Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

This report relates to work carried out by the Institute of Geological Sciences on behalf of the Department of Industry. The information contained herein must not be published without reference to the Director, Institute of Geological Sciences

D. Ostle
Programme Manager
Institute of Geological Sciences
Keyworth,
Nottingham NG12 5GG

No. 50

Geochemical drainage survey of central Argyll, Scotland

INSTITUTE OF GEOLOGICAL SCIENCES

Natural Environment Research Council

Mineral Reconnaissance Programme

Report No. 50

Geochemical drainage survey of central Argyll, Scotland

J. S. Coats, BSc, PhD
B. C. Tandy, MSc
U. McL. Michie, BSc

London 1982

A report prepared for the Department of Industry

Mineral Reconnaissance Programme Reports

1 The concealed granite roof in south-west Cornwall
2 Geochemical and geophysical investigations around Garras Mine, near Truro, Cornwall
3 Molybdenite mineralisation in Precambrian rocks near Lairg, Scotland
4 Investigation of copper mineralisation at Vidlin, Shetland
5 Preliminary mineral reconnaissance of Central Wales
6 Report on geophysical surveys at Struy, Inverness-shire
7 Investigation of tungsten and other mineralisation associated with the Skiddaw Granite near Carrock Mine, Cumbria
8 Investigation of stratiform sulphide mineralisation in parts of central Perthshire
9 Investigation of disseminated copper mineralisation near Kilmelford, Argyllshire, Scotland
10 Geophysical surveys around Talnotry mine, Kirkcudbrightshire, Scotland
11 A study of the space form of the Cornubian granite batholith and its application to detailed gravity surveys in Cornwall
12 Mineral investigations in the Teign Valley, Devon. Part 1—Barytes
13 Investigation of stratiform sulphide mineralisation at McPhun's Cairn, Argyllshire
14 Mineral investigations at Woodhall and Longlands in north Cumbria
15 Investigation of stratiform sulphide mineralisation at Meall Mor, South Knapdale, Argyll
16 Report on geophysical and geological surveys at Blackmount, Argyllshire
17 Lead, zinc and copper mineralisation in basal Carboniferous rocks at Westwater, south Scotland
18 A mineral reconnaissance survey of the Doon–Glenkens area, south-west Scotland
19 A reconnaissance geochemical drainage survey of the Criffel–Dalbeattie granodiorite complex and its environs
20 Geophysical field techniques for mineral exploration
21 A geochemical drainage survey of the Fleet granitic complex and its environs
22 Geochemical and geophysical investigations north-west of Llanrwst, North Wales
23 Disseminated sulphide mineralisation at Garbh Achadh, Argyllshire, Scotland
24 Geophysical investigations along parts of the Dent and Augill Faults
25 Mineral investigations near Bodmin, Cornwall. Part 1-Airborne and ground geophysical surveys
26 Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Preliminary report
27 Airborne geophysical survey of part of Anglesey, North Wales
28 A mineral reconnaissance survey of the Abington–Biggar–Moffat area, south-central Scotland
29 Mineral exploration in the Harlech Dome, North Wales
30 Porphyry style copper mineralisation at Black Stockarton Moor,south-west Scotland
31 Geophysical investigations in the Closehouse–Lunedale area
32 Investigations at Polyphant, near Launceston, Cornwall
33 Mineral investigations at Carrock Fell, Cumbria. Part 1-Geophysical survey
34 Results of a gravity survey of the south-west margin of Dartmoor, Devon
35 Geophysical investigation of chromite-bearing ultrabasic rocks in the Baltasound–Hagdale area, Unst, Shetland Islands
36 An appraisal of the VLF ground resistivity technique as an aid to mineral exploration
37 Compilation of stratabound mineralisation in the Scottish Caledonides
38 Geophysical evidence for a concealed eastern extension of the Tanygrisiau microgranite and its possible relationship to mineralisation
39 Copper-bearing intrusive rocks at Cairngarroch Bay, south-west Scotland
40 Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Final report
41 Metalliferous mineralisation near Lutton, Ivybridge, Devon
42 Mineral exploration in the area around Culvennan Fell, Kirkcowan, south-western Scotland
43 Disseminated copper-molybdenum mineralisation near Ballachulish, Highland Region
44 Reconnaissance geochemical maps of parts of south Devon and Cornwall
45 Mineral investigatons near Bodmin, Cornwall. Part 2 New uranium, tin and copper occurrence in the Tremayne area of St Columb Major
46 Gold mineralisation at the southern margin of the Loch Doon granitoid complex, south-west Scotland
47 An airborne geophysical survey of the Whin Sill between Haltwhistle and Scots' Gap, south Northumberland
48 Mineral investigations near Bodmin, Cornwall. Part 3 The Mulberry and Wheal Prosper area
49 Seismic and gravity surveys over the concealed granite ridge at Bosworgy, Cornwall
50 Geochemical drainage survey of central Argyll, Scotland

