribution of arsenic in stream sediments

within thrust slices of Lewisian in the Lairg area. Insufficient samples were collected from the Ratagain complex to ascertain the extent of the observed molybdenite in the quartz veins cutting the quartz monzonite (Alderton, 1988).

Silver

Values of silver in stream sediment are rarely higher than the limit of detection of the analytical method (2-3 ppm) and only the few above this limit are considered. High values appear to be scattered over the northern part of the area (Figure 10) and there may be some correlation with high Au values (Figure 13). However, silver shows too irregular a pattern to be predictive.

Tin

Tin in stream sediments is normally an indicator of contamination and there are no natural tin-bearing sources in the area. The limit of detection is similar to that for silver and values greater that 5 ppm indicate anthropogenic contamination. The sample KLC 3909 on the south shore of Loch Carron [186194 83444] shows the highest level 15 ppm Sn and metallic contamination is recorded at the site.

Antimony

Antimony does not reach very high levels in the stream sediments from this area, with the peak value being 6 ppm. The element is dominantly chalcophile in character in primary rock sources but in the secondary environment it can be scavenged by secondary Mn and Fe oxides. The latter behaviour is probably the reason for most of the slightly elevated values (4 - 6 ppm Sb) but a primary source in pyrite-bearing Lewisian hornblende gneisses is also a factor in the distribution.

Barium

Barium occurs mainly in alkali feldspar and mica, and the levels in metabasic rocks are relatively low. Over the Lewisian barium levels are generally within the background range (400-700 ppm) (Figure 11) but increase to greater than 1000 ppm over most of the Ratagain intrusion, the syenitic phases of which contain up to 6000 ppm Ba (May et al., 1993). This is probably mainly present in alkali feldspar but baryte may also be a minor constituent, as celestite ($SrSO_4$) is a common accessory mineral. Alderton (1988) does not record baryte in the paragenesis of the quartz veins cutting the complex but does identify baryte crystals within the fluid inclusions. The one anomalous stream sediment sample outside the Ratagain intrusion at [18516 82819] contains 2623 ppm Ba, a level which would normally indicate baryte mineralisation. However, this sample contains 3.2 % Mn, and heavy black staining of the stream clasts was noted. It is therefore likely that the precipitation of hydrous Mn oxides has scavenged barium. This is confirmed by the low content of barium in the panned concentrate sample from the same site.

Lanthanum and cerium

These rare-earth elements can be considered together because they have similar geochemical properties in stream sediments (Spearman rank correlation coefficient of 0.85). Only the reconnaissance samples were analysed for these elements, but they show a pattern of high values over the eastern margin of the area and in the few samples collected from the Ratagain intrusion (Figures 12 and 13). Higher values >85 ppm La and >150 ppm Ce are restricted to two sites on either side of Loch Duich; one derived from the Ratagain intrusion and the other from the Moine Boc Mor Psammite. The presence of heavy mineral bands in this unit has already been noted (May et al., 1993).

Gold

Gold varies from 0 to 41 ppb in the 98 samples analysed. A population break occurs at 10 ppb Au, and samples above this level occur north of Loch Alsh and in the north-east part of the area (Figure 14).

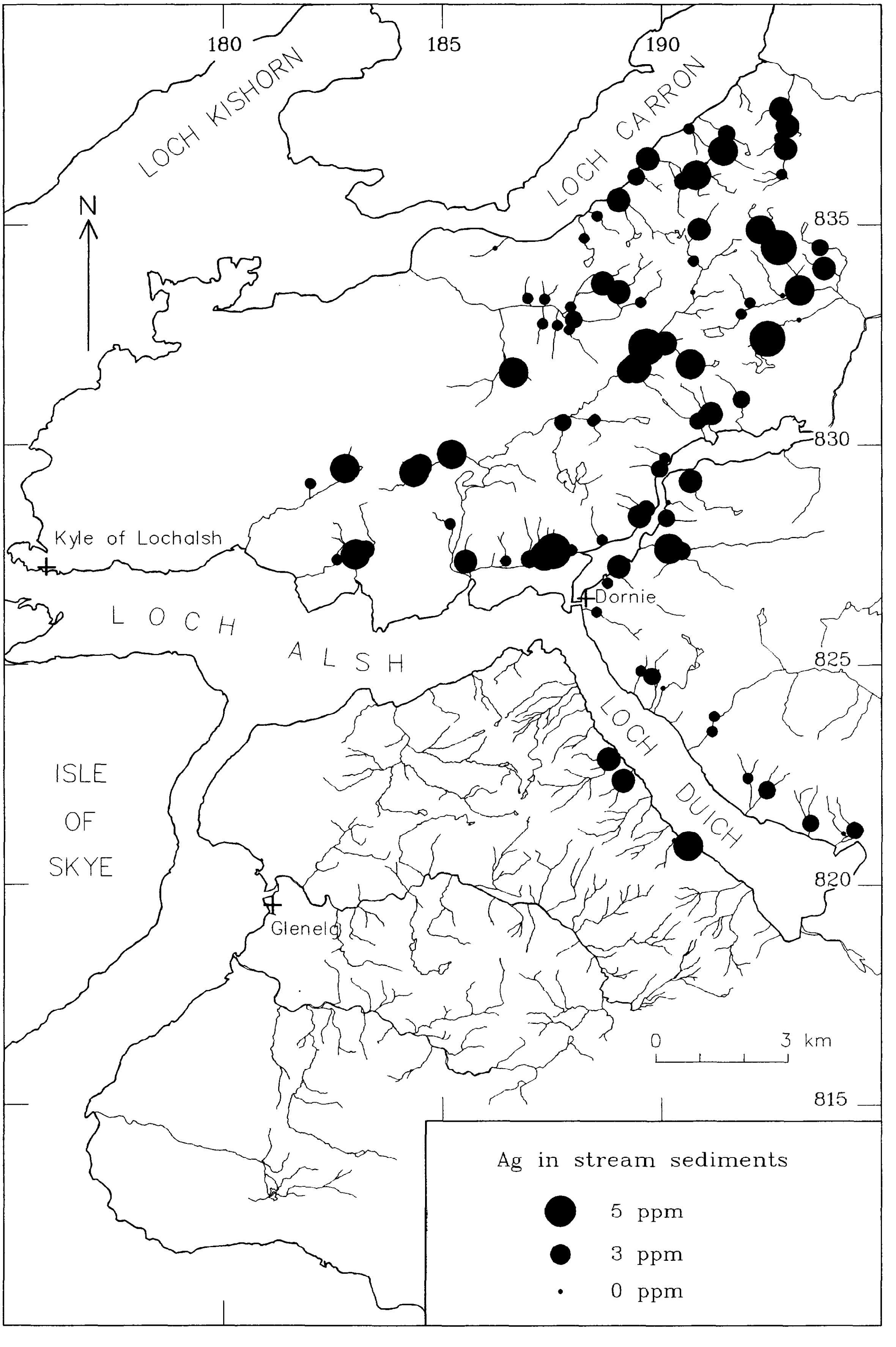

Figure 10 Distribution of silver in stream sediments

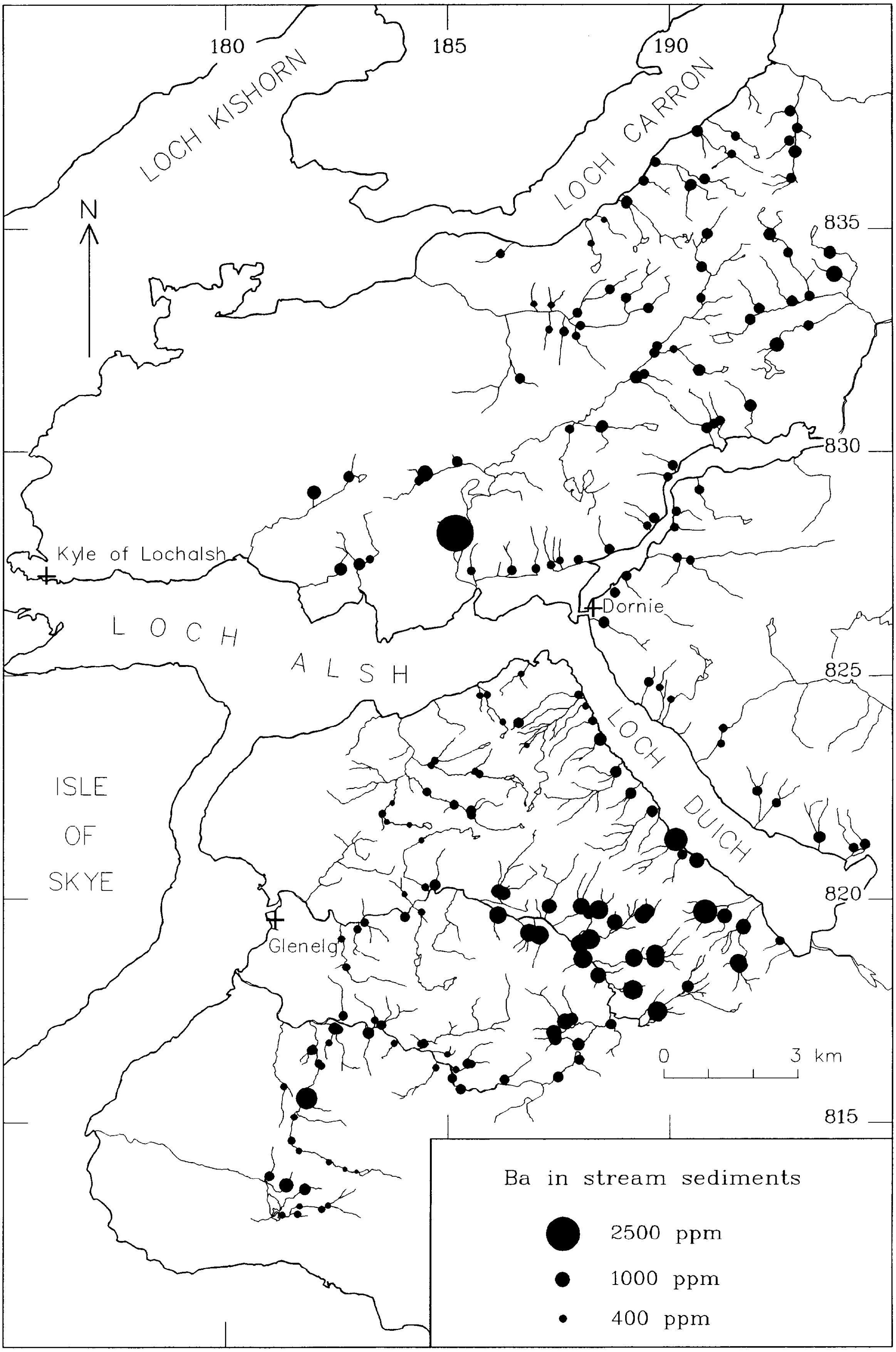

Figure 11 Distribution of barium in stream sediments

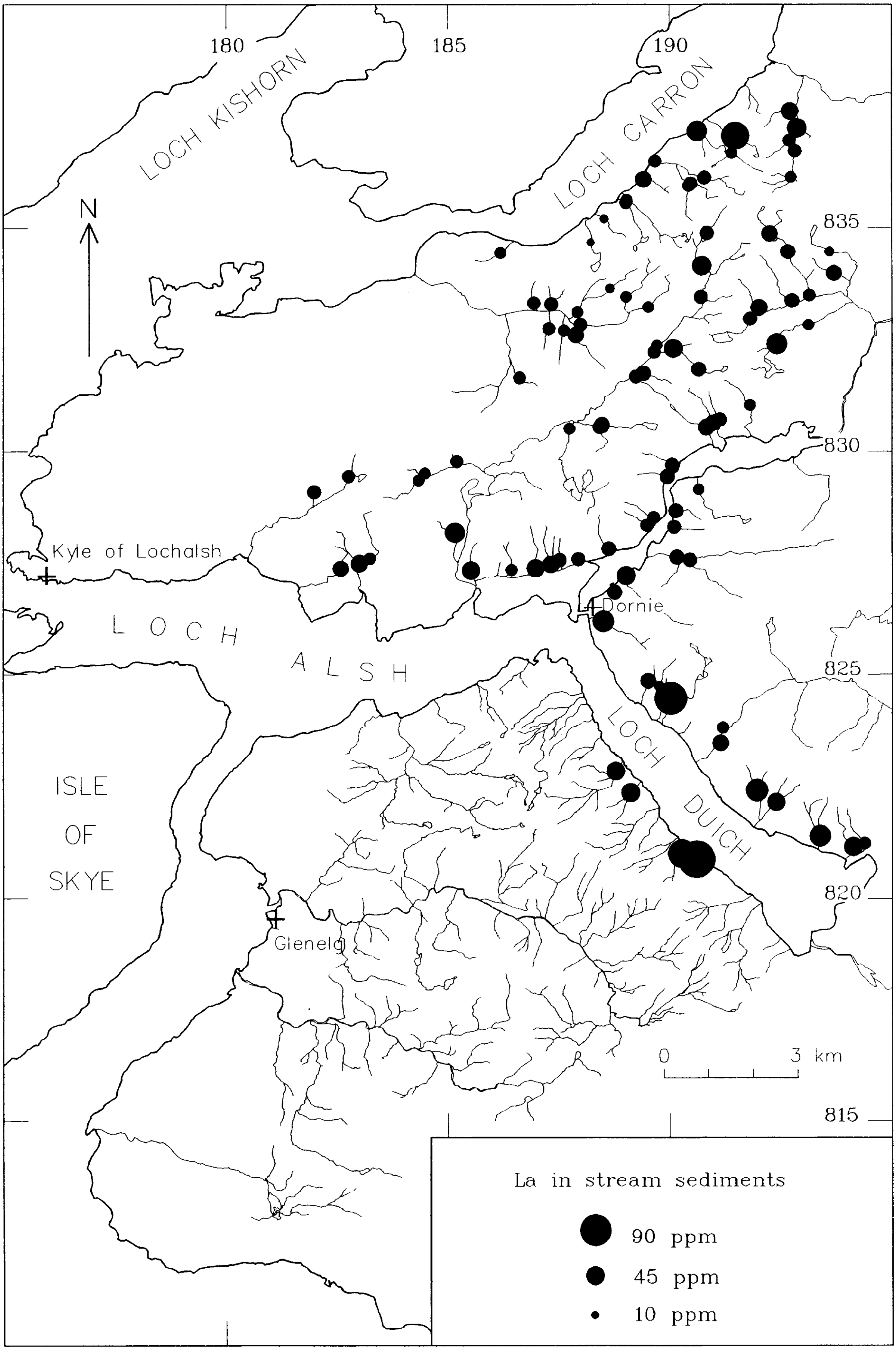

Figure 12 Distribution of lanthanum in stream sediments

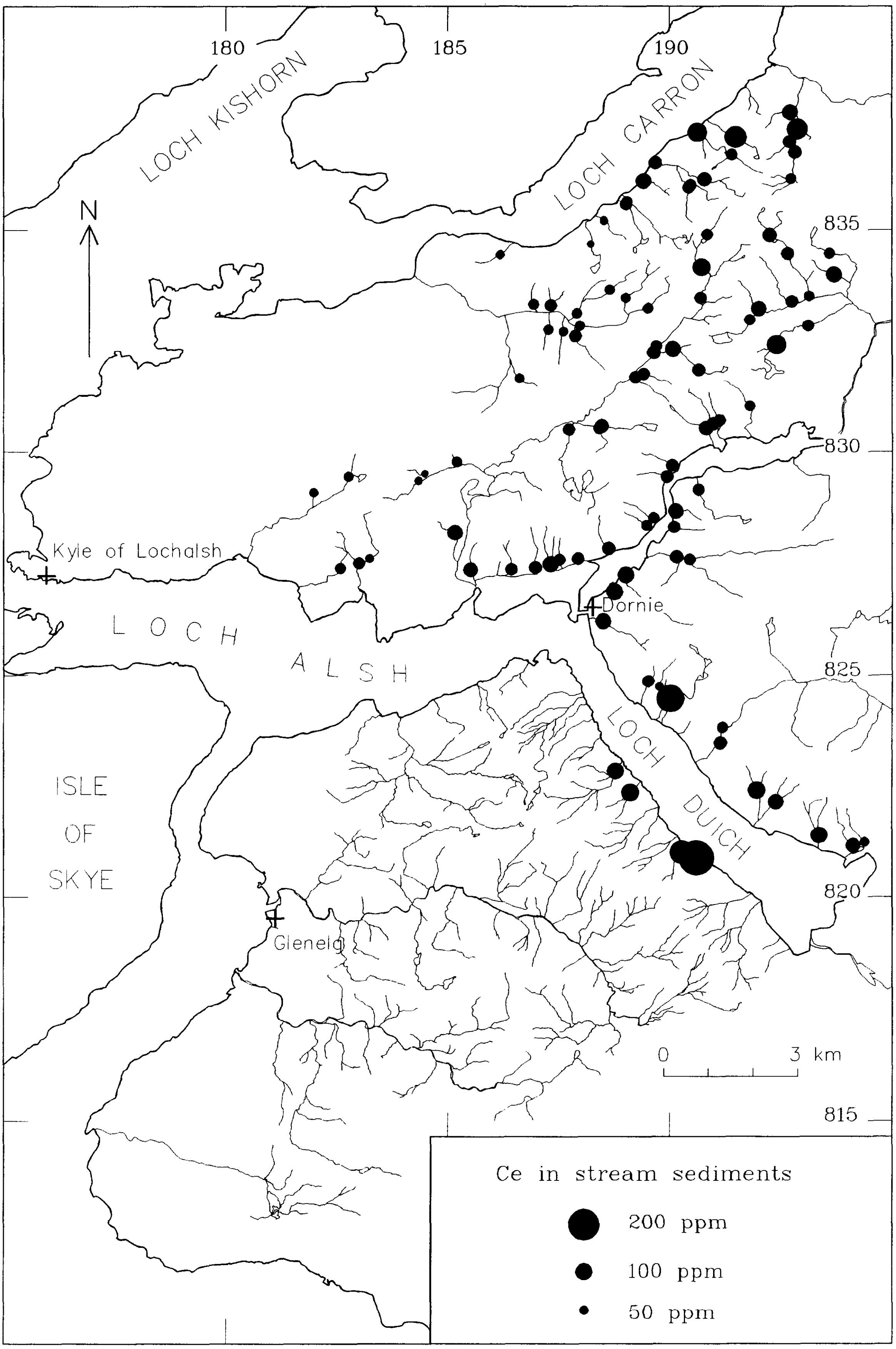

Figure 13 Distribution of cerium in stream sediments

The highest value, 41 ppb Au, was found in sample KLC 3919, just west of Auchtertyre at [18300 82750], and sample KLC 3915 from an adjacent stream is also anomalous in Au (14 ppb) and Pb (50 ppm). Both sites also show anomalous barium (and slightly anomalous arsenic) in panned concentrates, indicating baryte vein mineralisation in the catchment, accompanied by minor galena and arsenical pyrite. Gold may be associated with the Moine Thrust which runs through this part of the area (Figure 2), and another anomalous sample, KLC 3867 [18792 83312] (16ppb Au) also occurs on the Moine Thrust and shows anomalous barium in the panned concentrate. Further north, minor Au anomalies occur in the Western Lewisian and seem to be related to the outcrops of the hornblende gneisses which are often pyritiferous. A few samples on the eastern margin of the sampled area are slightly anomalous, such as those near Inverinate [ca. 194 821], and as the high La and Ce in these samples can be related to heavy mineral bands in the Boc Mor Psammite a similar source is proposed for the gold.

Lead

The median level of lead, 17 ppm, is relatively low, and most of the high-grade metamorphic rocks in the Glenelg area have backgound values of less than 20 ppm (Figure 15). Values over the Western Lewisian and Moine are slightly higher. During igneous differentiation lead increases from the more basic through to the later, more differentiated acid phases. However, during the last magmatic phase lead may become concentrated in the residual hydrothermal fluids and be deposited in ore minerals. This is shown in the Ratagain complex (Figure 15), where stream sediments collected over the quartz monzonite have high values of lead. Most of these high values are probably related to late veining, with galena being recorded in many of the veins (Alderton, 1988, and Nicholls, 1951). Other anomalous Pb values are found in sample KLC 3915 collected from [18258 82739] near Auchtertyre, which has been discussed above in the gold section, and KLC 3909 from [18619 83445] near Stromeferry. The latter sample is contaminated, as shown by its high contents of metallic elements such as Cu, Sn, Sb and Pb.

Bismuth

Only the reconnaissance samples were analysed for bismuth and no sample exceeds 1 ppm. The XRF method is either too insensitive to pick up significant variation or no bismuth-containing mineralisation is present in the area. Alderton (1988) records aikinite ($CuPbBiS_3$) and galena containing up to 3 % Bi in the veins from the Ratagain complex.

Thorium and uranium

These elements are strongly correlated (Spearman rank correlation coefficient of 0.36) and are considered together. Thorium levels are low with a maximum of only 14 ppm Th, but uranium has more anomalous values up to 28 ppm. The high values are all on the eastern margin of the sampled area, particularly in the streams east of Inverinate [ca 194 821]. These samples have high contents of zirconium and a similar origin for the uranium and thorium in heavy-mineral bands contained within the basal Boc Mor Psammite is likely. One sample, KLC 3925 collected from over the Ratagain intrusion at [19060 82088], has high Th (14 ppm) relative to U (7 ppm) and thorium is probably present in one of the accessory minerals, such as sphene, orthite or zircon.