The Institute of Geological Sciences was formed by the incorporation of the Geological Survey of Great Britain and the Geological Museum with Overseas Geological Surveys and is a constituent body of the Natural Environment Research Council

Bibliographical reference
Coats, J. S. and others. 1982. Geochemical drainage survey of central Argyll, Scotland. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 50

Photocopied in England for the Institute of Geological Sciences by Four Point Printing

CONTENTS

Summary 1

Introduction 1

General geology 3

Mineralisation 3

Regional reconnaissance survey 4
Introduction 4
Analytical methods 4
Statistical analysis 6

Regional geochemical variation of elements 9
Greyscale maps 9
Copper 9
Lead 12
Zinc 15
Nickel 15
Cobalt 20
Barium 20
Uranium 20
Molybdenum 23
Silver 23
Antimony 23
Tin 26
Iron 26
Cerium 26
Calcium 31
Manganese 31
Titanium 31

Detailed drainage surveys 31
Introduction 31
Tyndrum—Glen Fyne fault system 34
Garabal Hill—Glen Fyne igneous complex 40
Ardrishaig Phyllites 43
Pyrite Zone 45
Loch Tay Limestone 48
Green Beds 51

Conclusions 52

Recommendations 54

Acknowledgements 54

References 54

FIGURES

1 Central Argyll — location and geology 2
2 Central Argyll — mineral localities 5
3 Location of stream sediment sites *in pocket*
4 Location of panned concentrate sites *in pocket*
5 Copper in stream sediments *in pocket*
6 Copper in panned concentrates *in pocket*
7 Greyscale map of copper in stream sediments 10
8 Greyscale map of copper in panned concentrates 11
9 Lead in stream sediments *in pocket*
10 Lead in panned concentrates *in pocket*
11 Greyscale map of lead in stream sediments 13
12 Greyscale map of lead in panned concentrates 14
13 Zinc in stream sediments *in pocket*
14 Zinc in panned concentrates *in pocket*
15 Greyscale map of zinc in stream sediments 16
16 Greyscale map of zinc in panned concentrates 17
17 Nickel in stream sediments *in pocket*
18 Nickel in panned concentrates *in pocket*
19 Greyscale map of nickel in stream sediments 18
20 Greyscale map of nickel in panned concentrates 19
21 Barium in panned concentrates *in pocket*
22 Greyscale map of barium in panned concentrates 21
23 Greyscale map of uranium in stream sediments 22
24 Greyscale map of molybdenum in stream sediments 24
25 Greyscale map of antimony in panned concentrates 25
26 Greyscale map of tin in panned concentrates 27
27 Greyscale map of iron in panned concentrates 28
28 Greyscale map of cerium in panned concentrates 29
29 Greyscale map of calcium in panned concentrates 30
30 Greyscale map of manganese in panned concentrates 32
31 Greyscale map of titanium in panned concentrates 33
32 Anomalies in Upper Glen Fyne 36
33 Anomalies at Invercorachan 38
34 Anomalies in Lower Glen Fyne 39
35 Anomalies near Loch Sloy 42
36 Anomalies at Cruach Mhor and Strathlachlan River 47
37 Anomalies at Lephinmore 49
38a Anomalies at Lephinchapel 50
38b Anomalies at Evanachan 50

TABLES

1 Summary statistics of reconnaissance drainage samples 6
2 Class intervals for drainage samples 7
3 Correlation coefficients between elements determined in drainage samples 8
4 Class intervals and percentile limits for greyscale isopleth maps 8