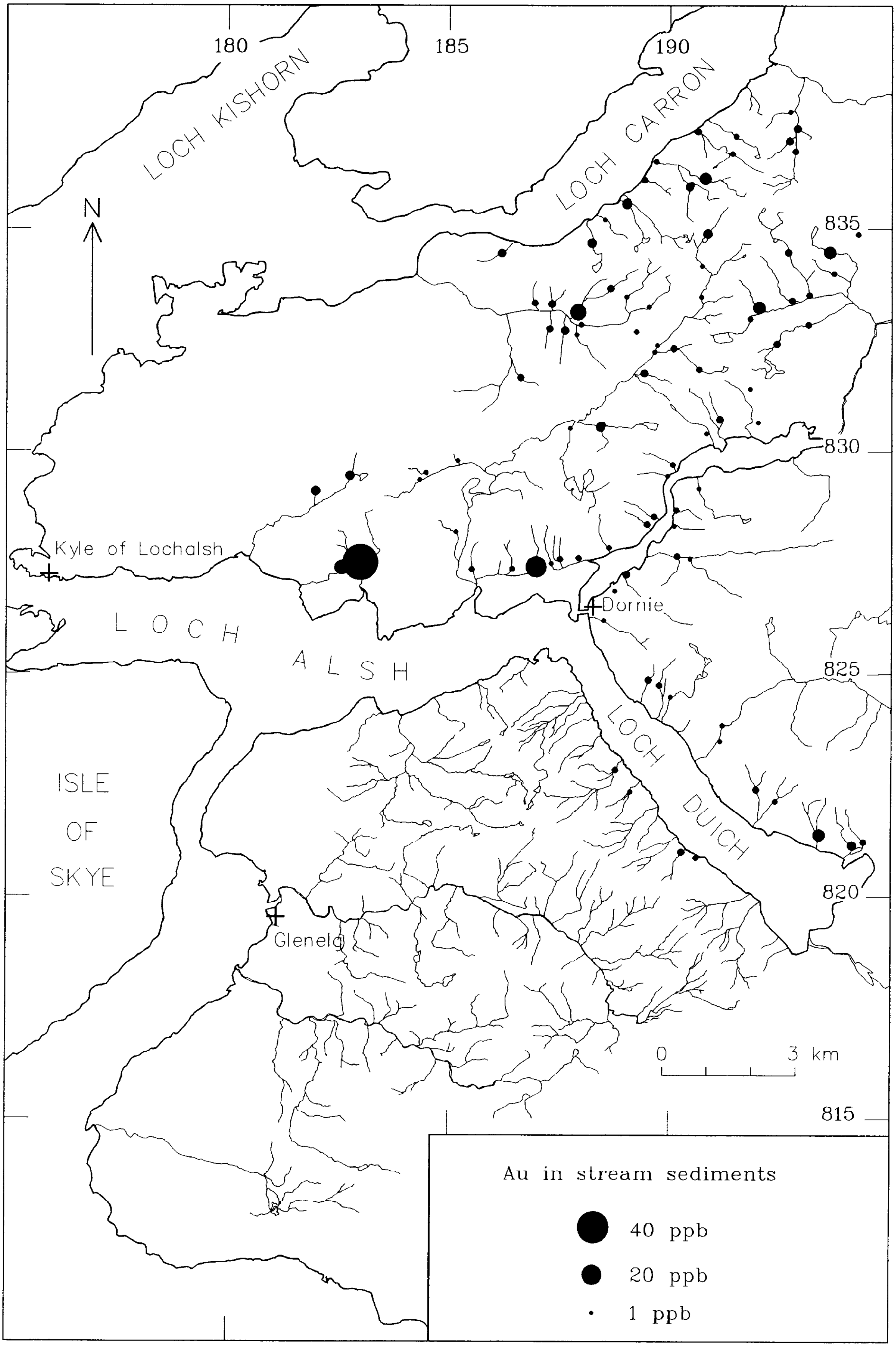

Figure 14 Distribution of gold in stream sediments

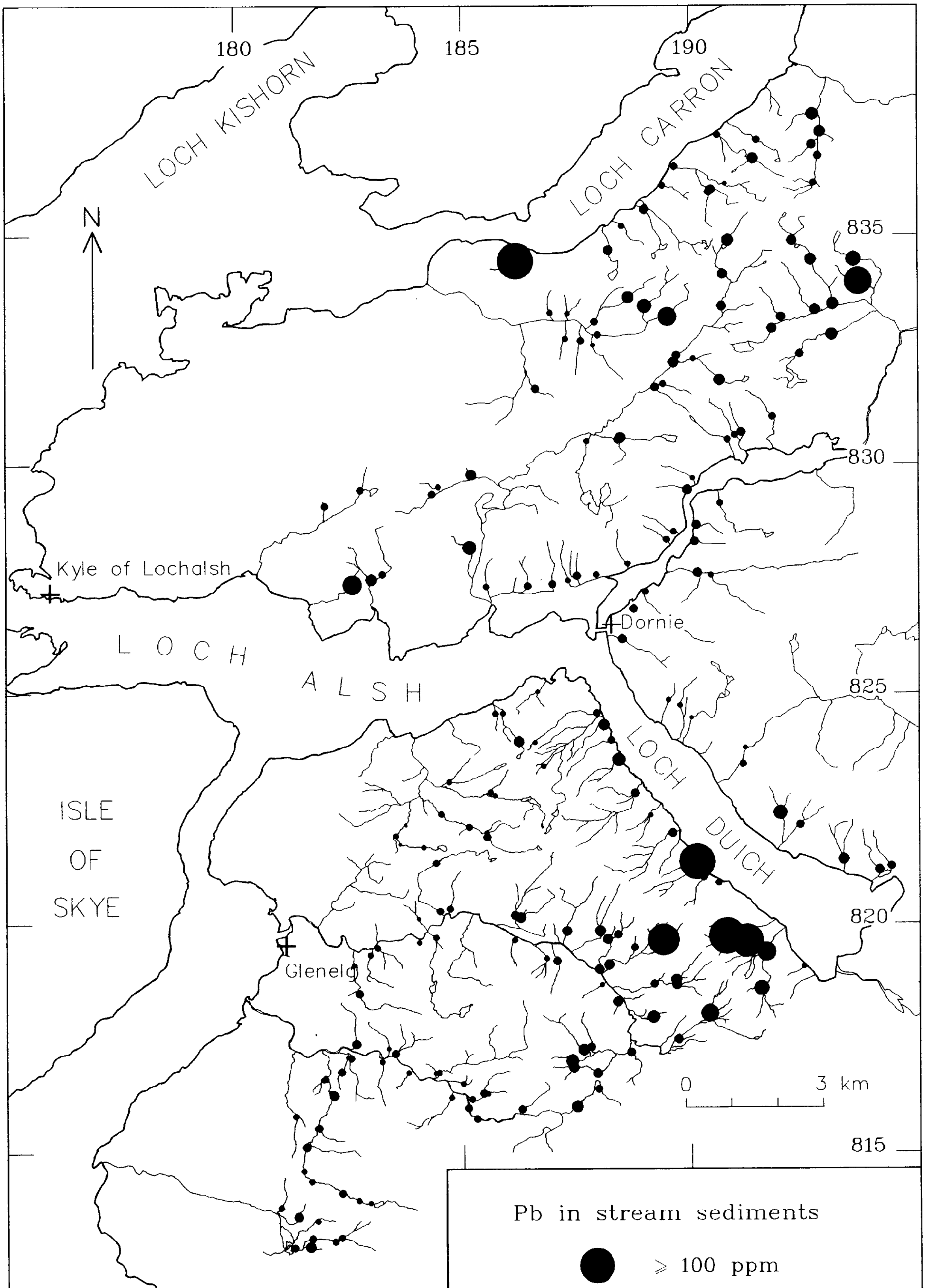

Figure 15 Distribution of lead in stream sediments

Panned concentrates

A summary of the analytical results for the panned concentrates is given in Table 3.

Titanium

The distribution of titanium in panned concentrates is controlled primarily by bedrock lithology, with the highest levels recorded over relict high-grade assemblages in the Western and Eastern Lewisian and over appinite-pyroxenite intrusions in the Ratagain complex (Figure 16). Lower levels characterise the dominantly quartzo-feldspathic lithologies of the Moine and the eastern quartz monzonite phase of the Ratagain complex. Over much of the Lewisian the variation of titanium can be broadly correlated with the proportion of heavy detrital minerals such as ilmenite and magnetite recorded in panned concentrates. Hornblende, especially when present as a major constituent of retrogressed gneisses, is also enriched in titanium. Consequently some of the panned concentrates from the Western Lewisian, estimated to contain up to 50 % hornblende, are particularly high in titanium. One of the most anomalous areas is the Allt Gleann Udalain catchment, where the high observed frequency of basic (camptonite-monchiquite) Permo-Carboniferous dykes may be a contributory factor (May et al., 1993). Average TiO_2 values of 3 % have been recorded for monchiquites from the western Highlands (Rock, 1983) and the second highest value in the present dataset of 2.3 % Ti was recorded only a short distance downstream of a camptonite dyke (KLP3872) [189420 831750].

In the Eastern Lewisian, elevated values of Ti ranging from 1 to >2 % are common in the area between Totaig and Glenmore [1875 8253] and [1846 8203], coincident with the north-north-east-trending zone of eclogites (Alderman, 1936). Detailed studies of the least retrogressed varieties of eclogite (Sanders, 1972) revealed maximum TiO_2 values of 3.31 % largely located in rutile. Retrogression results in loss of rutile and a concomitant increase in ilmenite and sphene, thus reducing the economic potential of these rocks (G E Norton, personal communication). On the southern shore of Loch Duich three very high values of titanium, including the highest of the dataset (2.6 %), are associated with variably high levels of V, Co, Ni, Cu, Ba, W, and Ag. Ultrabasic rocks are present in the catchment and provide a likely source for the enrichment.

Chromium

The variation of chromium in panned concentrates reflects the distribution of basic and ultrabasic rocks in the Lewisian inlier and the appinite-pyroxenite intrusions in the south-west part of the Ratagain complex. No data is available for the Lewisian or Moine rocks north of Loch Duich. Generally high values, derived from the Western Lewisian and the Ratagain complex on the south side of the loch, emphasise the dominant influence of basic lithologies, especially in the area south-west of Totaig [1875 8253], where the proportion of eclogite is notably higher than elsewhere in the inlier. In this zone the highest chromium value of the dataset, 890 ppm Cr in KLP 4392 at [186780 823430], is clearly related to one of the largest mapped ultrabasic bodies in the area. Unusually, chromium does not display a high degree of correlation with other elements of basic affinity, although iron is closely related to high chromium over much of the metasedimentary belt. This may reflect an enrichment of chromium in the magnetite and graphite-bearing pelitic gneiss, and May et al. (1993) also note that enrichment in chromium distinguishes the Lewisian from both Moine and Dalradian with similar mineral assemblages.

Over the Ratagain complex chromium shows increased levels of concentration over the hornblende diorite, appinites, and proxenite intrusions. Strong correlation with high nickel suggests that mafic silicates rather than spinels are the principal Cr-bearing phases.

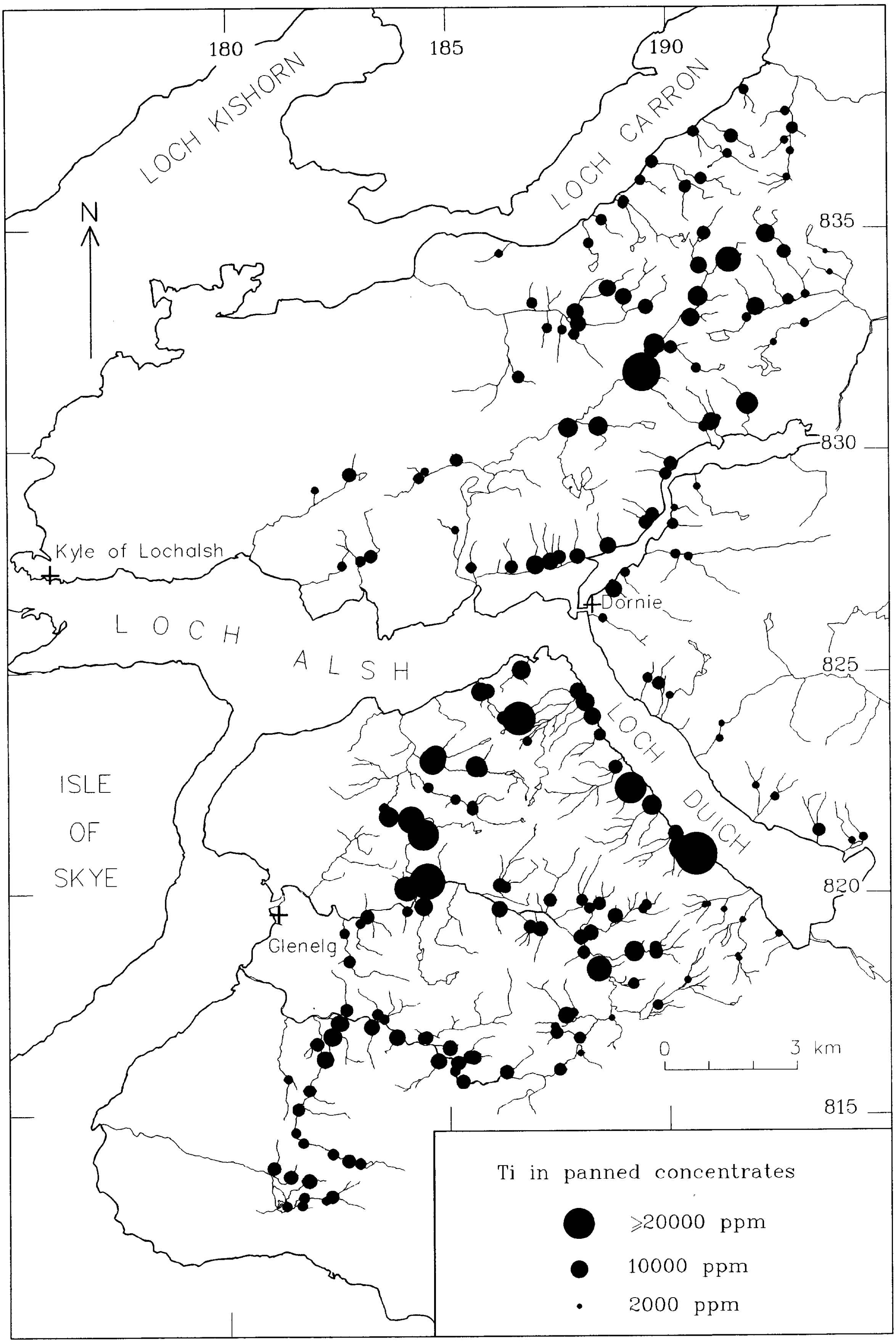

Figure 16 Distribution of titanium in panned concentrates

Table 3 Summary statistics for panned concentrate samples from the Glenelg area								
	N	Median	25 th percentile	75 th percentile	Mean	Standard deviation	Maximum	Minimum
Ca	211	40200	31800	51000	40513	15692	86200	4800
Ti	211	6650	4920	8580	7241	3654	26040	1870
V	98	135	102	168	139	61	413	27
Cr	113	202	141	282	223	139	890	14
Mn	211	2300	1650	3240	2669	1714	14210	480
Fe	211	80900	63300	100400	85066	34290	193100	14600
Co	98	29	18	40	38	33	194	5
Ni	211	47	32	66	55	37	241	2
Cu	211	21	12	35	27	24	201	3
Zn	211	66	52	83	68	21	118	16
As	67	0	0	1	0.9	1.8	9	0
Y	98	60	38	103	87	72	346	9
Zr	98	780	513	1220	945	661	3734	184
Nb	98	10	8	12	11	4	31	5
Ag	98	4	2	5	4	2	10	0
Sn	98	1	0	2	5	37	369	0
Sb	98	0	0	1	1	2	19	0
Ba	211	340	239	538	538	550	3726	101
La	98	31	25	40	33	13	85	8
Ce	98	63	50	86	70	32	178	15
W	67	2	0	4	3	5	25	0
Au (ppb)	196	2	1	3	32	394	5530	0
Pb	211	10	6	14	16	62	859	0
Bi	67	0	0	1	0.4	0.7	3	0
Th	98	7	5	9	8	5	45	0
U	98	1	0	2	1.4	2.1	15	0

All values in ppm, except Au in ppb

Manganese

The distribution of manganese in panned concentrates is dominated by the presence of garnet, which is widespread and abundant throughout the Lewisian inlier and the Moine metasediments. Average concentrations are higher in the Western than the Eastern Lewisian, probably reflecting the increased abundance of garnet amphibolite in the former. Detrital Fe oxides and Fe-Mn silicates minerals, such as pyroxmangite, rhodonite and manganiferous garnet, are locally abundant in eulysite and related grunerite-magnetite schists of the Eastern Lewisian (Tilley, 1937). These rocks give rise to increased levels of manganese but only background values of Y, in contrast to metabasites and Moine metasediments in which strong manganese enrichment is invariably accompanied by very high Y (e.g. over the Boc Mor Psammite at the head of Loch Duich). On the south shore of Loch Duich at [198120 822359] sample KLP 3923 has the highest value of 1.42 % Mn, but only Y (72 ppm), Fe, Cu and Ag are also anomalous, suggesting the presence of eulysite and sulphide mineralisation in proximity to a small outcrop of marble in this stream. Minor enrichment in manganese is evident over much of the paragneiss belt, the marked correlation with high iron and copper values suggesting that the pre-metamorphic sediments were enriched in this suite of elements. On the south side of Glen Beag sample KLP 4829 with 0.82 % Mn is conspicuously richer in manganese than other sites in this catchment, and the presence of unmapped eulysites is inferred.

Iron

The distribution of iron in panned concentrates is quite distinct from that in stream sediments. The dispersion pattern is strongly inflenced by detrital minerals derived from a wide variety of source rocks, including metabasite in the Western Lewisian and garnet kyanite gneiss, magnetite-bearing pelite, eulysite and eclogite in the Eastern Lewisian. Iron, along with V, Cr, Ti, and Ni, is considered to be relatively immobile in high-grade metamorphic processes, and regional-scale enrichment of iron (median = 8.1 %) is therefore apparent over the whole of the inlier relative to Moine metasediments in the orogen and igneous rocks of the Ratagain complex (Great Glen Geochemical Atlas, British Geological Survey, 1987).

Variations within the Western Lewisian can generally be correlated with the proportion of garnet, magnetite and hornblende recovered in the pan, the higher values occurring just west of Loch Long [190058 829699]. In the Eastern Lewisian a broad zone of high iron values can be traced south-west from the northern shore of Loch Duich, roughly coincident with the broad belt of metasedimentary rocks. Near Carr Brae, the eulysite is clearly identified by two samples containing up to 14.56 % Fe, up to 0.75 % Mn and slightly anomalous Cu and Co. A similar association occurs south-west of Totaig in sample KLP 3923 at [189120 822359], but is developed most prominently in Glen Beag in proximity to the marble and the main eulysite outcrop. In many of the anomalous samples high concentrations of magnetite and garnet were recorded, the source of which may include Fe-rich kyanite gneisses and eclogites (with 30-40 % almandine; Alderman, 1936), in addition to eulysite and magnetite schists.

At the extreme eastern margin of the project area just west of the Sgurr Beag slide, a group of four very high iron values, up to 19.3 % Fe at [194120 821160], corresponds to particularly strong enrichment of Y and Mn over the psammites of the basal Morar Division of the Moine. Compared with more pelitic formations, the Ben Killalan and Boc Mor Psammites are not especially enriched in garnet. However, garnet was estimated in the field to comprise up to 60 % of the concentrate and is the principal cause of the Fe, Mn and Y anomalies. Heavy-mineral laminae are fairly common in psammites of the Morar Division and are known to contain high concentrations of garnet, Fe-oxides and other placer minerals (May et al., 1993).

Cobalt

Cobalt levels in panned concentrates are closely related to lithology, the highest values (>45 ppm) occurring mainly over metabasic rocks in the Western Lewisian. The quartz-monzonite member of the Ratagain complex is characterised by lower cobalt levels. High correlations between Co and Ni, Cu, Ca, V, Ti and Zn confirm the significance of basic rocks in the Western Lewisian, particularly in Gleann Udalain [189420 831750] and the streams draining northwards from Carn nan Iomairean [189040 835620]. Anomalous cobalt values with increased concentrations of a suite of metalliferous elements including Cu, Ni, Zn, Au, and Ba occur in a north-east-trending zone along the south-east side of Loch Carron near the basal Moine - Lewisian junction. Maximum concentrations of cobalt for the entire project area of 194 ppm [188230 834680] and 188 ppm [192860 837250] are recorded here. The presence of abundant pyrite in panned concentrates from this area provides further evidence of mineralisation associated with tectonised Lewisian metabasites.

Near Carr Brae [190020 824470] and also on the opposite shore of Loch Duich, high Co values (91 and 102 ppm respectively) correspond to enhanced copper and iron and, in the former sample, to abundant pyrite in calc-silicate clasts. Both stream sites are located just downstream of marble outcrops.

Nickel

High nickel levels occur sporadically over much of the Lewisian, reflecting the distribution of the larger metabasic bodies in the Western Lewisian (Figure 17). Nickel anomalies are frequently related to increased levels of Cu, Zn, Co and, to a lesser extent, Fe, Ti, and Nb. Abundant hornblende, which is the principal Ni-bearing mineral of retrogressed gneisses (Beach and Tarney, 1978), was identified in many of the samples with high nickel levels. However, pyrite and pyrrhotite also concentrate Ni, Cu, Co and Zn and were recorded from the larger amphibolite bodies. Sulphides may therefore account for the high combined Ni, Co, Cu and Zn at sample site KLP 3906 [192650 834470]. It is notable that elements of mafic association such as Ca, Ti and V, not normally concentrated in sulphides, are only at background levels in this sample. A second group of anomalous nickel values extends north-east over the tectonised Lewisian-Moine boundary parallel with the south-east shore of Loch Carron. Copper, Au, Ag and Ba are variably associated with the high nickel and with abundant pyrite in rock clasts and in the heavy mineral assemblage. The highest nickel value in panned concentrates of 241 ppm at [18552 82735] also corresponds to the highest stream sediment value (363 ppm Ni) in this area. All of the anomalous streams intersect the strongly tectonised Moine-Lewisian unconformity, which may represent a favourable environment for the circulation of mineralising fluids.