SUMMARY

A reconnaissance geochemical drainage survey of 720 km^2 of Dalradian outcrop in central Argyll identified base-metal anomalies in the Pyrite Zone, Ardrishaig Phyllites, Loch Tay Limestone and the Green Beds. Faulting and igneous intrusion modified the distribution of metal content within these formations. In the results of the reconnaissance survey, copper reached maxima of 170 ppm and 1454 ppm in stream sediments and panned concentrates respectively; lead 1050 ppm and 2595 ppm; zinc 2500 ppm and 1114 ppm; and nickel 190 ppm and 998 ppm. Maximum contents of cobalt, uranium and molybdenum in stream sediments were 120 ppm, 11.8 ppm and 14 ppm respectively, that of barium being 5.67 per cent in panned concentrate.

Resampling and the investigation of anomalous stream courses defined parts of Glen Fyne, the Garabal Hill–Glen Fyne igneous complex, the southerly outcrop of the Pyrite Zone, and the Loch Tay Limestone as zones of base-metal mineralisation in which further investigation is recommended.

INTRODUCTION

The regional geochemical drainage survey of central Argyll, Scotland (Figure 1) formed part of a larger project covering a zone of weak stratiform pyrite and other sulphide enrichment within the Argyll Group of the Dalradian of the Grampian Highlands. Interest in this 'Pyrite Zone' was stimulated by comparison with similar lithologies in the Swedish Caledonides which contain economic, strata-bound, sulphide deposits (Zachrisson, 1971). The zone is traceable from central Perthshire (Smith and others, 1977a); through central Argyll to south Knapdale (Smith and others, 1978).

Preliminary sampling of the area took place in 1975 and stream sections which produced high concentrations of base metals in sediment and/or panned concentrate samples were selected for more detailed sampling and examination in 1976, when the area of preliminary survey was also extended. Some mining companies have also investigated parts of central Argyll, but this survey does not duplicate their work to any great extent.

The tract of central Argyll investigated lies 50 km north-west of Glasgow. It extends along the north-east to south-west Caledonian strike of the Middle and Upper Dalradian rocks from Tyndrum to Ardrishaig, and covers a total area of about 720 km^2.

Access to the area is by the A82 and A83 trunk roads from Glasgow, and by the Glasgow to Oban and Fort William railway line. Limited access by sea is provided by Loch Fyne to the south, and the Crinan Canal to the west.

The physiographical features are controlled by the north-east trending Caledonian grain, modified in parts by glacial effects. The highest ground is located in the north-east where it attains a height of 1130 m on Ben Lui. The drainage pattern in this area of high relief is basically radial-dendritic, with many streams rising high on the mountain sides and rapidly draining the steep topography, causing vigorous erosion. The tributaries join the main streams in more gently graded, glacially overdeepened valleys filled with alluvium. These rivers follow a reticulate pattern reflecting geological structures or the effects of glacial erosion. Drainage by the River Falloch into Loch Lomond, and by the Rivers Fyne and Shira into Loch Fyne, follows a south-western trend. Further south-west, the ridge and valley topography has a dendritic-reticulate drainage.

Loch Fyne is a glacially overdeepened fiord, up to 200 m deep, the ground on either side of the loch reaching heights of about 500 m. Drainage has a reticulate pattern, and several lochans on the plateau to the north-west are of glacial origin. The drainage is extensively modified by hydro-electric power schemes.

Vegetation on the higher ground includes rough grassland, heather and peat bog. Some small areas of the original Caledonian Forest are preserved, especially on the lower, steep valley sides but, generally, grazing has affected the vegetation. The lower ground to the north-west is boggy and acidic, and tracts of deer grass, heather and bracken are extensive. Grassland, however, forms better pasture where the ground is well drained. Locally the vegetation consists of recent forestry plantation.