Basic-ultrabasic dykes of Scourian to Tertiary age are common in the Western Lewisian and may, in the case of picritic compositions, contain > 2000 ppm Ni (Weaver and Tarney, 1981). In the extreme north of the project area the composition of sample KLP 3918 at [192860 837250] with 158 ppm Ni and 188 ppm Co may be influenced by the presence of a lamprophyre dyke which follows the stream course.

Within the Eastern Lewisian, moderately anomalous Ni values (50 - 102 ppm) are associated with Cu and Fe over metasediments. Maximum values are recorded from the streams draining the Lewisian marble, calc-silicate rocks and sulphidic graphite gneiss from Loch Duich to the southern limit of the area. For example, in Allt Tollaidh [185712 822790], 103 ppm Ni is accompanied by 160 ppm Cu together with elevated Fe just downstream of the marble outcrop. On the south shore of Loch Duich, close to the western margin of the Ratagain complex at [190273 821006], 100 ppm Ni with anomalous Cu, Co and W occurs close to small ultrabasic and marble outcrops.

Over the amphibole-rich basic facies in the southern part of the Ratagain complex, high nickel values form a distinctive cluster associated with high chromium, but very low copper (cf. the Lewisian marble horizon which has high Ni and Cu). Individual nickel values of up to 209 ppm are associated with the largest appinite intrusion in the Suardalan area [187800 817310], and also the least evolved member of the complex represented by olivine gabbro near Braeside [187060 819190]. May et al. (1993) and Alderton (1988) report very similar whole-rock values for these lithologies. Mafic silicates constitute up to 90 % modal abundance of these rocks and are undoubtedly the principal source of Ni, although Aucott and Collingborn (1971) determined 0.9 % Ni at the margins of pyrite grains in veins from the complex.

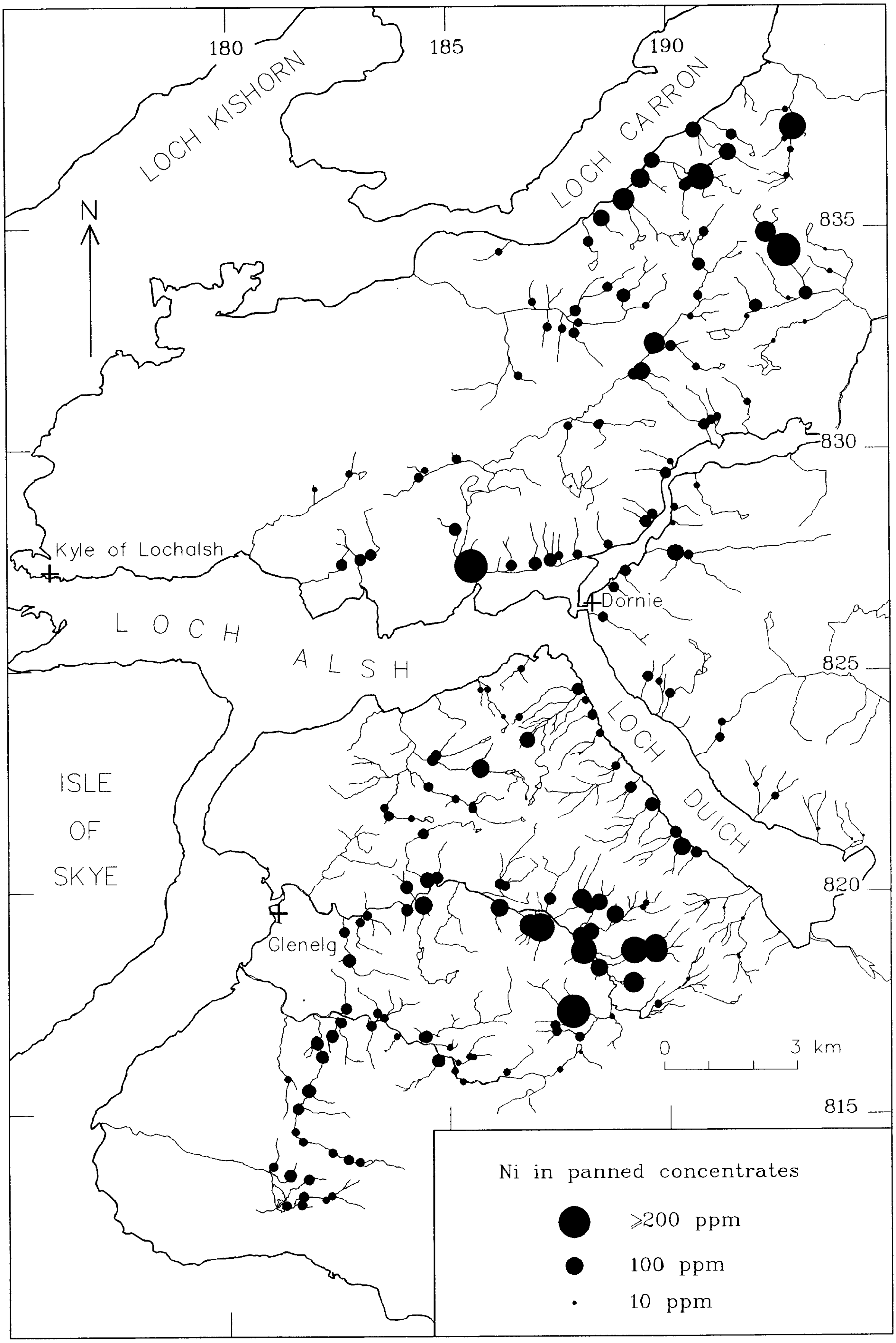

Figure 17 Distribution of nickel in panned concentrates

Copper

High Cu values in panned concentrates show a close relationship with occurrences of basic rocks in the Western Lewisian, and the outcrop of metasediments in the Eastern Lewisian (Figure 18). A conspicuous zone of high values occurs along the south-east side of Loch Carron near the tectonised Lewisian-Moine junction. In this area, pyrite is present as irregular streaks and clots in semipelitic clasts at sample site KLP 3877 [189040 835620]. The same site also yielded the highest copper value (201 ppm) of the project area, together with enrichment in Au, Ag, Ba, Ni, and Co. This element assemblage and the relatively low tenor of the anomalies suggest the possibility of minor sulphide and baryte mineralisation. There are several large metabasite bodies occupying much of the higher ground in the anomalous catchments, and the copper and other metals may be associated with them rather than mineralisation near the unconformity. To the south of this area, on the north side of Loch Alsh, high Cu, Ba, Au, Pb and As in samples from the Western Lewisian close to the Moine Thrust (KLP 3915, 3917 and 3919) probably reflect mineralisation as described in the section on stream sediment geochemistry.

In the Eastern Lewisian, a clear spatial relationship is evident between high copper values, in the range 40 - 60 ppm, and the outcrop of the marble, calc-silicate rock and graphitic gneiss. The anomalous zone extends from Carr Brae on the north side of Loch Duich to Loch na Lochain at the southern limit of the project area. Copper probably occurs as inclusions of chalcopyrite in pyrite, which is commonly observed as coarse cubes, up to 1.5 mm across, in panned concentrates and in outcrop. However, chalcopyrite has been noted in garnetiferous rocks (KLR 4706 with 0.29 %Cu) accompanying the eulysite in Glen Beag and is present as an accessory mineral in the calc-silicate rocks. May et al. (1993) reported a high Cu value of 245 ppm for a sample of marble from Allt a' Mhuilinn [19011 82458], although other samples of the same lithology yielded values below detection.

Copper mineralisation is also inferred by the presence of particularly high Cu values in panned concentrates: one sample containing 152 ppm Cu with high W (21 ppm), Co (102 ppm), Ti (1.5 %) and Ni (100 ppm) from a stream near the south shore of Loch Duich and a second with 160 ppm Cu with high Ni (103 ppm) from Allt Tollaidh [185712 822790]. Both sample sites are near marble and ultrabasic outcrops, and the former is close to the eastern margin of the Ratagain complex. A stream sediment from this site also contained highly anomalous Cu.

At the western margin of the Eastern Lewisian, a tributary of the River Glennan [190452 827586] contains high copper associated with barium. Abundant pyrite was noted in the concentrate, which was collected close to a major east-west-trending fault with localised intense brecciation and hematite-carbonate veining.

Zinc

Zinc in panned concentrates shows only a very limited range of variation, from 16 to 142 ppm, and low median abundance (68 ppm). The highest values occur almost exclusively over the Western Lewisian (Figure 19), where they are clearly associated with metabasites in the upper reaches of Allt Gleann Udalain [ca. 1895 8320] and in streams draining the north western flanks of Carn nan Iomairean [ca. 1911 8356]. In several concentrate samples from this area, pyrite was observed to be present in relatively coarse cubes, and was sometimes identified in stream clasts and locally outcropping amphibolite. For example, sample KLP 3868 [189710 832380] containing 116 ppm Zn was collected in Allt Gleann Udalain, 50 m downstream of a gossanous outcrop of pyrite-bearing amphibolite. The strong correlation of Zn with Ti, V, Cr, Co, Ni, and Nb is particularly evident over the Western Lewisian, suggesting concentration in Fe-Ti oxides, Cr- spinels and mafic silicates. There

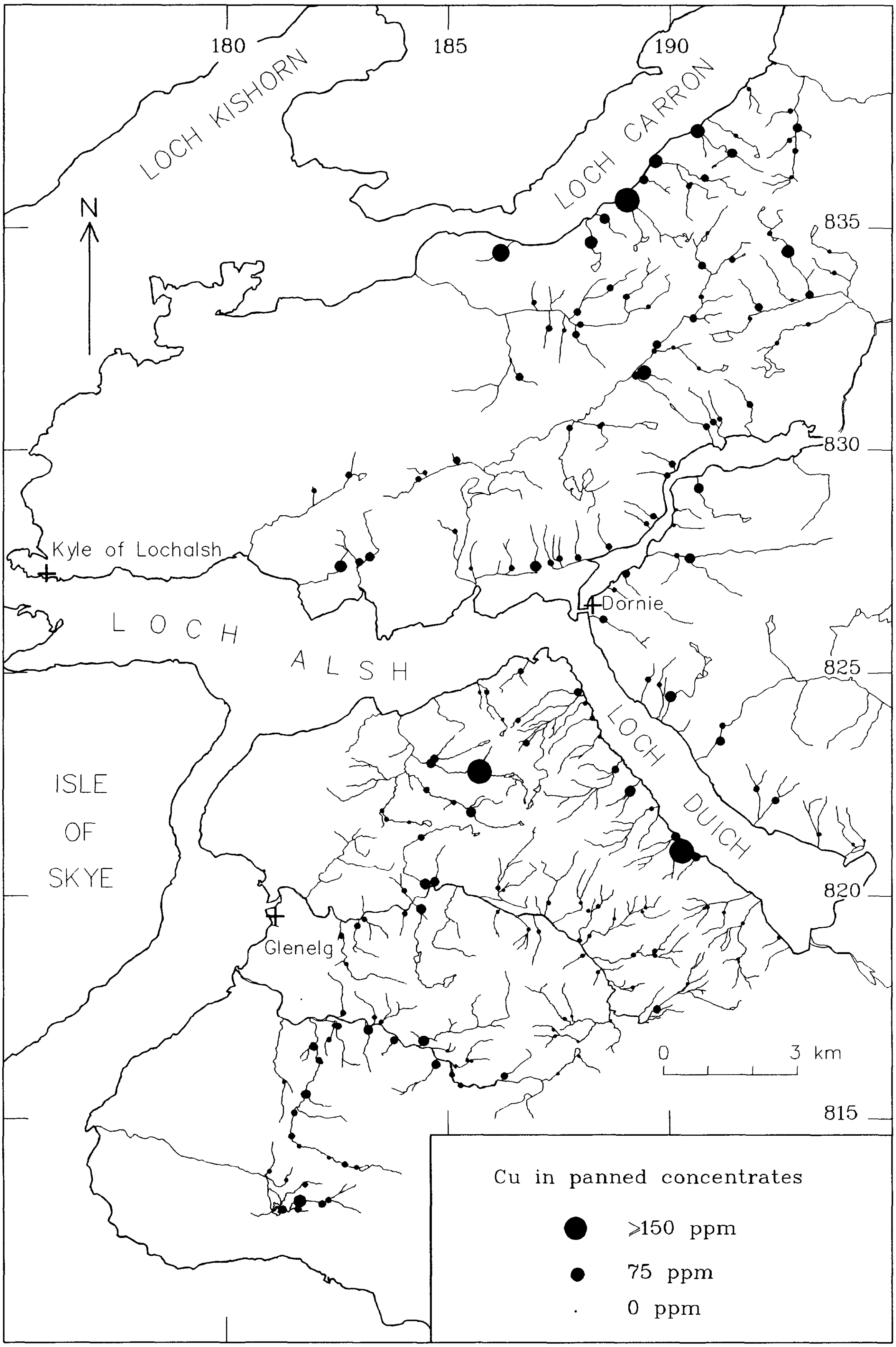

Figure 18 Distribution of copper in panned concentrates

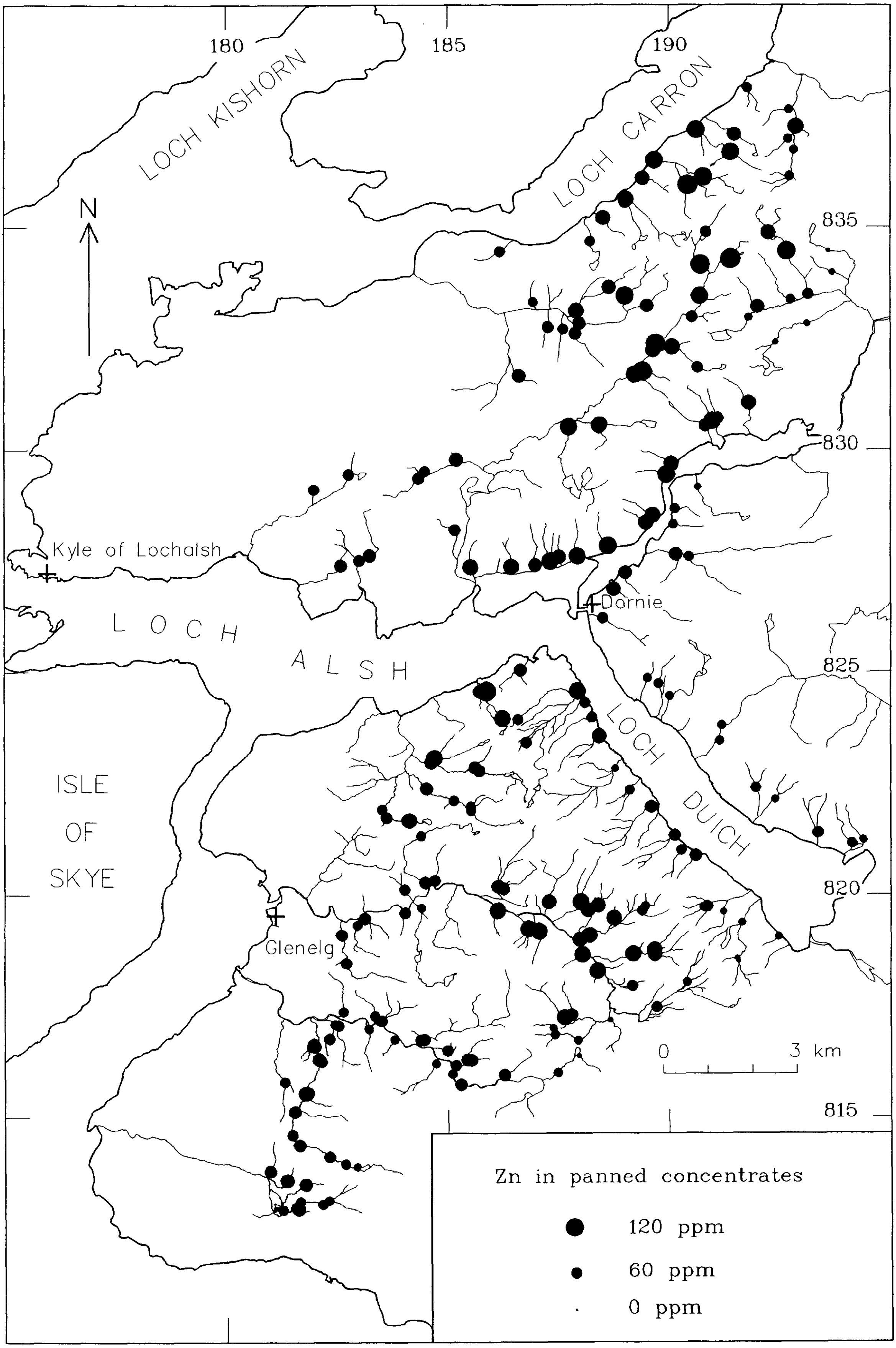

Figure 19 Distribution of zinc in panned concentrates

is no evidence of Zn enrichment over rocks of the Eastern Lewisian, and the high stream sediment values at the southern end of the area are not reproduced by Zn in panned concentrates.

The more basic dioritic facies and appinites of the Ratagain igneous complex, notably those in the Glenmore River catchment, contain slightly elevated zinc values (up to 100 ppm) associated with high nickel and chromium values. Mineralised veins in the quartz monzonite in the eastern part of the complex are known to contain sphalerite (Alderton 1988) but are not identified by zinc in panned concentrates, mainly on account of their limited development and small size.

Arsenic

Arsenic in panned concentrates shows a restricted range of variation from 0 to 9 ppm, but only 67 out of the total sample population of 211 were analysed, the majority of these being from the Western Lewisian. The pyrite-bearing lithologies associated with the marble bands in the Eastern Lewisian (Figure 2) contain elevated arsenic levels in stream sediments, but concentrate data is lacking.

In the Western Lewisian there is no evidence that increased arsenic is related to the abundance of pyrite recorded in panned concentrates. The highest As values of 5 and 9 ppm occur in two samples collected from adjacent streams located a few hundred metres west of the Moine Thrust on the north side of Loch Alsh. The former sample contains the highest Ba of the dataset (3726 ppm), moderately anomalous Au (18 ppb) and Pb (37 ppm). A third high As value of 8 ppm is located over basal Moine metasediments close to the south-east shore of Loch Carron. Variable enrichment of metallic elements including Cu, Co, Zn, Ni, Ba, Pb, Au and Ag defines a narrow north-east-trending zone . Intense tectonism accompanied by recrystallisation and mylonitisation is strongly developed in this zone. Pyrite was recorded in several heavy-mineral assemblages and in stream clasts and it is suggested that minor polymetallic vein mineralisation is present in the anomalous catchments.

Silver

The mean value of 3.7 ppm Ag is not significantly higher than the reported limit of detection (3 ppm) and, although samples for the main mineralised area south of Loch Duich were not analysed, there is little consistency in the spatial pattern of anomalous values (4 - 10 ppm). High silver values seem to be correlated with high iron levels in panned concentrates, and analytical interference by iron at the particularly high concentrations encountered over the Western Lewisian is the most likely explanation. Furthermore, no correlation with gold or other ore metals is observed as might be expected if mineralisation were the cause of the high silver. One notable exception is a sample (KLP 3877) located on the south-east side of Loch Carron with 7 ppm Ag, 20 ppb Au, anomalous Cu, Co, Ni, Ba and low Fe. This and adjacent samples define a north-east-trending anomalous zone coincident with strongly tectonised Moine - Lewisian junction.

Barium

The distribution of barium in panned concentrates shows little evidence of bedrock control except over the Ratagain igneous complex, where the element is strongly enriched over rocks ranging in composition from the least evolved olivine gabbros to diorite, syenite and quartz monzonite (Figure 20). West of Ratagain village, the highest individual Ba value (2914 ppm) over the complex corresponds to increased Pb (50 ppm), close to a north-north-east-trending fault associated with the Strathconon Fault zone. Although baryte was not observed in panned concentrates collected over the igneous rocks and baryte is only recorded from fluid inclusions in the quartz-fluorite-calcite-sulphide veins described by Alderton (1988), unidentified vein mineralisation may occur in the vicinity.