Most agricultural activity is confined to the richer pasture and arable land on the restricted coastal strip, and the large areas of upland pasture provide poor grazing for sheep and deer. Tourism is increasingly important, and forestry provides some employment. A small amount of fishing takes place in Loch Fyne. A porphyritic microgranite is

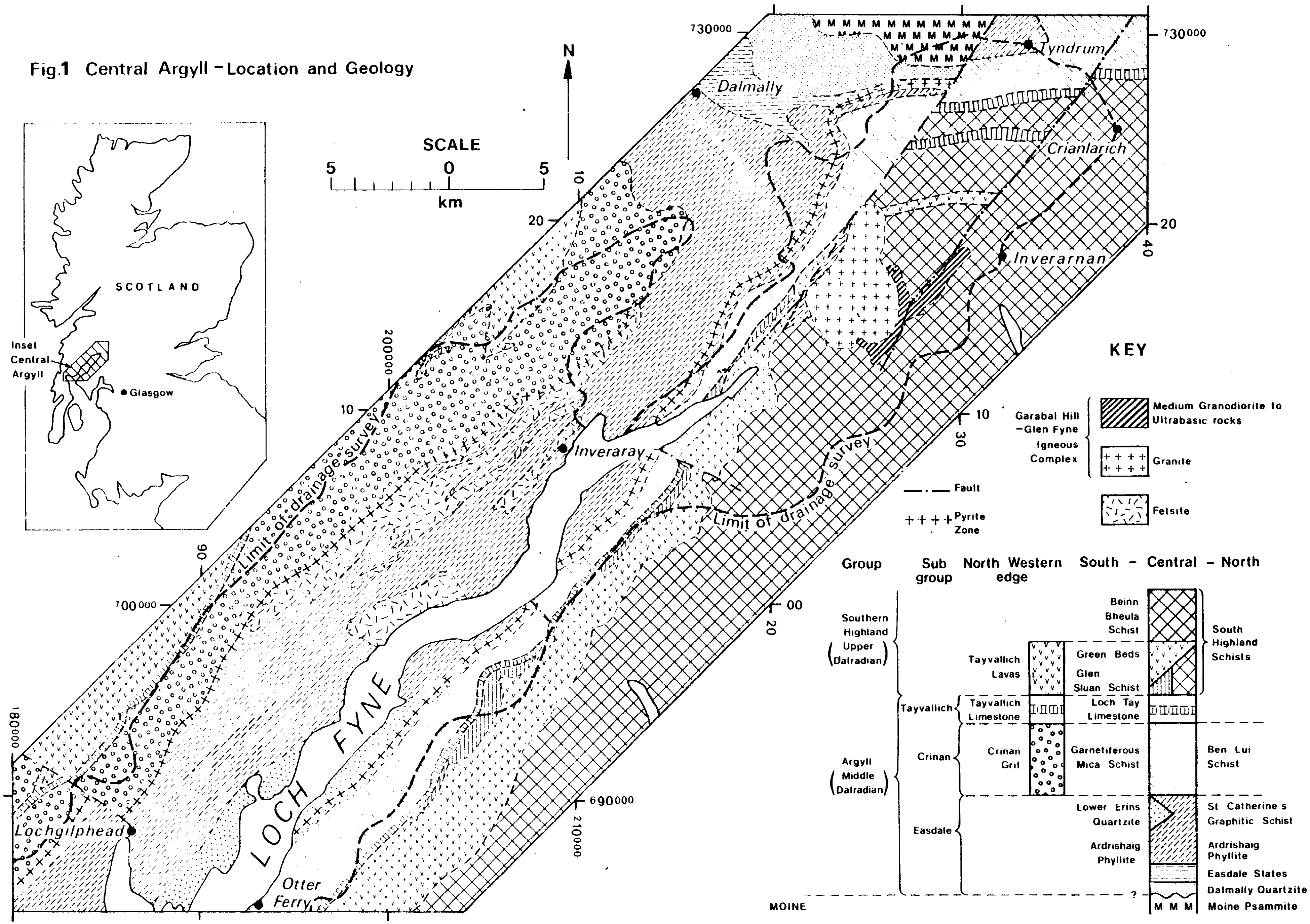


Fig.1 Central Argyll – Location and Geology

extensively quarried for roadstone, which is shipped from Furnace. The small population is confined mostly to the coast, and transport is difficult and circuitous. Access to the interior is by rough track and large distances have to be covered on foot.

GENERAL GEOLOGY

The area investigated forms part of the southern Grampians nappe complex (Johnstone, 1966), in which the Tay nappe, a recumbent anticline closing to the south-east, is the dominant early Caledonoid structure. The Ardrishaig anticline forms the root zone of this major fold. To the south-east, erosion has removed the upper limb, and the lower limb of the nappe presents an inverted stratigraphy ('Loch Tay inversion'). Further north-west, the upward facing Loch Awe syncline represents another early fold. The lower limb of the Tay nappe is also the upper limb of the large north-westward-closing Ben Lui—Kirkmichael recumbent syncline, which occupies the north-eastern part of the area.

The north-eastern limb of the Cowal anticline (antiform), a broad arch of late Caledonian foliation, crosses the south-eastern part of the area. Two north-eastward trending wrench faults, the Tyndrum—Glen Fyne fault and the Garabal fault, occur in the north-eastern part of the area. Their effects range from localised shattering to sinistral shifts of up to 8 km. The structural history of the area has been described by Roberts and Treagus (1977).

The oldest rocks in the area, of probable Moinian (Central Highland Granulite) age, are psammites in a small area just west of Tyndrum (Figure 1). Rocks of Middle and Upper Dalradian age (Argyll Group and Southern Highland Group respectively) underlie almost the entire area (Harris and Pitcher, 1975). The succession commences with the Easdale Subgroup, in which the pebbly Dalmally Quartzite passes upwards into the Easdale Slates. The overlying Ardrishaig Phyllites are a thick sequence of calc-sericite phyllites with intermittent thin limestones, such as the Shira Limestone, and quartzites, and include a graphitic schist at St Catherine's. In the north-west, towards the Loch Awe syncline, the phyllites underlie the Crinan Grits, and in the Ben Lui area they underlie garnetiferous mica schists (Ben Lui Schists). To the south-west, however, the lateral equivalent of these phyllites, schists and grits is the Erins Quartzite, a thick sequence of quartzites and interbedded mica schists. If the Pyrite Zone, which has been identified within these rocks in Knapdale (Smith and others, 1978), is equivalent to that between the Ardrishaig Phyllites and the Ben Lui Schists, and is a time marker then at least part of the Ardrishaig Phyllites must be correlated with part of the Lower Erins Quartzite. Such facies changes indicate that the supply of coarse sediment was most abundant in the south-west of the area and was reduced to the north and east (towards the head of Loch Fyne).

Subsequently, a break in the supply of coarse sediment allowed deposition of the Loch Tay Limestone and its lateral equivalent to the north-west, the Tayvallich Limestone, along with some interbedded black pelites and basic volcanics. Sills within the Crinan Grits and Ardrishaig Phyllites may represent subvolcanic feeders to these basic lava flows, which are best developed in the Tayvallich area.

The succeeding Southern Highland Group consists of coarse clastic sediments, probably deposited by turbidity currents but, in most of the area, another volcanic series (the Green Beds) separates the underlying Glen Sluan Schist from the overlying Beinn Bheula Schist.

Metamorphism, to the greenschist facies, and deformation affected the area, probably during early Ordovician times. A narrow zone of almandine-grade metamorphism extends from Tyndrum and the head of Loch Fyne into a narrow belt on the south-east side of the loch, within the outcrop of the Ben Lui Schist. The chlorite sub-facies occupies most of the western side of the area, and the biotite isograd corresponds approximately with the axial trace of the Ardrishaig Anticline and the Tay Nappe root zone (Winchester, 1974).

Caledonian intrusive rocks include the Garabal Hill—Glen Fyne igneous complex, ranging from peridotite to granodiorite (Nockolds, 1940), porphyritic microgranites and felsites. Dolerite dykes of Permo-Carboniferous and Tertiary age traverse the area.

MINERALISATION

The Pyrite Zone (Figure 1) coincides with the junction of the Ardrishaig Phyllites and Crinan Grits on the north-western margin of the area and their lateral equivalents (Lower Erins Quartzite, St Catherine's Graphitic Schist and Ben Lui Schists) elsewhere; although other zones of pyrite enrichment are known in the Highlands and the validity of the Pyrite Zone as a time marker is uncertain.