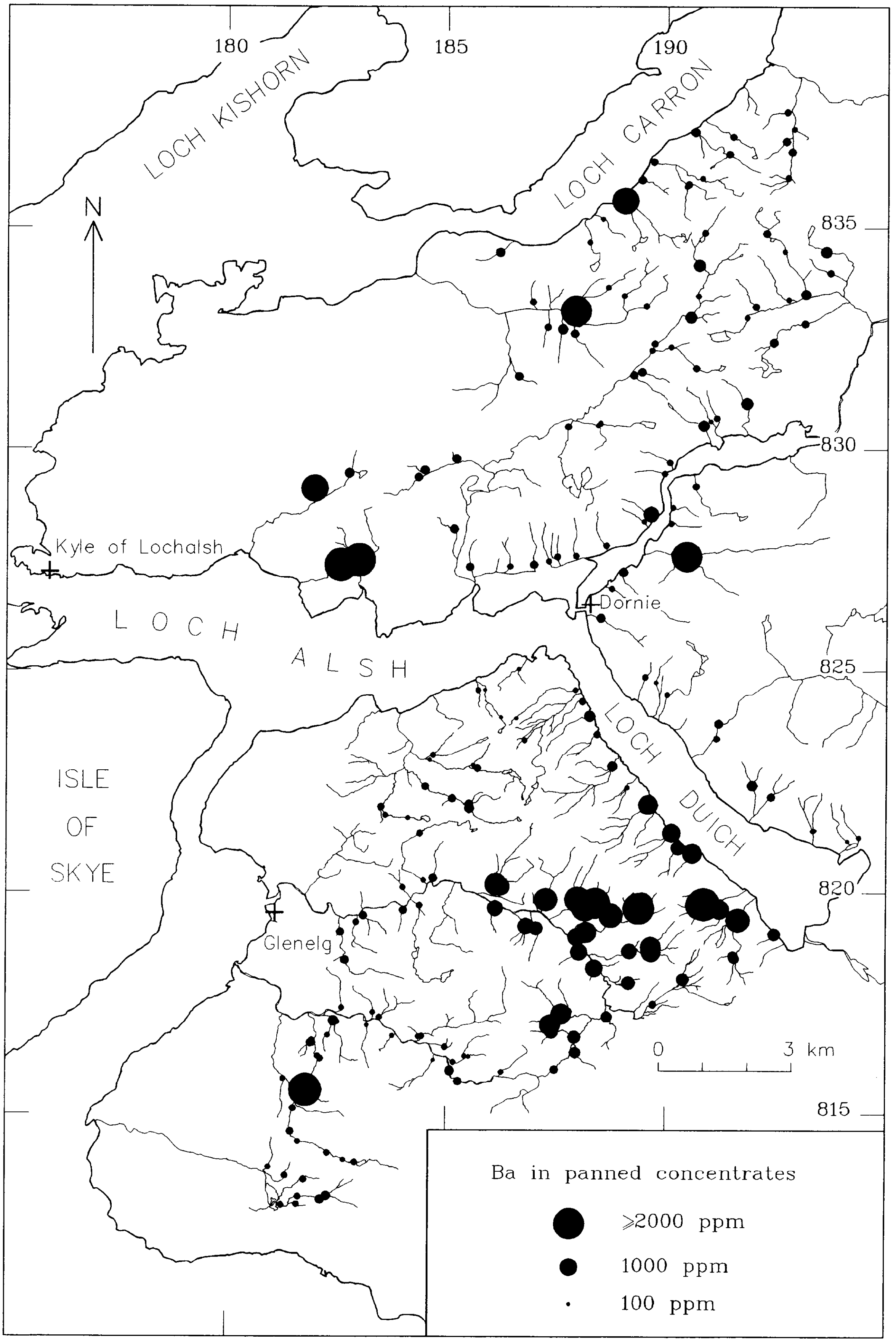

Figure 20 Distribution of barium in panned concentrates

(e.g. KLP 3877). Pyrite, constituting up to 1 - 2 % of the heavy-mineral assemblage, is also conspicuous as disseminations and blebs in semipelitic stream clasts at several sites. In a comparable structural setting, just east of the Moine Thrust on the north side of Loch Alsh, sheared Lewisian gneiss is associated with a low-order Au anomaly (18 ppb Au in KLP 3915) and abundant pyrite in the concentrate. It is possible, therefore, that extensively tectonised rocks of diverse lithology have provided favourable environments for mineralising fluids and subsequent formation of minor epigenetic baryte-pyrite-gold veins.

North-east of Dornie at [189020 827234], the highest Au value of the dataset, KLP 3817 with 5530 ppb Au, is recorded in a stream which follows a major north-west-trending fault cutting the Western and Eastern Lewisian, which contains an abundance of red-brown lamprophyre clasts. Lower Devonian lamprophyres form part of a north-west-trending dyke swarm in this area and may be linked genetically with Au mineralisation (Rock et al., 1987). Dykes of both the lamprophyre and camptonite-monchiquite suite are present in other catchments in the vicinity and may be responsible for the presence of low-tenor Au anomalies (KLP 3858 with 18 ppb Au and KLP 3819 with 16 ppb Au).

In the Eastern Lewisian, south of Loch Duich, several high Au values correspond to the main mineralised zone associated with the marble, calc-silicate-rock and graphitic gneiss outcrops (Figures 2 and 34). Although the maximum in this part of the area is only 37 ppb, the anomalies are spatially related to the zone of metasediments. One stream sediment collected from the northern side of Gleann Beag, KLP 4426 at [183350 817280], contains 113 ppb Au and is downstream of the outcrop of calc-silicate rocks (KLR 4418 and 4420). Another sample slightly further east (KLP 4424), with 80 ppb Au, probably has a similar derivation. They are not associated with other metal anomalies.

Three widely scattered, low-tenor Au anomalies occur over the Ratagain complex, one of which is from the quartz monzonite intrusion where Alderton (1988) identified rare grains of electrum in quartz veins in the vicinity of the Strathconon fault system. Possible visible gold was observed in panned concentrates from five sites; one from quartz monzonite, three from hornblende diorite and associated appinite and one from the Moine near the margin of the western granite. None of the field observations correspond to high analytical Au values.

Lead

Levels of lead are generally low over the project area, with only 30 samples exceeding 30 ppm. There is little evidence of lithological control or of significant metalliferous mineralisation involving galena. Contamination in the vicinity of roads and habitation is the most probable explanation for the three most anomalous values. These are widely scattered, with two close to roads. The highest value (859 ppm), is associated with elevated levels of Sn (369 ppm), Sb (19 ppm), and Th (45 ppm); all except Th are commonly present in solder. Other contaminants, such as lead glass, may account for the isolated high lead value on the northern shore of Loch Long (278 ppm)

Unlike the geochemical patterns displayed by Fe, Mn and the chalcophile elements, lead shows no evidence of increased concentration over the main sulphide-bearing zone in the Eastern Lewisian metasedimentary belt. The occurrences of minor mineralisation containing lead on the northern side of Loch Alsh and on the south-eastern side of Loch Carron have been discussed above. Near Dornie, sample KLP 3817 contains 39 ppm Pb and also the highest Au value (5530 ppb). Abundant lamprophyre clasts were noted at the site indicating a possible genetic relationship between dyke intrusion and mineralisation similar to that described by Rock et al. (1987).

DETAILED INVESTIGATIONS OF THE CARR BRAE AREA

Detailed orientation work involving rock and shallow overburden sampling, geophysical surveying and geological mapping was carried out over the Carr Brae area, which contains the type locality for the rock called eulysite by Tilley (1936) and would now be generally described as a banded iron formation or BIF. The Carr Brae area was selected for detailed survey on the basis of the eulysite outcrop, the presence of the old gold trial in the vicinity, and outcrops of sulphidic calc-silicate lithologies. The area is situated close to the north-east shore of Loch Duich and is shown in Figures 3 and 23.

Overburden geochemistry

Survey area and methods

To investigate the base-metal and Au potential of the Carr Brae area a limited shallow overburden sampling and geophysical programme was carried out to establish the nature and extent of mineralisation. The shallow overburden is generally thin (<2 m) and composed of a brown earth soil developed over bedrock, and is therefore considered suitable for mineral shallow overburden sampling using hand augers. Traverses were surveyed by theodolite at 250 m separation and sample sites taped at 25 m intervals (Figure 21). Terrain corrections were made during surveying to allow for the steep gradients in the northern part of the area. A total of 139 soils were collected using 1.5 m hand augers.

In order to provide a representative sample of adequate size each site was sampled a number of times within a 0.5 m radius and the sub-samples amalgamated. Wherever possible samples of B/C horizon material were collected, from depths below 0.15 m. In a few areas the presence of a thick peaty A horizon prevented the collection of a good quality mineral soil, and the samples contained a high organic content.

Table 4 Summary statistics for shallow overburden samples from the Carr Brae area

Variable	25 % percentile	Median	75 % percentile	90 % percentile	Minimum	Maximum
Ti	5180	5740	6340	6860	1320	9260
Cr	85	117	151	172	22	512
Mn	740	1280	1280	5410	170	51320
Fe	55800	66700	66700	93400	9800	177800
Ni	19	28	46	56	1	104
Cu	22	39	56	75	<1	388
Zn	35	53	69	88	5	154
Ba	315	397	484	571	<1	861
Pb	9	13	16	20	1	97
Au	1	1.5	3	4	0	8

N = 139 for all elements except Au (18). All values in ppm except Au (ppb)

Analysis was carried out on -180 micron material by XRF on pressed powders for a range of trace elements (Table 4). Gold analyses were also carried out on 18 selected samples with enhanced base-metal values by Acme Analytical of Vancouver using an aqua regia attack, MIBK extraction and an AAS finish.

Results

Most trace elements show a wide range of analytical values, reflecting the diversity of bedrock types in the sampling area. Maximum values of Fe and Mn are exceptionally high for soils. Copper, Cr, Mn, Fe, Zn and Ni are all closely correlated (Spearman rank correlation coefficients range from 0.42 and 0.64, which is significant at the 99 % level). The scatterplot of Cu vs Fe (Figure 22) indicates the close association between these elements and also shows the presence of two outliers of relatively high Cu (>150 ppm Cu) but lower Fe, which lie along the line of the Sgurr Aoidhe fault. The distribution patterns for elements Cr, Ni and Zn are broadly similar, with higher values occurring on the steeper slopes to the north-east of the Sgurr Aoidhe fault on traverses 00, 200N and 500N. It is probable that these higher values from thinner soil profiles reflect the entrainment of resistate minerals at the bedrock interface. By contrast, Fe and Mn values show a much larger spread, with the highest occurring at three adjacent sites over eulysite outcrop on traverse 00, where maximum values of 5.1 % Mn and 17.8 % Fe were recorded. Soils at these sites are also thin (<1 m) and patchy eulysite outcrop can be seen. The Mn plot (Figure 23) indicates that eulysite extends in a south-easterly direction from the mapped outcrop and this is confirmed by the geophysical survey.

The highest copper value (388 ppm) occurs on line 200S to the east of the main eulysite outcrop [190337 824549] immediately downslope of the Sgurr Aoidhe fault (Figure 24). The soils over mapped eulysite outcrop are also slightly enriched in copper (105 and 256 ppm). However, these samples were not enriched in zinc or lead and there is no evidence to suggest base-metal enrichment associated with sulphides in other parts of the sampling area. A suite of 18 samples enriched in copper were selected for Au analysis. Results indicate only minor Au enrichment, up to a maximum of 8 ppb in a sample from line 200S, which also has enhanced Mn (1.8 %) and Fe (15 %).

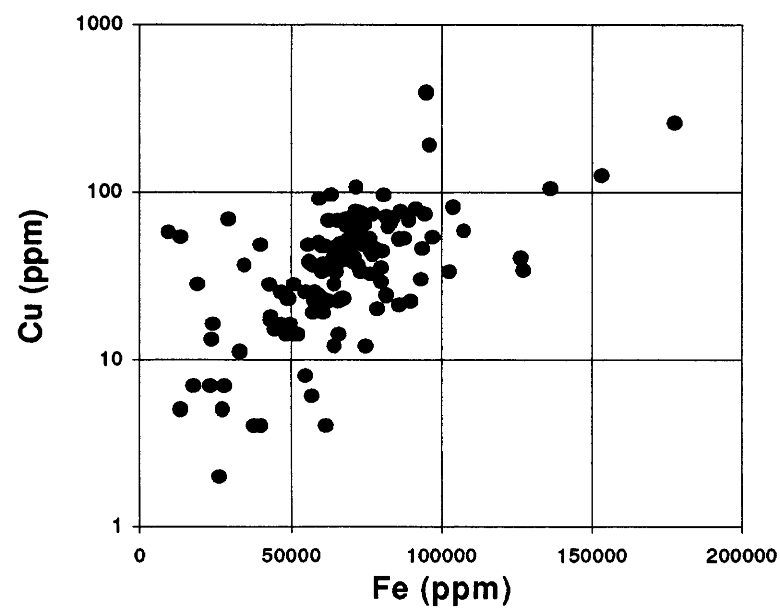

Figure 22 Plot of Cu vs Fe for shallow overburden samples, Carr Brae

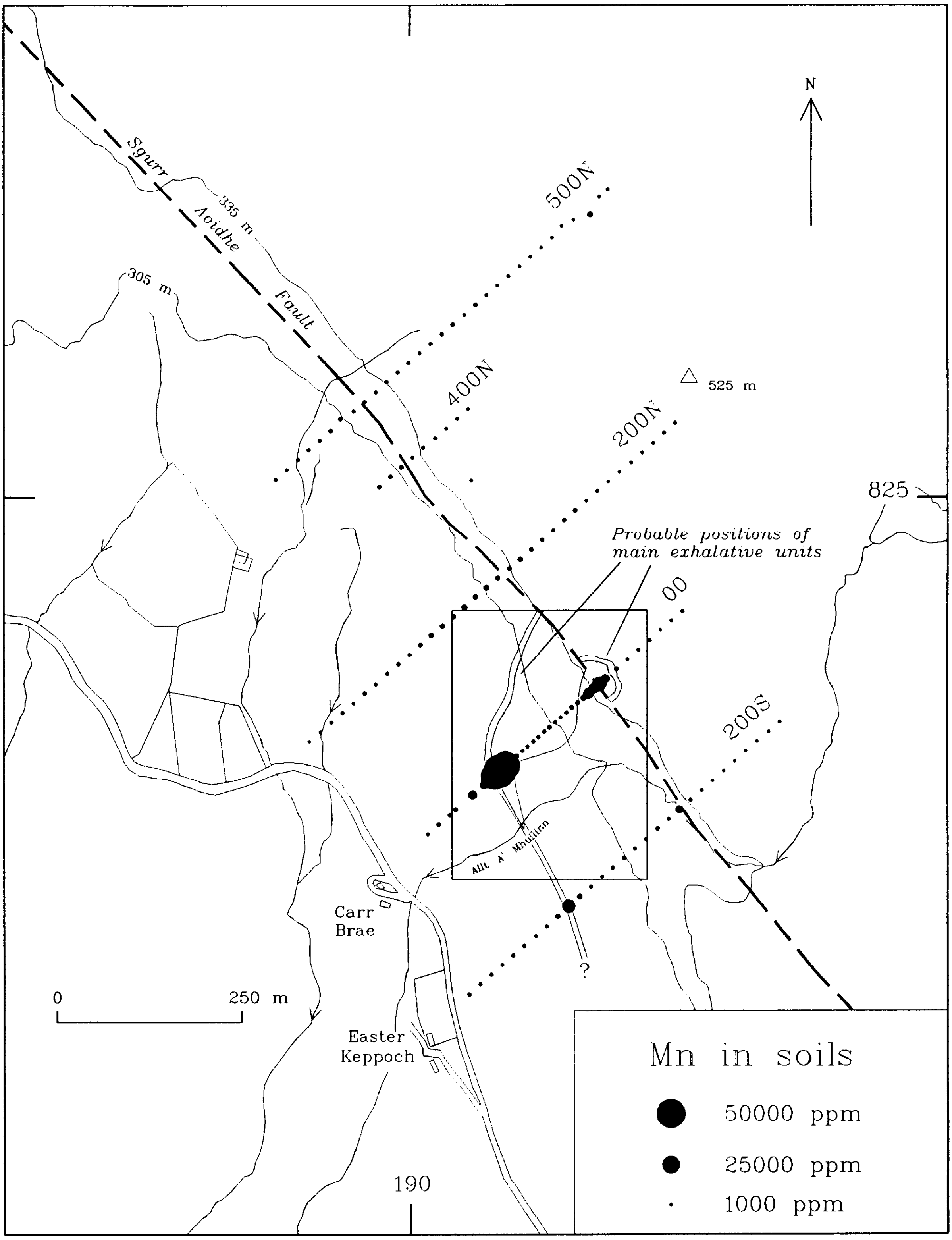

Figure 23 Distribution of manganese in shallow overburden, Carr Brae

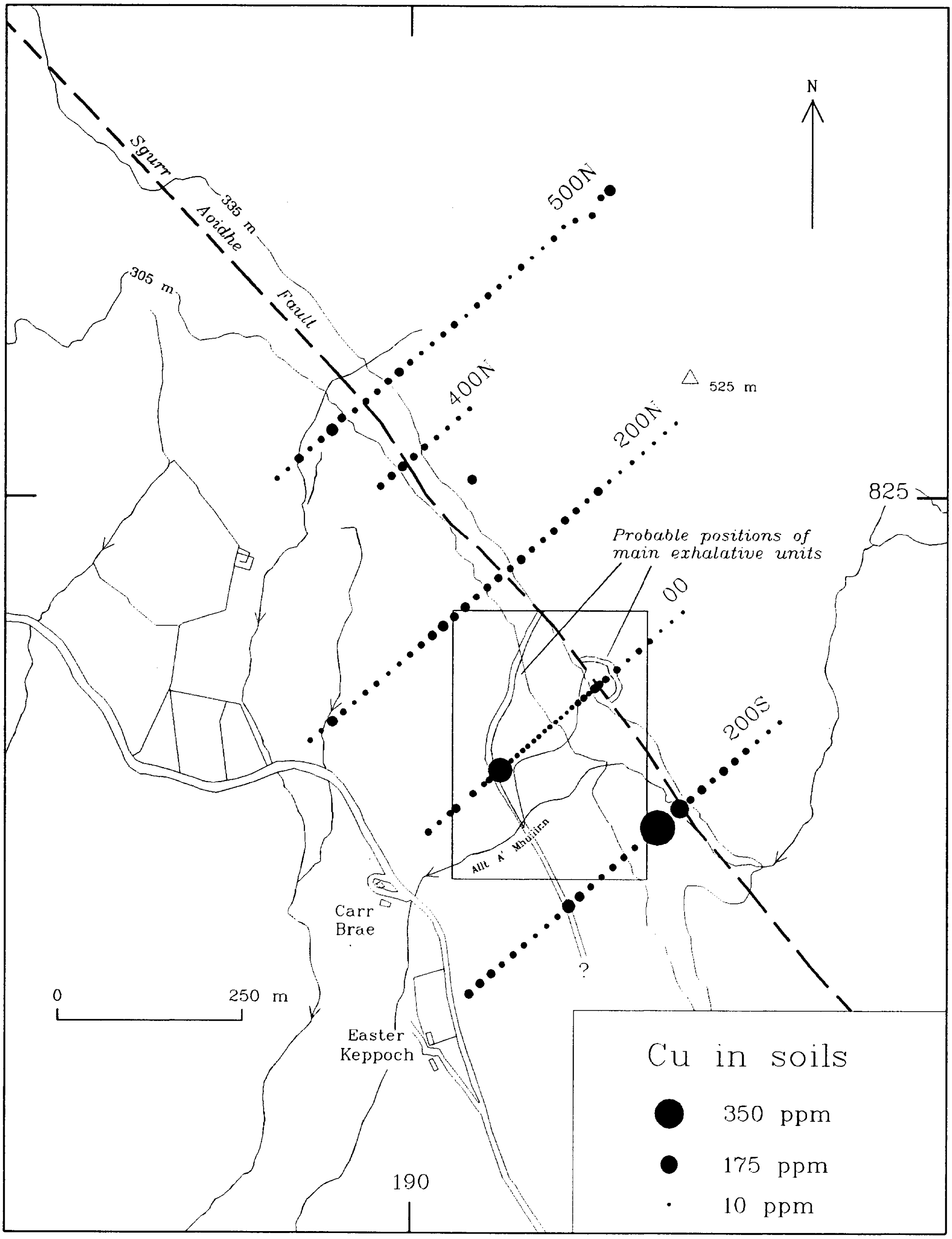

Figure 24 Distribution of copper in shallow overburden, Carr Brae

Conclusions

The close association between copper and iron (Figure 22) indicates that the iron-rich eulysite is slightly enriched in copper but there is no such association with Zn, Pb or Au at this site. Gold is slightly enriched at one sample site on the eulysite. Slight copper enrichment also occurs in deeper soils over the eulysite on traverse 200S. Minor amounts of copper also appear to be present along the Sgurr Aoidhe fault. Manganese and iron appear to be the best diagnostic indicators of the eulysite outcrop.

Geophysics

Detailed magnetic and VLF observations were made along a grid with an origin at [190145 824647] and a main traverse orientation of 049°, identical to the grid used for geochemical sampling. All magnetic and VLF measurements were made using a Scintrex IGS-S module with digital data recorded in the field.

Magnetic observations of the total field were made along five lines of the grid: 200S, 0, 200N, 400N and 600N. Data were collected at intervals of 5 m along the lines. In addition twelve lines were surveyed as paced traverses with data collected at a nominal separation of 12.5 m. Corrections for diurnal change were made using repeated observation at a field base station at [189840 824650]. Total field observations range from less than 47000 to over 54000 nT, although the International Geomagnetic Field value for epoch 1991 at this site is about 49712 nT. Maximum anomalies occur close to the grid origin in a restricted zone just north-west of a prominent bend on the Allt a' Mhuilinn above Wester Keppoch (Figure 25). Along several sections of the survey lines the Scintrex IGS-2 was unable to measure the total magnetic field using the proton bottle at 2 m above ground level on account of excessive gradients in the field. An attempt to measure the field at 3 m above ground was also unsuccessful. The existence of magnetic gradient in excess of 5000 nT m^{-1} indicates a high frequency anomaly, indicative of extremely magnetic material very close to the ground surface. The magnetic zone appears to be very localised. There is no suggestion that the zone extends across the grid as far north as 200N. On line 200S (Figure 25) a significant minimum in the field about 100 m west of the baseline is associated with a few stations where data could not be recorded, suggesting that the main magnetite-rich zone might extend at least as far south as line 200S. The baseline traverse indicates a minimum anomaly to the north of the magnetite-rich zone, suggesting predominantly induced magnetisation. There are some thin but significant anomalies which can be identified on lines 0, 200N, 500N, 600N and on the supplementary lines south of the main grid (Figure 25) but some of these are associated with quartz-mica gneiss.