The zone is up to 800 m wide, possibly due to repetition by folding, and it persists throughout Argyll, and into Perthshire where it has an average thickness of 180 m (Smith and others, 1977a). The sharply-bounded pyritiferous rock is distinguished only by its pyrite content, of up to 5 per cent (rarely up to 20 per cent) usually in the form of banded disseminations of grains elongated along the foliation. Grain sizes vary up to one centimetre. Associated chalcopyrite is usually in trace amounts, although it may be enriched in conjunction with remobilised quartz-carbonate segregations.

In the central Perthshire area this type of mineralisation is not confined to one stratigraphic level (Ben Lawers—Ben Lui Schist junction), but is occurs almost throughout the thickness of the Ben Lawers Schists (equivalent to Ardrishaig Phyllites). The Pyrite Zone is characterised by being the richest and most distinctive zone of pyrite enrichment in the region.

Other lithologies possibly associated with mineralisation include epidiorite dykes controlling the location of copper and nickel sulphides; porphyry and felsite dykes containing disseminated copper, molybdenum and iron minerals; and limestones, metasomatically replaced by ore minerals. Other potential mineralisation controls include the Glen Fyne—Tyndrum fault and the Garabal Hill fault.

The richest known mineralisation is at the Cononish Mines (Figure 2) where several thick veins carrying galena and sphalerite, with minor chalcopyrite and some pitchblende, are closely associated with the main Tyndrum fault (Wilson, 1921).

Near the southern end of this fault, in lower Glen Fyne, small baryte, calcite and siderite veins at Eagle's Fall and Achadunan (Figure 2) carry specks and strings of galena in a crush zone. At the nearby Clachan Beag Mine (Figure 2), a (30 cm thick) metasomatic replacement of a limestone contains disseminated galena, sphalerite and pyrite, with traces of gold and silver, in a siderite matrix (Wilson, 1921).

A stratiform band of siliceous schist up to 7 m in apparent thickness, at McPhun's Cairn (Figure 2), contains a pyrite-rich zone (up to 2 m wide) with associated sphalerite and galena and traces of silver and gold, over a short lateral extent (Smith and others, 1977b). A similar zone nearby, at Creggans, contains only pyrite.

Small veins near Bridgend carry galena in a crush zone controlled by a felsite dyke. Copper was mined at Castletown, and, near Kaimes, quartz veins contain galena and chalcopyrite.

Two copper mines, at Coille-bhraghad and Craignure (Figure 2), also produced nickel (pyrrhotite and pentlandite) and the ore minerals contained traces of cobalt and arsenic. The ore seems to be a metasomatic replacement of quartzitic bands in the schists, associated with a suite of epidiorite intrusions. Both ore bodies lie on the same line of strike, and mineralisation in the intervening ground is therefore a possibility. Similar massive sulphide mineralisation, but devoid of nickel, is exposed in a small trial at a higher stratigraphical level at Garbh Achadh (Figure 2). Here, low grade disseminated copper mineralisation is also associated with a small, calc-alkaline feldspar-porphyry intrusion (Ellis and others, 1978).

REGIONAL RECONNAISSANCE SURVEY

INTRODUCTION

From the results of an orientation survey in areas of known mineralisation (McPhun's Cairn and Coille-bhraghad), and experience elsewhere in the Highlands, a sampling density of about one sample site per km^2 of drainage basin was chosen for a preliminary regional reconnaissance (Figures 3 and 4). Individual sites were selected, usually just upstream of confluences and at regular (approximately 1 km) intervals along stream courses. Sample sites are referred to throughout this text by the project code letters CZ followed by a number. On Figures 3 and 4, sites are indicated by the number alone.

Active sediment from each site in the stream was washed successively through 30 mesh and 100 mesh nylon sieves, using the minimum amount of water to ensure that as little as possible of the clay fraction was lost. Suspended particles were allowed to settle out by flocculation for about 20 minutes before the relatively clear supernatant liquid was decanted and rejected. Settling of the suspended material does not occur very readily at sites with a large amount of organic matter in the sediment. The advantage of this technique is that much of the lighter fraction of sediment, on which many metallic ions are adsorbed, is preserved, and the sensitivity of the sampling increased. At most sites, the -30/+100 mesh fraction was panned to produce a heavy mineral concentrate. Approximately 20 g of the minus 100 mesh sediment and 25 g of panned concentrate were collected in Kraft paper bags and sent to a processing laboratory for drying. Each sample was labelled with the site number, preceded by the code letters CZC for sediment and CZP for panned concentrate. This convention is used throughout the text.

ANALYTICAL METHODS

Each dry sample of sediment was ground, and a sub-sample of each was analysed by atomic absorption spectrophotometry (AAS) for copper, lead and zinc, after digestion in hot nitric acid. Cobalt, nickel and silver were also determined on some samples using the same method. During the early part of the project, each sediment sample was analysed for uranium by the delayed neutron method (DNM) at the Atomic Weapons Research Establishment, Aldermaston. Molybdenum in sediments was determined by colorimetry, X-ray fluorescence spectrometry (XRF), or optical emission spectrography (OES) according to prevailing requirements. Some other elements were also determined by XRF and OES during the orientation part of the project. The panned concentrates were dried, split and ground and analysed for barium, antimony, tin, lead, zinc, copper and nickel by XRF. Most samples were also analysed for iron, and some for calcium, titanium, cerium and manganese.

Fig.2 Central Argyll – Mineral Localities

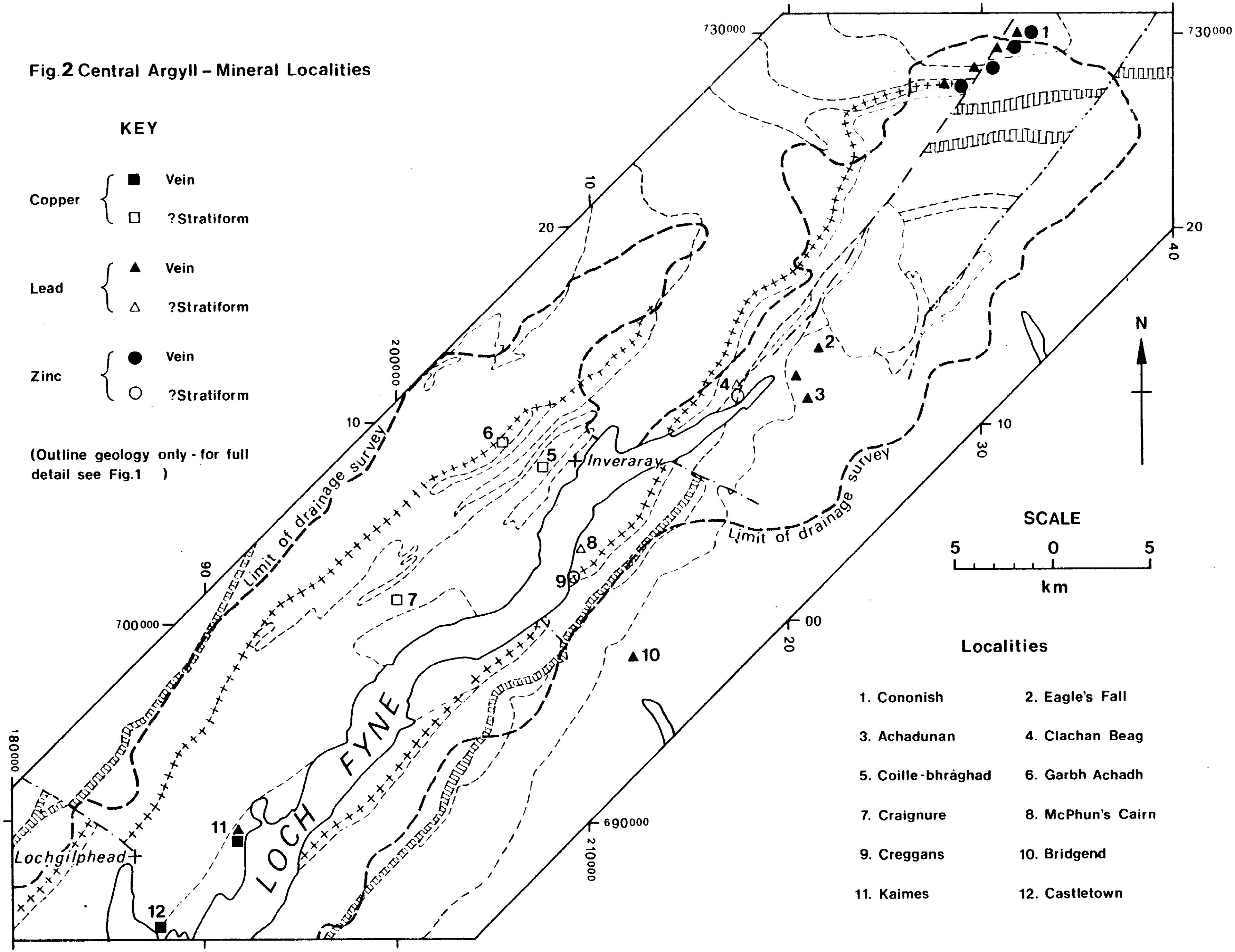


Table 1 Summary statistics on reconnaissance drainage samples

	Minimum	*Maximum*	*Arithmetic mean*	*Mode(s)*	*Number of analyses*
Stream sediment					
Copper	1	170	21	15, 30	881
Lead	8	1050	43	30	881
Zinc	40	2500	160	130	881
Cobalt	10	120	30	30	209
Nickel	2	190	40	25, 45	876
Silver	0	3	1	1	738
Uranium	0	11.8	2.04	2.23	394
Molybdenum	0.5	14	1.12	1	756
Panned concentrate					
Copper	1	1454	19	15	761
Lead	1	2595	18	13	761
Zinc	1	1114	100	115	761
Nickel	1	998	34	35	761
Barium	4	56 659	140	180	761
Antimony	1	60	4	2, 3	761
Iron*	1.37	31.89	7.94	6.3	625
Tin	1	2051	2	1.6	761
Cerium	0	1100	46	40	390
Calcium*	0.08	20.99	1.99	2.23	390
Manganese*	0.01	1.26	0.12	0.12	374
Titanium*	0.36	13.48	2.04	2.39	390

All concentrations in ppm, except *iron, calcium, manganese and titanium — in per cent.

STATISTICAL ANALYSIS