Several of the traverses were sampled thoroughly using a hand-held kappameter. Over 100 sites were examined at every available outcrop or section along the traverses. At each site about 12 measurements of the magnetic susceptibility were collected and log mean values derived. The site mean data (Table 5) show that mean susceptibility at some sites is above 0.4 SI, and that some individual samples have a measured susceptibility above 0.8 SI. This is close to the values observed for pure magnetite. The data overall show a strong bimodal distribution (Figure 26). About 80 % of the samples have a low mean susceptibility (less than 0.002 SI) and about 20 % with a mean susceptibility above 0.058 SI. A plot of the site mean susceptibility data (Figure 27) indicates the restricted nature of the magnetite-rich outcrop.

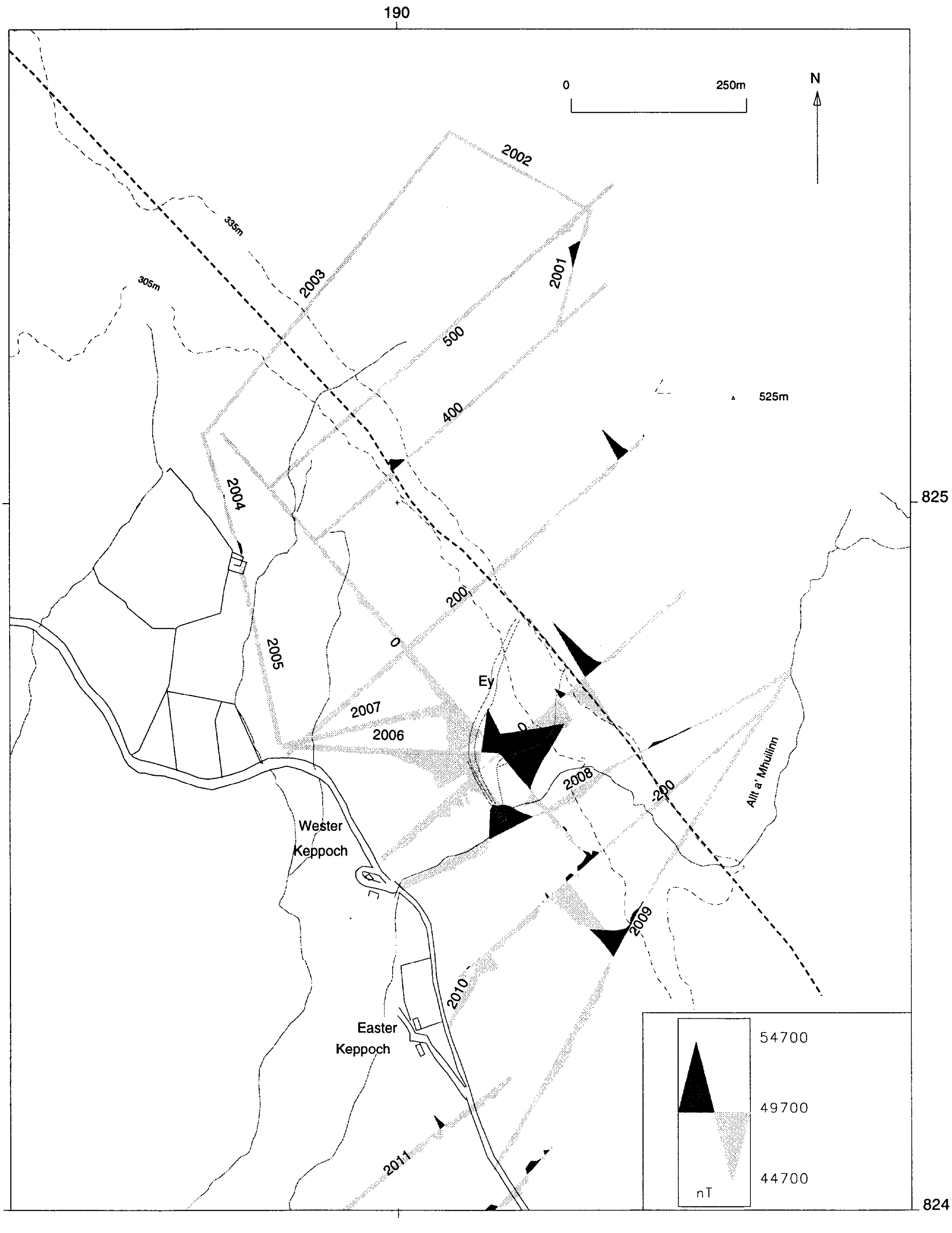

Figure 25 Total-field magnetic data at Carr Brae. Anomalies are corrected for diurnal change and plotted relative to 49700 nT. Ey is the mapped eulysite.

Table 5 Mean susceptibility values in SI x 10^3 for selected formations in the Glenelg area						
Formation	Number of sites	Site Mean	Site Minimum	Site Maximum	Standard deviation	Total number of measurements
Moine Supergroup	325	4.35	0.02	216.00	13.32	4354
Lewisian (NW Scotland)	538	19.68	0.01	466.00	57.33	5577
Lewisian gneiss (this study)						
North of Loch Duich	113	43.11	0.03	448.67	101.33	1017
Glenelg to Loch Duich	138	36.81	0.03	448.67	94.32	1208
Eulysites	17	224.38	26.32	448.67	137.17	168
Ratagain Igneous complex	49	9.84	0.10	59.43	9.22	565

Notes Each field site has between 4 and 13 measurements. The statistical values of geometric mean and standard deviation, minimum and maximum refer to the averaged values for each site. Individual measurements of susceptibility for the eulysites range up to 0.99 SI units

A number of other lithologies, including hornblende schist/amphibolite, quartz-feldspar gneiss and garnet-biotite schist, display a wide spread of values which extend up to 0.1 SI units. The range of values obtained from marble is less extensive, but is still unusally broad. The higher values do not appear to coincide with proximity to eulysite and mainly occur in the lowest horizon in the Allt a' Mhuilinn section. Although the bulk of the biotite-schist susceptibilities are less than 0.001 SI units a small group have values in excess of 0.1 SI. These enhanced readings were all obtained from a 3.5 m thick band of compact dark schist in the lower part of the crag section north of the Allt a' Mhuilinn (Table 7).

VLF data were collected independently of the magnetic data along the primary grid traverses only. The magnetic VLF field was observed using the GB Rugby transmitter (16 kHz). The in-phase (real component) of the VLF field is everywhere positive, with values locally above 50 % of the primary field (Figure 28). A strong feature appears to be traceable across most of the lines north-west of the origin. Characteristically it has a strong gradient to the east, with a cusp depression in the out-of-phase component. Such anomalies are typical of strong resistivity boundaries.

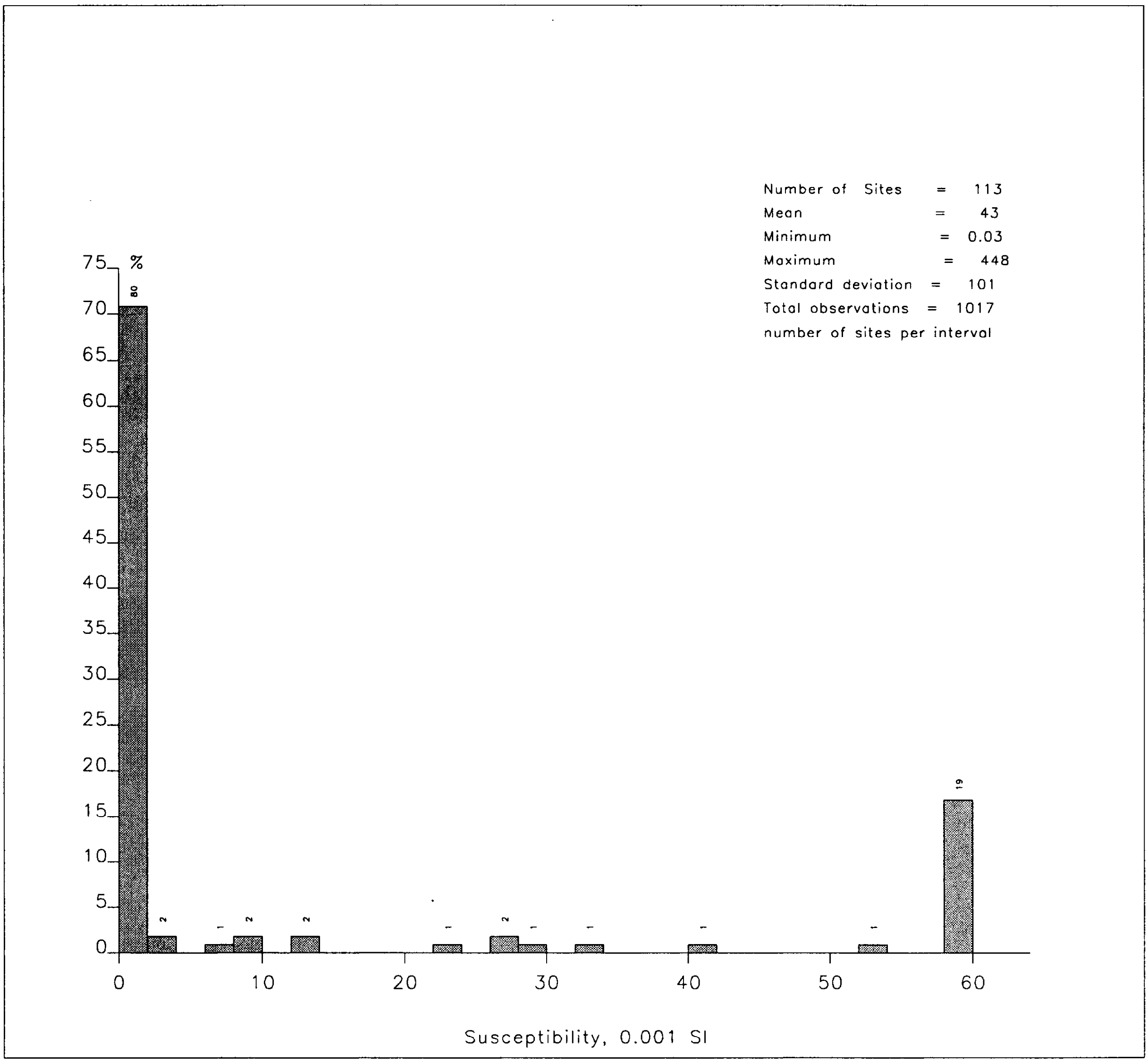

Figure 26 Histogram of site mean susceptibility data from 113 sites for Eastern facies Lewisian in the Carr Brae area, north of Loch Duich. Histogram truncated at 0.06 SI and most of the population above this level are eulysites with susceptibities above 0.1 SI.

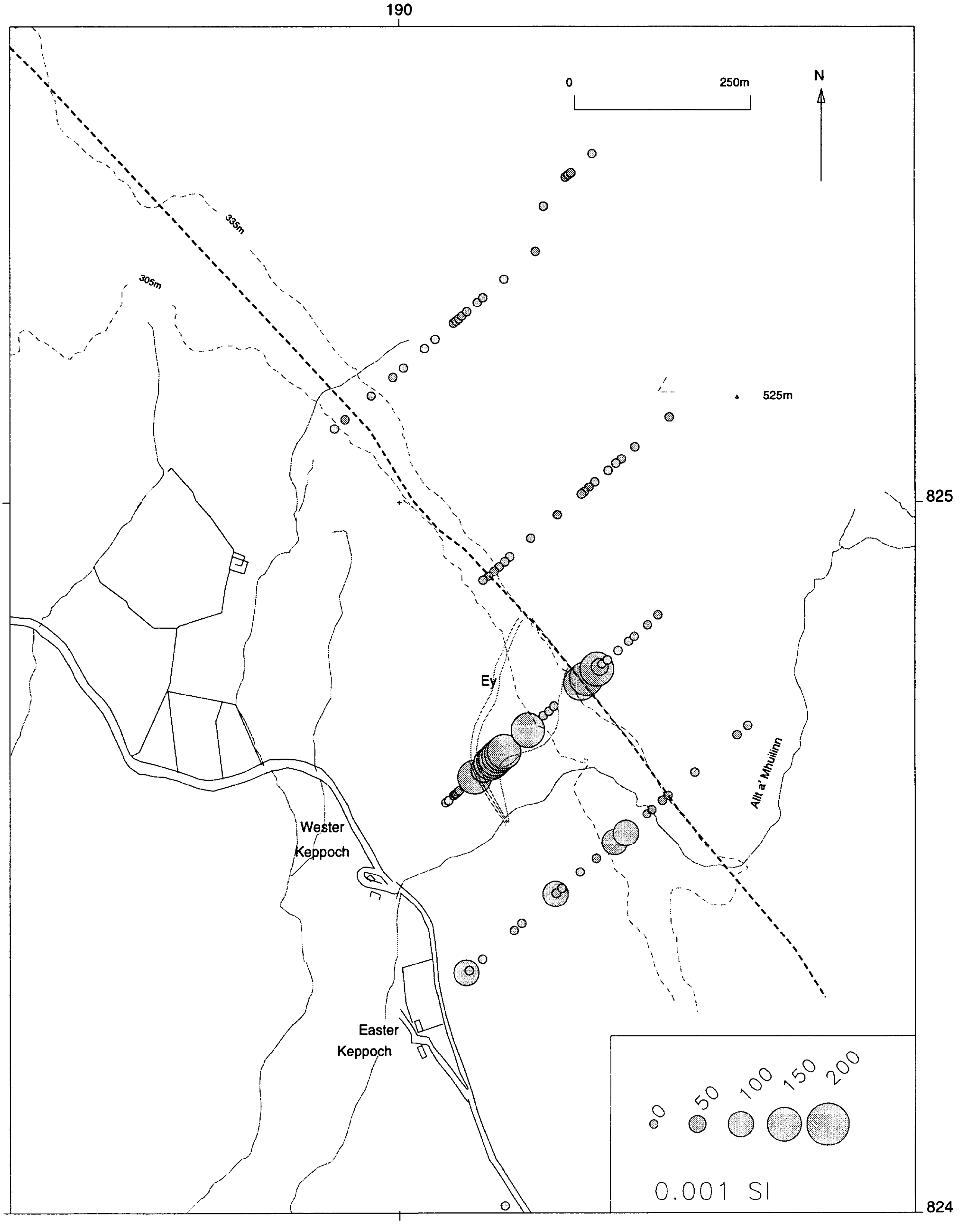

Figure 27 Site susceptibility data (geometric mean values posted along geophysical lines), Carr Brae. Data truncated at 0.2 SI.

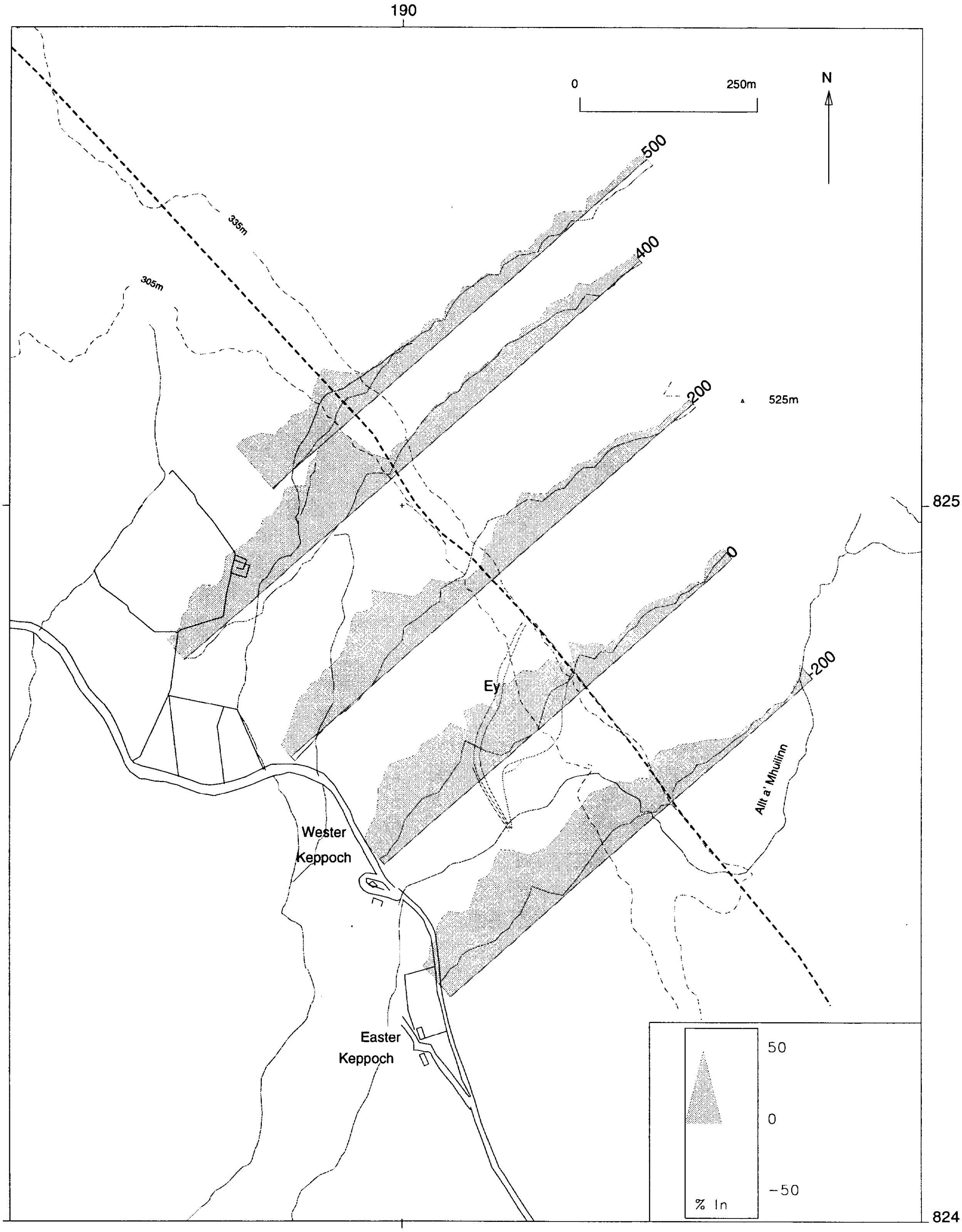

Figure 28 VLF data, Carr Brae. VLF Magnetic-field data for GB Rugby 16.0kHz. In-phase component data shaded, out-of-phase component shown as a solid line.

Detailed Geology

Carr Brae

The lower ground in the Carr Brae area is largely occupied by migmatitic hornblende and biotite gneiss (Figures 3 and 29). The western boundary of the central metasedimentary belt appears to coincide with the base of the rocky crags some 80 m east of the road. Thus the (structurally) lower part is almost continuously exposed in the gorge section of the Allt a' Mhuilinn (Table 6) and in the crags immediately to the north (Table 7). However the level of exposure drops significantly where the gradient slackens above the 200 m contour.

The metasedimentary succession, which encloses the eulysites, consists largely of biotite pelite, garnetiferous in places, with lesser volumes of semipelite, psammite, marble and quartz-feldspar gneiss. Over much of the area the lithological layering dips moderately (20-40°) to the east. However, at the northern end of the main eulysite (Figure 29), around [19025 82476], the orientation shows considerably more variation and the general distribution of the lithologies suggests that the rock lies in the core of a fold closure. The closure is separated from the succession to the south-west by the north-west-trending Sgurr Aoidhe Fault, which can be traced for over 5 km between Dornie and Inverinate. In the area of Figure 29 the fault zone is marked by a concave break in slope, but to the south-east it forms a distinctive linear topographic low which has partly been exploited by the Allt a' Mhuilinn.

The main eulysite, centered on the rocky knoll at [19014 82465], has a somewhat distorted and inverted pear-shaped outcrop whose maximum width of over 80 m in the north corresponds to a true thickness of between 27 and 45 m. The outcrop width tapers to the south, and at its extremity in the Allt a' Mhuilinn section the eulysite is seen to thin rapidly from 3 m and in as many metres pinch out between marble and biotite schist. The eulysite is devoid of any banding so it is not immediately apparent whether the outcrop form is tectonically induced. Certainly on the north-east side of the Sgurr Aoidhe Fault, as has been suggested above there is ample evidence that the shape is the result of folding. The eulysite consists of a coarse-grained crystalline rock (KLR 4664) generally devoid of foliation. In outcrop the true nature of the rock is often masked by by a crust of iron oxides. On the north-east side of the Sgurr Aoidhe Fault the unit can be divided into an upper coarse garnet-biotite-quartz rock and a lower diopside-garnet rock.

The main eulysite is underlain by a band of coarse white marble, up to 3.5 m thick, which can be followed (Figure 29) with some certainty from the Allt a' Mhuilinn to the fault. South-west of the eulysite knoll the marble is underlain by 1-4 m of pink-weathering quartz-feldspar gneiss with magnetite-rich heavy-mineral bands and occasional thin (up to 0.15 m) units of garnet-biotite schist. However, in the Allt a' Mhuilinn the same marble is underlain by over 3 m of eulysite. The lateral tranisition between the two rock types takes place about 45 m north-west of the stream at [19012 82457] where eulysite, quartz-feldspar gneiss (streaky in places) and quartz-biotite schist are interbedded. At this point the succession also includes 0.3-0.4 m of manganese oxide-coated quartz-garnet rock.

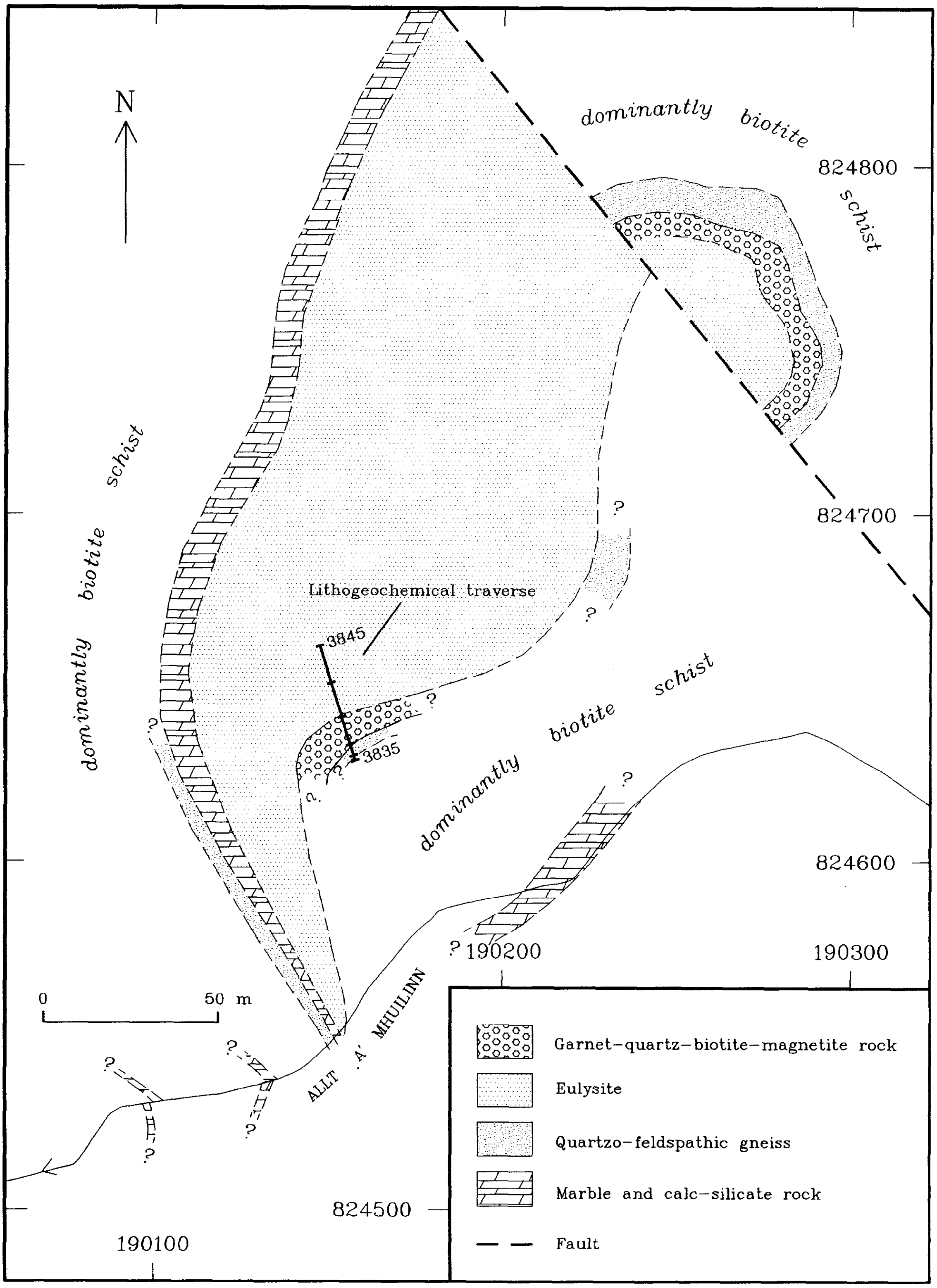

Figure 29 Detailed geology of the area north-east of Carr Brae. The area covered is outlined on Figures 23 and 24.

Table 6 Geological section of Allt a' Mhuilinn between [19008 82449] and [19014 82454]

Thickness (m)	Description	Magnetic Susceptibility SI x 10^3	Mineralisation
?	Pink quartz-felspar gneiss		
?	Calc-biotite schist with pitted weathering	0.43-0.53	
3	Biotite schist	0.20	
0.25	Coarse biotite-hornblende rock	0.75	Disseminated sulphide
0-3	Eulysite	220-832	
3.5	Marble	0.70-4.86	
3+	Eulysite	144-999	
10	Biotite-garnet schist with quartz-felspar stripes, hornblendic and pale green calc-silicate bands	0.30-1.04	
2	Massive calc-silicate schist	0.23-0.47	
0.10	Marble		
0.20	Ribbed schist		
0.17	Striped quartz-biotite rock		
3	Banded biotite-hornblende schist with quartz-feldspar stripes and ribbed weathering		
4.5	Massive weathering, compact purple schist with pale green calc bands	0.25-0.40	
1.6	Banded biotite-hornblende schist with quartz-feldspar stripes and ribbed weathering. Trails and disseminated sulphides	0.13-0.36	Disseminated pyrite and chalcopyrite
3	Marble, spotted grey-white, coarsely crystalline and homogeneous with calc-silicates		
6	NO EXPOSURE		
14	Flaggy to massive biotite semipelite with some interbanded micaceous psammite	0.20-0.48	Little visible sulphide
4	NO EXPOSURE		
11	Rusty weathering schist, psammitic in parts with two thin marbles and garnet-hornblende schist pods 5-6 m above base	0.17-3.64	Much disseminated pyrrhotite
1	NO EXPOSURE		
1.2+	Pink quartz-feldspar gneiss with magnetite-rich layers. Unit includes psammite bands up to 0.25 m with biotite laminae	1.98-10.4	
2	Marble, spotted, and massive pale green calc-silicate rock	2.52-13.8	
8	NO EXPOSURE		
7	Compact biotite schist with pale feldspathic stripes and carious weathering, locally includes 0.5-0.6 m fine hornblende schist	0.31-0.48 2.37 0.69-1.35	Disseminated pyrrhotite Abundant pyrite
1+	Quartz-feldspar gneiss with biotite lamellae	0.10-0.40	Trace pyrite
?	Migmatitic hornblende-biotite gneiss	0.20-0.41	

Table 7 Composite geological section of crags between [19004 82462] and [19017 82457]			
Thickness (m)	Description	Magnetic Susceptibility SI x10^3	Mineralisation
	Blocky to flaggy quartz-biotite schist with rusty weathering in places	0.22-0.32	
9	Marble, spotted		
1.3	Quartz-sericite schist, soft, with rusty weathering in places	0.25-1.10	
10.5	Massive biotite amphibolite, slightly more schistose near top	0.18-0.94	Trace pyrite
0.5	Quartz-feldspar gneiss with dark amphibole	0.03	
2	Hornblende schist, garnet enriched in certain bands. Also magnetite-rich and striped quartz-biotite bands. Uppermost 0.2 m includes coarse amphibole	3.37-13.6	
2	Eulysite, fine grained, massive with biotite and hornblende and occasional bands of biotite-garnet schist. Rusty weathering in places	2.09-686	
1.5	Garnet-biotite schist with interbanded garnet-hornblende schist	2.67-136	
9	Pink-weathering quartz-feldspar gneiss with amphibolite pods	0.13-0.36	
3	Marble, lensoid, passing along strike into biotite schist		
3.5	Quartz-feldspar gneiss, pink weathering, flaggy with biotite partings	0.20-0.48	
5	NO EXPOSURE		
1.2+	Biotite schist with quartz stripes, pitted weathering	0.19-0.71	Trace sulphide
3.5	Compact dark grey schist with biotite and sericite, lustrous to leaden, includes lensoid marble up to 1.7 m thick		Trace pyrite
0.4	Quartz-feldpar gneiss, pink weathering, with dark partings, leaden in parts, containing irregular bands and lenses of marble	0.01-0.94	
4+	Marble, knobbled weathering, pale grey, spotted with pale green patches and calc-silicate lenses		

There appears to be more lithological variation in the rocks overlying the main eulysite. For instance, on the south side of the knoll the eulysite is against an apparently lensoid body of coarse garnet rock, which is not seen elsewhere (KLR 3839). It consists of garnets up to 10 mm across set in a green matrix of quartz, biotite and magnetite. The rock is interbedded with quartz-feldspar gneiss (KLR 3835 and 3837), which on the south side of the lens dominates and has abundant quartz-rich layers. In the Allt a' Mhuilinn the eulysite is overlain by 0.35 m of coarse biotite-hornblende rock which passes up through more than 3 m of biotite schist into quartz-feldspar gneiss. Elsewhere, blocks of marble are seen near the upper margin of the eulysite. On the north-east side of the fault the eulysite is encircled by a band of pink-weathering quartz-feldspar gneiss up to 14 m thick. The gneiss locally contains quartz strings and may be separated from the eulysite by 0.1 m of banded quartz-magnetite rock. The main quartzo-feldspathic gneiss unit (Figure 29) can be interpreted as a metamorphosed acid igneous intrusion (May et al. 1993), a feldspathic sandstone or, more tentatively, as a rhyolite dome.

A second, but considerably thinner, horizon of eulysite was recorded in the crags to the north of Allt a' Mhuilinn, north-east of the Sgurr Aoidhe Fault (Figure 29). The band is 2 m thick and comprises a fine-grained massive rock with biotite and hornblende and occasional bands of biotite-garnet schist, and has a rusty weathering crust in places. The succession below the eulysite comprises in descending order, 1.5 m of garnet-biotite schist, 9 m of pink quartz-feldspar gneiss and 3 m of marble. The latter is probably equivalent to the lowermost marble in the Allt a' Mhuilinn section (Table 5).

Only one sample (KLR 4664) from the outcrop to the north-east of the Sgurr Aoidhe Fault was examined petrographically (Fortey 1993). It is composed dominantly of very pale green amphibole (possible actinolite) with salmon pink garnet forming irregular, 2-3 mm wide, brown bands. The opaque constituents are 8 % magnetite, 2 % pyrite and accessory chalcopyrite.

Easter Keppoch

Eulysite is exposed in a small cut on the east side of the road at [19013 82407]. The cut is 100 m south-south-east of the junction with the track to Easter Keppoch and 400 m south-south-east of the Allt a' Mhuilinn. Two bands of eulysite are present in the section, 1.1 m and 0.75 m in thickness. The lower is notably garnetiferous and has a rusty weathered crust (KLR 4260, 4662) and the upper is more magnetite-rich (KLR 4261). They are separated by a thin band of greenish hornblende-quartz rock with coarse garnet porphyroblasts and traces of pyrite. The eulysite is enveloped by greenish quartz-feldspar gneiss which in places looks quite strongly sheared. Immediately below the lower eulysite is a 0.25 m band of pink quartz-feldspar gneiss with occasional muscovite partings, which resembles a sheared pegmatite. The upper eulysite is directly overlain by 0.4 m of slightly leaden looking garnet-biotite-sericite schist which contains occasional bands highly enriched in garnet.

Mineralogical examination of KLR 4662 shows the eulysite to be a garnet-magnetite-actinolite amphibolite similar to KLR4664 (Fortey 1993). The dominant mineral is a colourless amphibole of possible actinolite composition. Magnetite forms about 15 % of the rock in 0.05 - 0.5 mm grains and is associated with salmon pink garnet in mm-scale bands. Pyrite is a common accessory mineral, forming about 0.5 % of the rock in 0.1 - 0.3 mm grains.

Loch na Folaig

This eulysite is situated 400 m west-south-west of the southern end of Loch na Folaig. The outcrop (Figure 30a) is 14 m wide and 23 m long on an east-north-east - west-south-west alignment which broadly reflects that of the foliation in the adjacent rocks. It forms two parallel mounds; the intervening depression could well represent an old trial. The northern mound consists predomintly of magnetite schist. However, at the south-west corner there is a 1.8 m wide band of eulysite which is distinctly more magnetic and which appears to comprise alternating garnet-rich and green amphibole-rich bands. The southern mound consists of magnetite schist and eulysite with garnet- and quartz-rich bands. Exposure of the rocks surrounding the eulysite is patchy, but to the south and east they consist principally of coarse garnet schist. Immediately east of the southern knoll is a small patch of coarse garnet-quartz rock, south of which is noticeably striped quartz-biotite schist with wine-coloured garnets up to 25 mm in size.

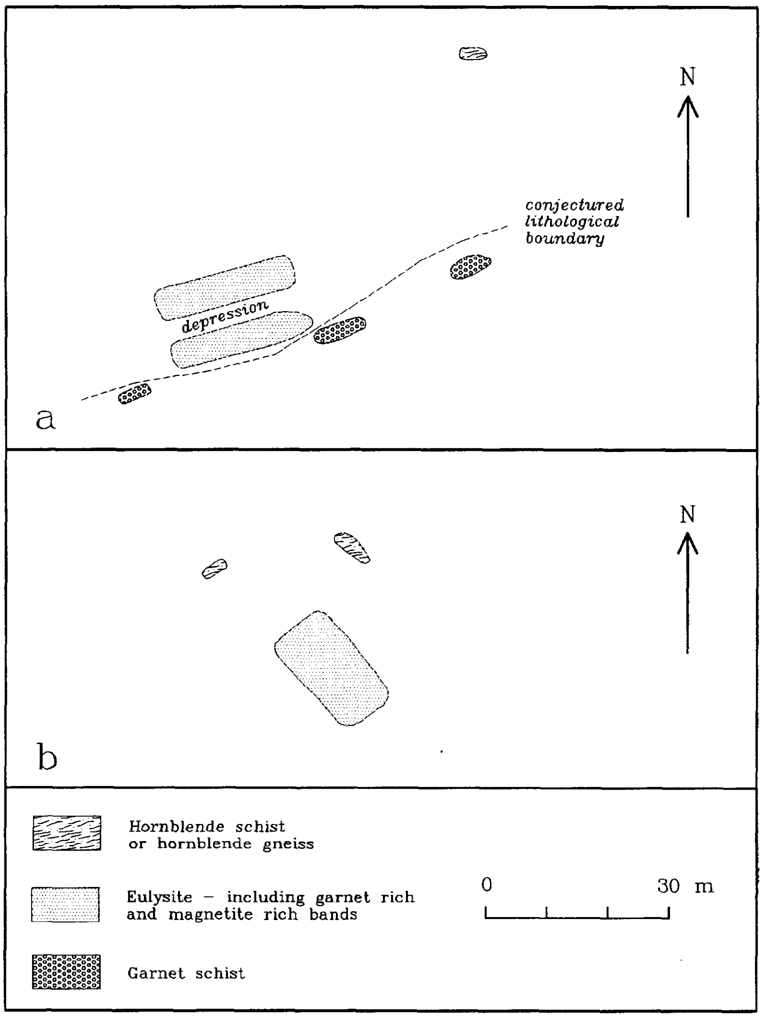

Figure 30a Geology of the eulysite locality at Loch na Folaig [19028 82535]

Figure 30b Geology of the eulysite locality at Loch a' Mhuilinn [19047 82519]

Loch a' Mhuilinn

Eulysite forms a low knoll some 400m west-north-west of the northern end of Loch a' Mhuilinn at [19047 82519]. The knoll (Figure 30b) is c. 20 x 10 m, the longer axis paralleling the north-westerly strike of the foliation in the adjacent gneiss. The eulysite is coarse grained and looks like amphibolite. It includes red garnet-rich bands up to 0.3 m thick and, more rarely, paler quartz-rich units and occasional quartz stringers. There is no contact with the surrounding rocks, which comprise garnetiferous hornblende-biotite gneiss and flaggy striped hornblende gneiss.

Mineralisation

Iron sulphides were noted at fifteen localities in the Carr Brae area. The greatest concentration, both in terms of number of occurrences and visible suphide content, occurs in the lower reaches of the Allt a' Mhuilinn gorge section between [19007 82451] and [19008 82452]. Within this section (Table 6) sulphides are particularly common in two units. The lower comprises a 7 m thick band of compact biotite schist which has disseminated pyrrhotite, and includes 0.5 - 0.6 m of fine hornblende schist with abundant pyrite. Roughly 12 m above this is an 11 m thick band of rusty weathering schist which contains much diseminated pyrrhotite and has magnetic susceptibilities of up to 4 x 10^{-3} SI. Further sulphide enrichment is evident 25-30 m above this, where trails and disseminations of pyrite and possible chalcopyrite characterise a 1 - 2 m thick unit of banded biotite-hornblende schist.

Two further examples of sulphide concentration were recorded higher up the Allt a' Mhuilinn section. At [19017 82457] a 2 m band of marble is overlain by a succession of calc-silicate schist which includes a bright green pelite carrying disseminated sulphide. Approximately 45 m to the east-north-east of this a further marble unit exposed in the stream section is overlain by calc-silicate schist rich in pyrite. These lithologies are similar to those sampled in the An Leth-allt and described below in the section on the lithogeochemistry of the calc-silicate rocks.

Lithogeochemistry

A suite of six rock samples of the major lithologies were collected across the eulysite outcrop at Carr Brae (Figure 29). Grab samples were also collected of the eulysite exposed by the Easter Keppoch roadside at [190130 824070]. Figure 31 shows the variation of the five major and first-row transition elements across the Carr Brae section from south-east (KLR 3835) to north-west (KLR 3845). As expected iron and manganese show the greatest variation, increasing from the quartz-feldspar (-mica) gneiss, KLR 3835 and 3837, to the eulysite of the last two samples. KLR 3839 is a sample of a coarse garnet-rich gneiss and shows an increase in Fe (13.5 %), Ti (1.18 %) and Mn (0.37 %) as well as trace elements V, Ni, Cu and Zn. The iron and manganese are most probably present in garnet in the almandine and spessartine molecules but the titanium and vanadium are probably present in ilmenite, as evidenced by the mineralogical examination of a similar garnet-rich sample KLR 4706 from the Gleann Beag section (Fortey, 1993). The extremely iron-rich composition indicates that the protolith of the garnet-bearing rock is unlikely to be a normal sediment but has chemical component of precipitated iron and mangenese oxides (Figure 31). Calcium shows a steady increase across the section and probably indicates that the protolith of the Fe-rich eulysite samples contained a carbonate mineral. Copper shows an increase to 550 ppm in sample KLR 3845, which is a rusty weathering facies of the eulysite and presumably contains pyrite and minor chalcopyrite. Most of the other trace elements, particularly Ba, Rb, Sr, and Zr, show a decline across the section indicating that most of those present in clays and detrital minerals. However, the rare earth elements La , Ce and Y appear to increase slightly into the eulysite.

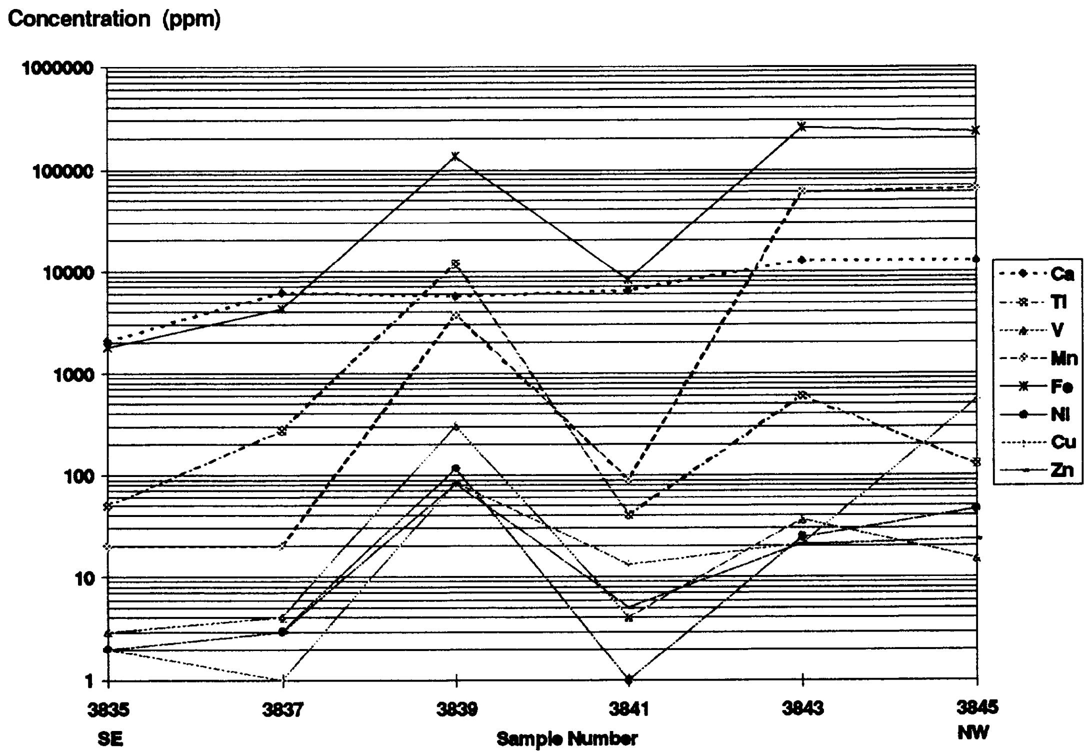

Figure 31 Variation of Ca, Ti, V, Mn, Fe, Ni, Cu and Zn across the lithogeochemistry traverse, Carr Brae. Samples KLR 3835, 3837 and 3841 are quartz-feldspar (-mica) gneiss, KLR 3839 is a coarse garnet-quartz rock, and samples KLR 3843 and 3845 are eulysites.

The chemistry of the eulysites across the whole project area is discussed in a later section, but the detailed sampling across the Carr Brae knoll shows an interesting pattern with a relatively sudden increase in iron and manganese from the levels normally found in metasediments. Interbanded garnet-rich rocks also exhibit a chemical or exhalative input to the original sediment, as evidenced by the high levels of iron and manganese.

Other eulysite samples (KLR 4260, 4261 and 4662) were collected from the roadside south-east of Easter Keppoch and (KLR 4664) from the outcrop north-east of the Sgurr Aoidhe Fault (Figure 29). They all have broadly similar chemistry, but KLR 4260 and 4664 have elevated Cu levels of 210 and 216 ppm respectively.

Other sulphide-bearing rocks from the area were also analysed. Samples of calc-silicate gneiss adjacent to the main marble outcrop in An Leth-allt, KLR 3828 at [190960 823300] and KLR 3830 at [191040 823400] show abundant pyrite and have Cu values of 821 and 964 ppm respectively. Further samples from these outcrops yielded slightly lower Cu levels of 250 - 620 ppm. Samples of a similar lithology collected from the vicinity of the old gold trial near the shore of Loch Duich at [189530 824320] show lower concentrations of copper in the range 50 - 150 ppm.

LITHOGEOCHEMISTRY OF THE EASTERN LEWISIAN

Samples of most of the major rock types in the Eastern Lewisian were collected during this survey and, in total, 134 samples analysed for Ca, Ti, V, Cr, Mn Fe, Ni, Cu, Zn, As, Sr, Ag, Sb, Ba, Pb and Bi by automated X-ray fluorescence spectrometry in the BGS laboratories. Gold was determined on a 30 g sample using an aqua-regia attack, MIBK extraction and graphite furnace atomic absorption spectrometry at the Acme laboratory in Canada. Sampling was concentrated on outcrops showing sulphide mineralisation, iron-staining or forming part of the assemblage containing the eulysites. All the analytical results and sample locations are available on request from the MRP database. A detailed discussion of the lithogeochemistry along with the summary statistics is presented here for the eulysite, pyrite-bearing calc-silicate rock and graphitic gneiss samples.

Twenty-five samples of veins and crush rocks from the vicinity of the Ratagain igneous complex were sampled and analysed by similar techniques. These include some rocks from within the Lewisian and Moine outcrops, but these are considered to form part of the vein-style mineralisation connected with the igneous body and are reported in a later section.

Eulysites

In recent years the common association of banded iron formation (BIF) with stratabound base-metal deposits in Archaean or Proterozoic rocks, such as Broken Hill (Stanton 1976), has led to a greater interest in these rocks and their use as a guide to unexposed ore deposits. Also, in several ancient shield areas banded iron formations are associated with gold deposits (Gross, 1988; Ford and Duke, 1993), which current metallogenic models explain by reaction between gold-bearing hydrothermal fluids and the reactive BIF. Sulphidation of the iron oxide BIF causes deposition and concentration of the gold from the hydrothermal solution. Many recent analogues of ore deposits, such as the Red Sea deposits or the 'black smokers' in the Pacific, have extensive iron- and manganese-rich aprons or deposits of chemical sediments around the actual vent, and this volcanic-exhalative model is used by Williams et al. (1985) to explain the association of the Besshi-style Cu-Zn-Au ore deposit at Gairloch with the associated BIF. However, as stated by Stanton (1976), there are 'banded iron formations and banded iron formations', and the distinctions between BIFs of sedimentary and exhalative origin are not always clear cut. One of the aims of this survey was to study the chemistry of the eulysites in the Loch Duich and Glenelg areas and to evaluate their potential as chemical markers for stratabound base-metal deposits and gold mineralisation. Because iron-oxide-rich rocks are highly reactive to sulphide-bearing mineralising fluids by reaction to form pyrite, another possibility is that the BIFs could form chemical traps for gold-bearing fluids moving within veins or shear-zone complexes (Ford and Duke, 1993).

Twenty one samples of iron-rich rocks, which are called eulysites because of the original naming by Tilley (1936), were collected from the Eastern Lewisian, extending from Loch Duich along strike for 14 km to the south-west. The outcrops of the eulysites are shown in Figure 32 and it can be seen that they occupy a consistent stratigraphic position relative to the marble outcrop. Many of these outcrops are marked on the original field slips dating from when the area was mapped by the Geological Survey early this century, and a few show evidence of small trials and excavations as possible sources of iron ore, such as that near Loch na Folaig (Figure 30a). The exposure in the Gleann Beag gorge below Dun Grugaig [185140 815860] also shows signs of old working, which may even be prehistoric in age and related to the nearby brochs. Further exposures of eulysite were discovered when outcrops were examined with the susceptibility meter and this has extended the strike south-west to Loch na Lochain [1811 8132]. The lithologies associated with the eulysites are normally garnet amphibolites

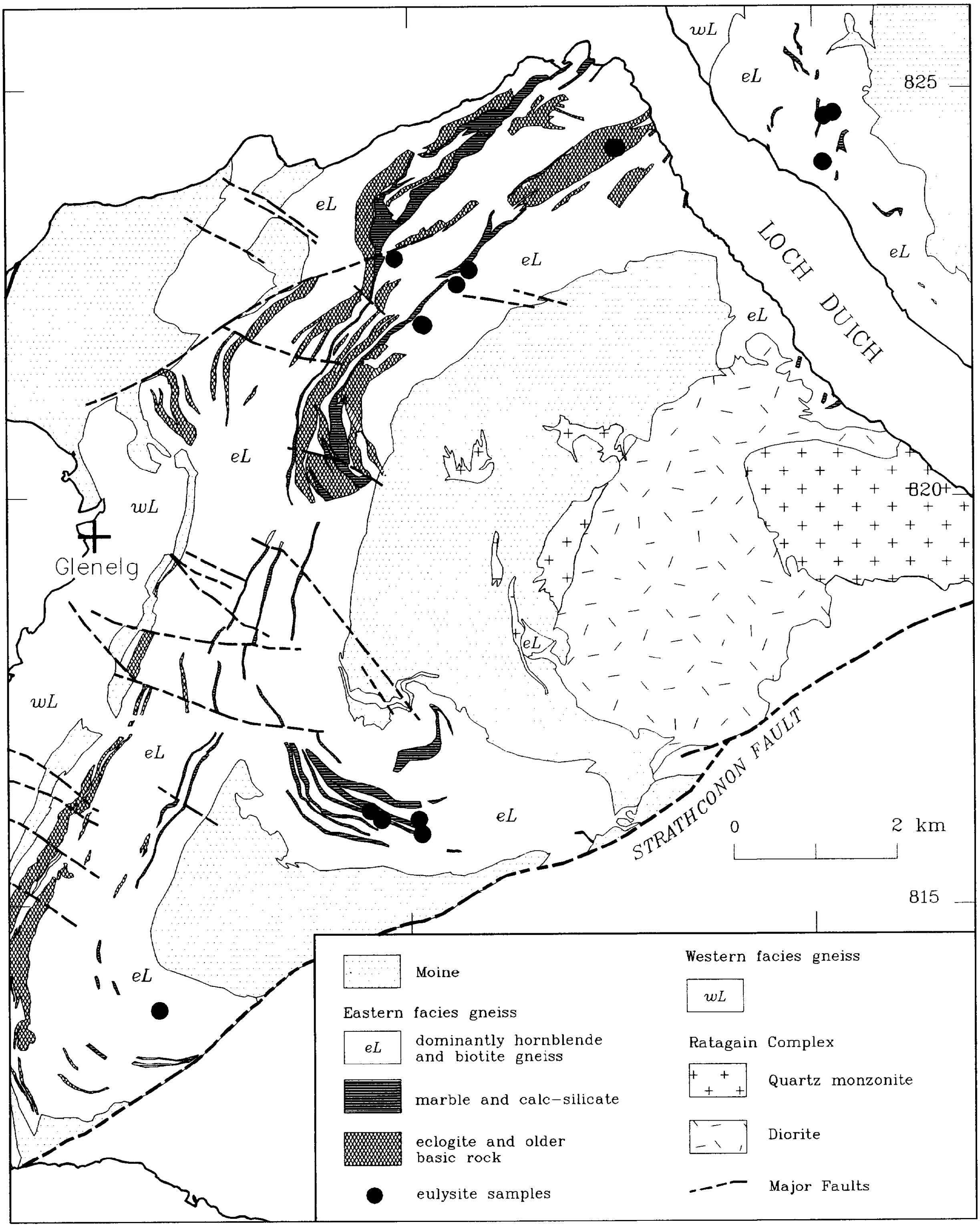

Figure 32 Location of eulysite samples in the Eastern Lewisian

or eclogites, except at Carr Brae where the eulysite is interbanded with quartz-feldspar and quartz-garnet rocks in a metasedimentary or sedimentary-exhalative assemblage. Garnet-rich rocks are closely associated with the eulysites where they are well exposed at Carr Brae and, also, in the Gleann Beag gorge section [185140 815860]. In the latter section the metasedimentary exhalative unit is about 2.5 m thick, of which 0.5 m is magnetite-rich eulysite (susceptibility readings 0.4 - 0.7 SI), which is separated by a 1 m thick hornblende gneiss unit from 5 m of calc-silicate rock and marble.

The chemistry of the twenty one samples of eulysite is summarised in Table 8. Iron and manganese are the two elements most characteristic of the eulysites, and the iron content varies over a fairly wide range from 14 to 30 % total Fe and the manganese content from 2.3 to 6.6 % Mn. These variations are partly due to sampling, as most of the eulysites are strongly banded with alternating layers rich in magnetite, garnet, olivine, pyroxene and amphibole. Most of the silicate minerals are iron-rich varieties such as almandine, fayalite, hedenbergite and grunerite (Tilley, 1936; May et al., 1993) so there is no simple relationship between, for example, the magnetite and the iron content. Plotting Fe and Mn against each other shows a good positive correlation, but gives little information on the origin of the eulysites. However, plotting Fe/Ti against Mn produces a good discrimination between the eulysite samples and the normal metasedimentary and meta-igneous rocks (Figure 33). This plot shows that the eulysite samples and related garnetiferous rocks have elevated iron and manganese relative to titanium. Titanium in most metasedimentary rocks is an indicator of the detrital component and normally covaries with iron, both elements increasing with the clay fraction, except where iron is introduced by chemical processes. Rocks plotting along a trend parallel to the x-axis, with an increase in the Fe/Ti ratio but little increase in Mn, are pyritiferous calc-silicate rocks and marbles, and serpentinites. Most metabasic rocks have Fe/Ti ratios between 2 to 20 and 1000 - 2000 ppm Mn, because differentiation in basic rocks is dominated by spinel and pyroxene crystal separation from the magma. Because the eulysite trend appears to branch away from the main scatter in the metabasic region of the plot it is suggested that the original source rock, before the chemical addition of iron and manganese, was a metabasite rather than a calcareous or dolomitic one. This hypothesis is supported by the common association of eulysites and metabasites. Another feature shown on this plot is the fact that the garnet-quartz rocks associated with the magnetite-rich eulysites plot along the same trend, indicating that both have a similar origin as chemical sediments. High values of manganese in iron-rich rocks indicate either a hydrothermal or a hydrogenous origin (Binns et al., 1993), but cobalt, the most diagnostic element that can be used to distinguish these origins, was unfortunately not determined in this study. Rocks rich in spessartine garnet such as coticules, are, however, normally regarded as indicating an exhalative origin (Valliant and Barnett, 1982) and the association of BIF and Mn-rich rocks is similarly indicative.

The only complete major element analysis of a eulysite is given by Tilley (1936) and this shows a Si/Fe ratio of 0.50. This rock would be classified as a Type 3 deposit using the classification of Hekinian et al. (1993) who studied the recent Fe and Si oxyhydroxide deposits of the South Pacific and EPR region. The Type 3 deposits were originally composed of clay-rich Fe-Si oxyhydroxides and deposited on the sea floor around submarine vents by precipitation from relatively cold solutions produced by mixing between sea water and hydrothermal fluids. A similar origin is proposed for the eulysites.

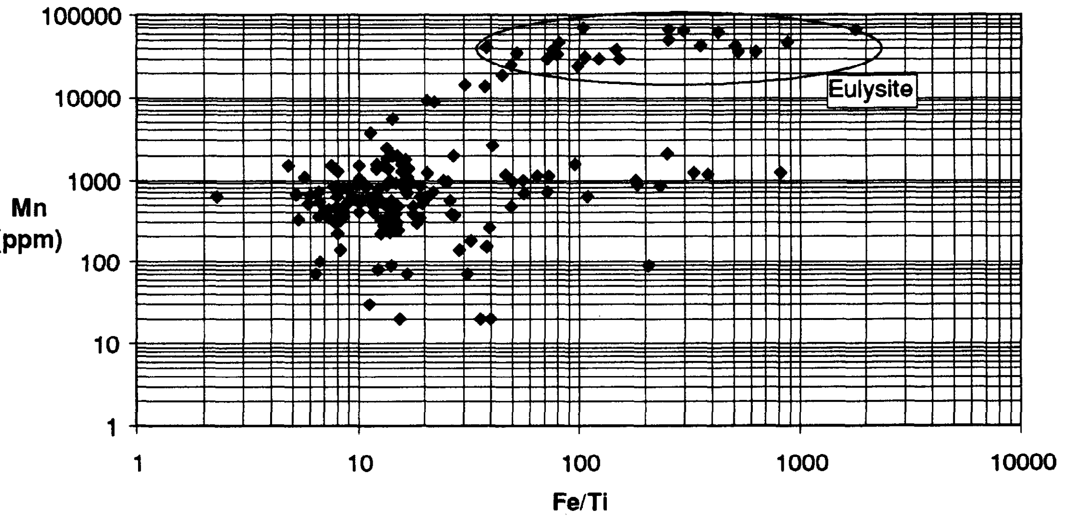

Figure 33 Variation of Fe/Ti vs Mn in the lithogeochemistry samples

Comparison of the trace and major element compositions of the Glenelg metabasites (Sanders, 1972 and this study) on various discrimination plots given in Rollinson (1993) indicates that they can be classified as fairly primitive MORB-type basalts, possibly intruded into a back-arc basin setting. The median metabasite values for K, Ba, Zr, Ti, Sc, Ni, and Cr vary by less than a factor of two from the standard MORB composition. However, this conclusion must be rather tentative because of the lack of determinations of several critical elements, such as Sr, Nb, Y and Ce, and the very high degree of metamorphism which may have affected the trace element ratios.

The gold content of the eulysites is low with between 1 and 5 ppb Au in the 22 samples. Gold is correlated with copper and nickel, and these elements probably occur in the sulphide patches that are found in some of the eulysites and related garnet-rich rocks. These patches are usually quite small, of the order of 10 cm in maximum length at the Carr Brae and Gleann Beag outcrops. Sample KLR4706 is a garnet-quartz rock adjacent to the eulysite in Gleann Beag and contains an estimated 10% visible sulphide. This sample has a relatively high gold content of 7 ppb Au and also contains 2926 ppm Cu. There is a large range from 21 ppm to 1091 ppm Cu in the eulysites, and higher values are correlated with the occurrence of sulphide-rich segregations. Zinc and lead contents of the eulysites and related rocks are low, but copper, as the above example shows, does reach quite high levels. Compared with the quartz-magnetite schists (QMS) at the Gairloch deposit (Jones et al., 1987) the eulysite is strongly enriched in Mn and Cu (Table 8). Jones (op. cit. p. B139) postulated that the copper content of the QMS is a useful exploration guide to the ore horizon, and the enhanced level of copper at Glenelg is a positive indication for sulphide mineralisation. However, there are differences between the iron-rich rocks in the two area; being generally quartz-free at Glenelg and dominantly quartz-magnetite schists at Gairloch (Williams et al., 1985). Garnet-quartz rocks are present at Glenelg and garnet-grunerite silicate facies rocks, similar to the eulysites, are also are also found at Gairloch (Williams, 1986).

Table 8 Comparison of median composition of eulysites from the project area with those of quartz-magnetite schists (QMS) from Gairloch and average compositions of banded ironstones from Canada					
	(1) Median of eulysite	(2) QMS (hanging wall)	(3) QMS (surface samples)	(4) Algoma iron formation	(5) Lake Superior iron formation
Ti	1370	1139	<100	750	170
Fe %	21.78	-	11.68	30.91	30.96
Mn	38250	1730	1400	1120	5130
V	62	-	-	60	30
Cr	65	85	67	78	110
Ni	29	-	15	80	30
Cu	179	67	19	50	10
Zn	39	28	12	60	30
As	3	-	-	120	2990
Sr	23	<50	-	70	30
Y	26*	-	-	20	40
Zr	6*	-	-	40	60
Mo	5*	-	9	-	-
Ba	33	<500	-	210	170
Au (ppb)	1	-	-	38	19
Pb	3	<10	<5	-	-

Values in ppm except where otherwise stated

- not determined

* only 2 determinations (other elements between 18 and 21 determinations)

Sources: Column (1) Eulysite, this study; (2) Table 6, Quartz-Magnetite-Schist (QMS) Jones et al. (1987); (3) Table 7, QMS Jones et al. (1987); (4) Table 6, Gross (1988); (5) Table 6, Gross (1988).

Mineralogy and origin of the eulysites and related rocks

Six samples of the eulysite and related garnet-rich rocks were examined petrographically (eulysites - KLR 4662, 4664, 4676, 4707, 4754 and a garnet-quartz rock (KLR 4706) from Gleann Beag). Tilley (1936) and Sanders (1972) also give detailed petrographic descriptions. The mineralogy of the rocks is relatively simple, being predominantly composed of magnetite, garnet and a pale actinolite. The garnet is a manganoan almandine with an average composition of $Pyr_{5.45}$ $Alm_{46.46}$ $Spess_{32.73}$ $Gro_{10.32}$ $And_{5.04}$ and contains in excess of 12 % MnO (Fortey, 1993).

The eulysites are stratabound and were deposited within a mixed assemblage of volcanic rocks (primitive MORB-type basalts) and sedimentary rocks (limestones, calcareous pelites and pelites). These iron-rich rocks have an unusual chemistry, and the protolith has been described as a sedimentary ironstone by Tilley (1936) and a similar conclusion was reached by Sanders (1972). However, the unusual chemistry of the eulysite, with very high levels of Mn and Cu and low levels of elements such as Ti, Zr and Ba, indicates that a detrital origin is unlikely. Associated rock-types, such as the spessartine-rich coticules (Kennan, 1986), also indicate an exhalative origin rather than a detrital one. Comparison with modern analogues in the Pacific (Hekinian et al., 1993) indicates that it could have been formed as a submarine exhalite from solutions formed by mixing between sea water and hydrothermal fluids issuing from a submarine volcanic sequence. The discontinous nature of the eulysite may be an original feature, as modern analogues are commonly found with dimensions of the order of tens of metres across (Binns et al., 1993), distributed at intervals along a line of submarine vents. In summary, therefore, the eulysite and associated garnet-rich rocks are believed to have been formed as a submarine exhalative sediment within a mixed volcanic and sedimentary assemblage.

Pyrite-bearing Calc-silicate rocks

At several localities in the Carr Brae area pyrite-bearing calc-silicate gneisses occur adjacent to the main marble units. These are typically green in colour with between 5 and 10% sulphides visible in hand specimen. Three samples examined petrographically are composed of plagioclase, tremolite and various accessory minerals, including sphene, clinozoisite, quartz and muscovite. The rocks were sampled for their sulphide content, which is predominantly pyrite with accessory pyrrhotite, chalcopyrite and molybdenite. Graphite is also present in two of the three samples examined mineralogically. Calc-silicate rocks or metamorphic skarns are often described as being extremely inhomogeneous, mineralogically variable, they are often monomineralic or bimineralic, with compositions that reflect carbonate-silicate reactions, rather than original sediment composition (Rock, 1987).

Thirty samples of the calc-silicate gneisses were collected, and the locations can be obtained from the MRP Geochemistry Database. The chemical data is summarised in Table 9. The calcium content ranges from 0.91% up to 13.65%, but there is a clear cluster with around 4.6 %Ca. This wide range is a typical feature of calc-silicate rocks, as stated above, but the clustering around the median indicates that there was a common parent composition. Iron behaves in a similar fashion and suggests that the rocks were derived from the metamorphism of muddy, impure dolomitic rocks or marls.

Gold is significantly above detection limit (5 ppb) in only two samples (KLR 4270 with 46 ppb and KLR 4271 with 25 ppb) both of which were collected in Leth Allt at [190980 823340]. These samples have elevated copper values of 256 ppm and 410 ppm repectively, but other pathfinder elements, such as As, Ag, Sb and Bi are low. The low content of gold (1 - 4 ppb) in the calc-silicate samples KLR 3847, 4667 and 4668 collected from the vicinity of the old gold trial to the north west of Inverinate is in contrast to the 1.8 ppm Au reported by Peach et al. (1910). One sample (KLR 4667) has the highest arsenic content of any of the calc-silicate rocks but at 10 ppm As this cannot be regarded as a gold pathfinder. Nickel, another element reported in the early account (0.8% Ni), is also low (56, 29, and 31 ppm Ni) in samples from the old trial.

Copper is enriched in the calc-silicate rocks, with a median content of 275 ppm. This contrasts with the low levels in the marbles with medians of 2 ppm Cu (May et al. 1993) and 3 ppm Cu (this study). Copper is positively correlated with nickel (Spearman r=0.56) but not with iron (r=-0.11), and seems to be controlled by the sulphide content, rather than the clay silicate input from sedimentary sources.

The maximum content of 1049 ppm Cu is found in sample KLR 4697 from the southern part of the Glenelg area at [181490 813940].

Three samples of the calc-silicate gneiss were examined petrographically (KLR 4667, 4695 and 4697). The first sample was collected from the pyritic calc-silicate unit at the old gold trial at [189530 824320] and in thin section is composed of granulitised bands of quartz, amphibole, muscovite and feldspar. The amphibole has a relict core of silicic edenite (a sodic variety of hornblende) and granulitised margins of tremolite. Sphene and clinozoisite are present as accessory minerals, accompanied by about 2% pyrite and pyrrhotite. Graphite is also present as clusters of flaky grains, typically 0.4 by 0.2 mm in size, forming about 4% of the rock by volume. KLR 4695 collected at [182200 814030], 800 m west of the outlet of Loch Bealach na h-Oidhche, has a similar mineralogy of oligoclase, tremolite, sphene, pyrite and graphite but accessory molybdenite is also present. KLR 4697 from [182490 813940] 300 m nearer the loch has a different mineralogy with andesine and augite being the major phases accompanied by sphene, pyrite and accessory pyrrhotite and chalcopyrite. The differences in mineralogy are probably the result of metamorphic retrogression from granulite facies (May et al., 1993), but the original sediment must have been quite variable in composition with some of the precursors being enriched in carbon and molybdenum.

Table 9 Summary statistics for the calc-silicate gneiss samples

	N	Median	25 % Percentile	75 % Percentile	Mean	Standard Deviation	Minimum	Maximum
Ca	30	46100	33450	63400	52950	29045	9100	136500
Ti	30	2810	2218	4180	3449	2029	100	8730
V	30	110	78	248	190	196	21	1054
Cr	25	141	85	206	150	86	9	384
Mn	30	610	435	880	703	403	220	2020
Fe	30	42200	31850	51000	43523	17167	15100	90500
Ni	30	64	39	107	73	45	7	190
Cu	30	275	149	383	370	307	5	1049
Zn	30	27	8	46	36	32	2	129
As	25	1	0	3	2	3	0	10
Sr	17	412	322	1034	650	465	70	1492
Ba	30	159	82	539	344	383	27	1644
Au (ppb)	30	2.5	1	4	4.8	8.9	1	46
Pb	30	4.5	1	7	5	6	0	29

(All values in ppm, except Au in ppb)

The elevated contents of copper and, to a lesser extent gold, are scientifically interesting but the present sampling indicates that the calc-silicate rocks have little economic potential. The accuracy of the analyses reported by Peach et al (1910) is questionable and may overstate the gold assays to interest potential investors. Alternatively, a small sulphide-rich lens may have been present at this trial and was subsequently mined away causing abandonment of the enterprise. The reported 55 % Fe content of one sample (Peach et al. 1910) indicates either a massive sulphide body or extremely selective sampling. The memoir describes "many strings and finely disseminated particles of pyrites", which is similar to the calc-silicate rocks exposed close to the trial today.

Graphite-bearing gneiss

Graphite-bearing rocks with a noticeable pyrite content are exposed at several locations in Glenelg and can be traced across the project area from Loch Duich to Gleann Beag (Figure 34). These occurrences were also noted by Peach et al., (1910) and two localities near Lochan na Beinne Faide [1861 8236] were singled out as being particularly rich in graphite (op cit. p174). In the present survey graphite was recorded in twenty-four rock samples and fourteen of these were estimated to contain more than 5% visible graphite and are compared as a group. The summary statistics of their chemistry is given in Table 10 and when normalised to the average shale given by Taylor and MacLennan (1985) can be compared (Figure 35) with average black shale (Vine and Tourtelot, 1970) and to Keretti black schists of Proterozoic age in Finland (Loukola-Ruskeeniemi 1992). The Glenelg graphitic gneiss is depleted in Ba, Pb and Zn but enriched in Ca, Cr, Cu and V, reflecting a basaltic rather than crustal input to the black shale basin. The high level of copper (median 178 ppm Cu) is noteworthy, nearly reaching the levels (230 ppm Cu) in the Keretti black schists, which are associated with the well known Outokumpu ore deposits in Finland.

Table 10 Summary statistics for samples of graphitic gneiss

	N	Median	25 th percentile	75 th percentile	Mean	Standard Deviation	Maximum	Minimum
C	12	21000	8950	38000	35383	44178	161600	2500
S	12	15850	8450	21250	17505	14317	43700	100
Ca	13	25300	14300	38975	29346	20477	71000	9000
Ti	13	4390	3550	5038	4280	1597	6800	530
V	13	225	162	282	224	102	402	51
Cr	13	178	139	232	194	72	357	99
Mn	13	620	470	823	642	310	1380	220
Fe	13	41800	35600	47625	51400	27860	110100	21500
Ni	13	52	39	68	59	35	143	17
Cu	13	178	111	411	268	236	794	55
Zn	13	50	24	55	50	33	126	10
As	13	2	0	3	4	9	34	0
Sr	7	206	110	263.5	194	104	339	63
Ba	13	177	74	586	379	420	1243	22
Au	13	3	2	4	4	2	10	1
Pb	13	7	2	22	21	41	153	0

All values in ppm, except Au in ppb

The median content of carbon is not very high (2.1% C) compared with the average black shale (3.2% C) but just above the cut-off level of 1% C used to distinguish black from normal marine shales. Normal marine sediments deposited from oxygenated bottom waters show relatively constant C/S ratios of about 2.8 (Lyons and Berner 1992), but the samples from Glenelg exhibit a wide scatter and do not follow this trend. Sediments deposited under euxinic conditions typically have higher sulphur levels but still follow the same C/S trend. The wide scatter of carbon and sulphur values at Glenelg does not allow even this hypothesis to be accepted. The high metamorphic grade will have modified

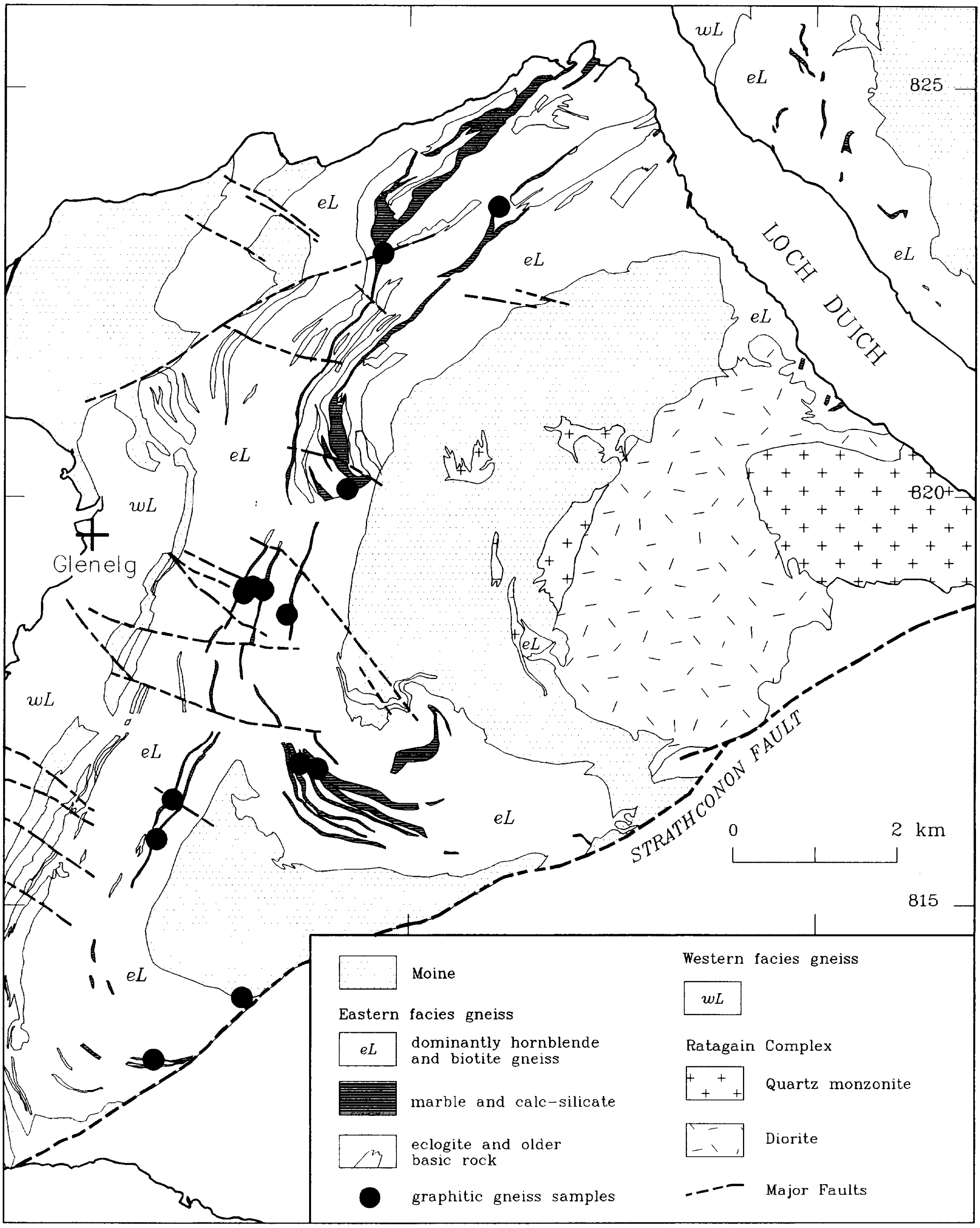

Figure 34 Location of graphite gneiss samples in the Eastern Lewisian

the original carbon and sulphur distribution, but it seems more likely that the original occurrence of pyrite and organic matter in the sediments was very variable. Further work involving stable isotopes may be needed to elucidate the effect of metamorphism on the bulk composition of the rocks.

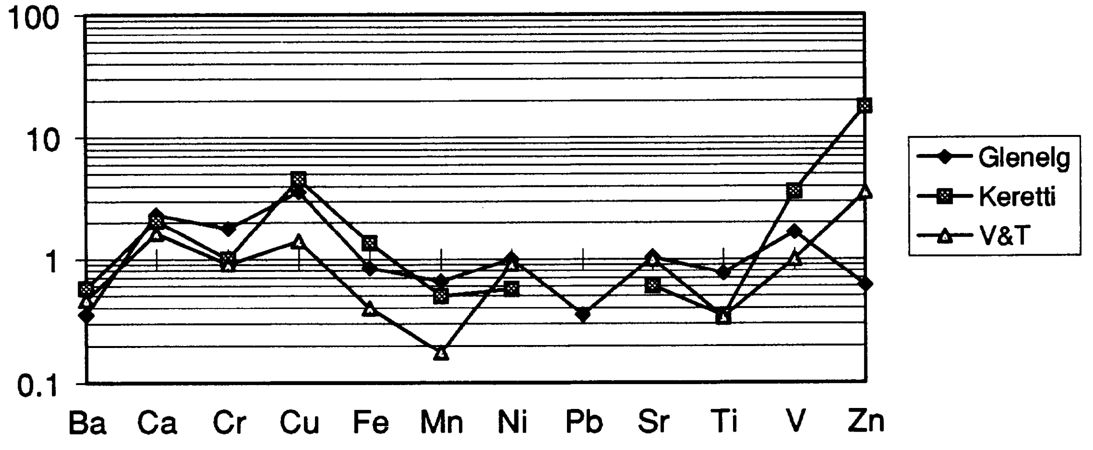

Figure 35 Comparison of Glenelg graphitic gneiss, Keretti black schists (Loukola-Ruskeeniemi 1992), and average black shale (Vine and Tourtelot 1970), normalised to Taylor and MacLennan's average shale (1985).

Rocks with graphite are sufficiently unusual in the United Kingdom to warrent some further investigation, particularly as the mineral is fairly coarsely crystalline. Twelve samples were selected for the determination of their total carbon and sulphur contents using the Leco method by Acme Laboratories. The results are shown in Table 11 and the presence of a high carbon content is confirmed in most samples. The richest sample KLR 4370 was collected from a 0.5 m gneiss layer interbanded with amphibolites at [184680 822980] and this locality is probably one of those recorded by Peach et al. (1910).

One sample, KLR 4712, which occurs at [182105 816305] as a 20 cm thick band between two marble units, was selected for petrographic study (Fortey, 1993) as being fairly typical of the graphitic gneiss. The bulk of the rock is crudely banded, with a fine grained interlocking mosaic of oligoclase, phlogopite and actinolite with accessory sphene, apatite and zircon. Beautifully formed crystals of flake graphite are very common, forming about 5 % of the thin section by volume and varying in size from 0.4 by 0.08 mm up to 2.0 by 0.6 mm. The graphite is accompanied by chalcopyrite, pyrite and rare pyrrhotite. The occurrence of calc-silicate minerals in black schist from the Outukumpu assemblage is recorded by Loukola-Ruskeeniemi (1992), who suggested a black, dolomitic mudrock precursor.

Table 11 Total carbon and sulphur contents of graphitic gneisses

Sample number	C	S
KLR4370	161600	100
KLR4388	6000	43700
KLR4404	36900	43000
KLR4406	39100	18700
KLR4411	29600	15700
KLR4462	1000	55300
KLR4467	2500	18400
KLR4700	62600	100
KLR4712	47500	10500
KLR4730	6400	9600
KLR4731	10200	23800
KLR4733	12400	5000
KLR4738	9800	16000

All values in ppm

THE RATAGAIN IGNEOUS COMPLEX

A suite of Caledonian igneous rocks forming the Ratagain igneous complex is intruded into the Lewisian and Moinian metamorphic rocks and this has been the subject of several recent studies (May et al., 1993). Previous workers have recorded the presence of mineralisation in the complex (Peach et al., 1910; Aucott and Collingborn 1971; and Alderton, 1986, 1988) and a small sampling programme of the observed veins and shear zones to investigate spatial distribution of the electrum mineralisation was carried out.

Twenty-five samples of mineralised veins and brecciated crush rocks were collected from several host rock types, mainly different units of the Ratagain igneous complex but also Moinian and Lewisian rocks. Alderton (1988) sampled twelve localities in the Ratagain complex and found anomalous values of gold, up to maximum of 5.46 ppm Au at his site 12. This site lies near the eastern margin of the intrusion and within the Strathconon fault zone. Another four samples of vein material were collected in 1989 by A G Gunn of the Minerals Group during the course of exploration for platinum group elements. One of these samples, PGR 8079, resampled the Alderton site 12 anomaly at [193950 819850] and the results are given in the following description. Because of the host rock variation, summary statistics for the veins were only calculated for a few of the chalcophile elements (Table 12) but full details of the analyses are available from the MRP database on request.

Table 12 Comparison of gold and base metal contents of veins in the Ratagain complex and the Moine and Lewisian country rocks						
	N	Median	25 th percentile	75 th percentile	Minimum	Maximum
Ratagain Complex						
Au	16	6	2	20	1	100
Ag	13	1	0	5	0	52
Cu	17	18	6	29	1	1745
Zn	17	49	35	111	9	>5000
As	17	0	0	0	0	2
Pb	17	94	19	465	2	3895
Bi	13	2	1	5	0	87
Lewisian and Moine country rocks						
Au	6	1	1	2	1	4
Ag	5	1	0	1	0	2
Cu	6	24	12	37	7	65
Zn	6	48	42	51	25	72
As	6	2.5	0.5	9.75	0	18
Pb	6	9	6	13	1	14
Bi	5	1	0	2	0	2

All values in ppm, except Au in ppb

Gold levels in the veins are not very anomalous. Sample PGR 8079 contains 0.975 ppm Au, which is probably more representative of the vein because of the larger sampling mass of the fire assay method used by BGS compared to the 1.5 gm used in the neutron activation method employed by Alderton. Further sampling (KLR 4262) of the vein in the course of this study produced only 37 ppb Au. Mineralised veins in the Ratagain complex are concentrated within the quartz monzonite and have a higher and more variable gold content (range 1 - 100 ppb and median 6 ppb Au) than veins and breccia zones in the Moinian and Lewisian country rocks which have low concentrations of gold (range 1-4 ppb Au in six samples). One unusual feature of the chemistry is that the veins in the Ratagain complex have lower levels of arsenic, even though Alderton (1988) recorded two arsenic minerals, tennantite and gersdorffite.

The exceptions to this are the Srath a' Chomair veins, which are thin, 10 - 100 mm quartz-carbonate veins cutting micaceous gneiss of the Eastern Lewisian and exposed in the upper reaches of the Abhainn a' Ghlinne Bhig at [187100 815870]. Two samples of these veins, KLR 4428 and 4430, contain 400 and 110 ppb Au respectively and high levels of Cu (1.2 and 0.2 %), Pb (both >1 %) and Zn (both >0.5 %). Arsenic is also enriched to a lesser extent (95 and 23 ppm) along with nickel (74 and 70 ppm).

Zones of fenite-type, soda-metasomatism occur within the Ratagain igneous complex, most notably in a roadside cutting at [189215 819855]. Blue Na-amphibole, shown by mineralogical work to be Mg-riebeckite (Mitchell, 1994), and possible aegirine (not confirmed by XRD) are found on joint coatings and in marginal alteration selvages. This metasomatism is closely similar to that described by Garson et al. (1984) in the Great Glen and, also, to alteration in the Loch Ailsh (Coats, unpublished work) and Loch Borralan intrusions (Rock, 1977). One sample of the metasomatised quartz monzonite contains 17 ppb Au but low values of base metals. The metasomatism is another feature showing the geological similarities between the Ratagain complex and the alkaline syenites of similar age in the north west Highlands, which are intruded into the Lewisian foreland close to the Caledonian Moine Thrust rather than within the thrust zone as is Ratagain.

The mineralisation in the Ratagain complex is concentrated within the quartz monzonite and, whilst widespread and sporadic in extent, is never very localised or intense and gold grades are low. Late-stage magmatic fluids are suggested by Alderton (1988) on the basis of fluid inclusion studies to have caused the mineralisation and they seem to have caused extensive, low-grade mineralisation rather than being focussed by a small late-stage intrusion or an active fault zone. The relationship between these late-magmatic hydrothermal fluids and that responsible for the soda metasomatism is unknown. The Srath a' Chomair veins are a more interesting target since, like the one auriferous vein (site 12) described by Alderton (1988), they occur within the Strathconon fault zone. This fault extends for about 100 km and has been shown to have drainage anomalies for gold in the Scardroy area (Coats et al., 1993). The fault is normally poorly exposed, and detailed drainage sampling and prospecting along its length is justified.

CONCLUSIONS

The project area contains several promising indications for the occurrence of economic mineralisation. The rocks of the Eastern Lewisian can be classified into three main groups: metasediments, basic and and ultrabasic rocks, and hornblende and biotite gneisses. The hornblende and biotite gneisses may form part of an earlier migmatite complex into which the igneous rocks were subsequently emplaced and the sediments were deposited in a basement - cover relationship (May et al., 1993). The metasediments are pelite, marble and calc-silicate, and quartzo-feldspathic gneiss, and closely interbanded with these metasediments are basic and ultrabasic rocks, which have all been subsequently metamorphosed to at least granulite facies. The most likely depositional environment seems to be a rift setting, with primitive basaltic material being intruded into high levels in the crust and on to the sea floor. Exhalative activity on the sea floor, with the mixing of seawater with hydrothermal fluids emanating from the volcanic pile, could allow the production of highly iron-and manganese-rich exhalative sediments, now represented by the eulysites and garnet-rich rocks. In such highly deformed rocks it is difficult to prove a stratigraphic succession, but the eulysite seems to be associated with the top of the igneous rocks and within the mixed sedimentary and, possibly, tuffaceous sequence (Tables 6 and 7). At modern sea-floor vents intense bacterial activity takes place and this could produce the highly carbonaceous and pyritic rocks seen in this area. Deposition of limestone, dolomitic sediments and black shales (now represented by the marble, calc-silicate rock and graphitic gneiss) took place with some input of igneous material during the waning part of the volcanic activity.

The Eastern Lewisian in the Glenelg area has affinities with Lewisian rocks in South Harris in terms of the rock types present, the chemistry of marbles (Rock 1983) but the occurrence of iron or manganese rocks has not been recorded in the Outer Hebrides. There are more similarities with the Tiree and Gairloch areas, where BIFs have been recorded and these will be the subject of a later report. The occurrence of BIFs at Glenelg and Tiree is indicative of exhalative activity in the Lewisian, and may be related to similar gold and base metal mineralisation to that recorded at Gairloch (Jones et al., 1987).

If the eulysite is an exhalative deposit, as is suggested, it could provide a stratigraphic marker to Besshi-style or volcanic massive sulphide deposits. However, despite tracing the outcrops of the eulysite for 13 km very little evidence for base-metal mineralisation could be found except for some marginally high copper values. Some of the rock types associated with the eulysite show slightly better potential, and the calc-silicate rocks do contain relatively high (though subeconomic) levels of copper and some gold.

In the metasedimentary sequence the graphite-bearing lithologies have the highest economic potential and it is recommended that further work is undertaken to investigate the occurrence of coarsely crystalline graphite. Graphite is a valuable industrial mineral, ranging in price from $250 to $500 per metric tonne. The variation in price is dependant on the grain size of the graphite, coarse, highly crystalline graphite attracting the highest prices. A full economic evaluation of the graphite has not been attempted in this study but there is clearly some potential. Laboratory testing is required to ascertain that the graphite can be easily liberated from the host rock. and the resultant grain size. Further field sampling to assess the representivity of the samples will also be necessary.

The project area has some potential for further discoveries of gold-bearing sulphide veins. It is not considered that there are any to be found within the Ratagain complex, which is relatively well exposed and has been extensively mapped and explored. However, the indications of vein-style mineralisation, which have been found by drainage sampling, on the north side of Loch Alsh and, perhaps, on the southern side of Loch Carron are promising, and may repay limited exploration. The Strathconon fault zone is also considered to be propspective for gold mineralisation.

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