The analytical results for each sample were transferred to punched cards, either manually or by a computer programme from paper tape produced by the analytical instrument (Tait and Coats, 1976). These analytical files were then merged in the computer with a locational file derived from cards punched with the grid reference of each sample. All computer programmes used are part of the G-EXEC package, a unified suite of programmes for data handling, statistical analysis and presentation in the geological field (Jeffery and others, 1977). Statistical treatment of the data was performed and the basic functions for each element are summarised in Table 1.

The cumulative frequency distribution of each element (summarised in Table 2) was plotted by hand on logarithmic concentration — probability axes, and populations that could be separated were replotted using the methods of Parslow (1974).

Most of the elements show one or more sensibly lognormal populations. Class divisions for plotting the geochemical maps were chosen at inflection points on cumulative frequency plots and/or at means and standard deviations of lognormal populations. The choice of significant inflection points is reasonably objective, but some degree of subjectivity enters the choice of the smaller class intervals. A subdivision at fixed percentile levels is less subjective but might submerge the relatively small number of samples with concentrations at economically interesting levels in the general background pattern, which is best displayed on greyscale maps.

The elements which show some indication of economic potential in this area are plotted in symbols related to the class intervals at a 1:100 000 scale so that individual sites can be identified. The distribution of each element which has been determined is illustrated in the form of greyscale maps, with the exception of cobalt and silver.

Correlation coefficients

Correlation coefficients of all the elements determined, in both stream sediments and panned concentrates, were calculated (Table 3).

Samples collected in both the preliminary and later detailed drainage surveys were used to

Table 2 Class intervals for drainage samples

	Class I	upper percentile	Class II	upper percentile	Class III	upper percentile	Class IV	upper percentile
Stream sediment								
Copper	1–20	50	21–37	84	38–100	99.2+	101–170	100
Lead	0–100	97	101–360	99+	361–1050	100		
Zinc	40–160	50	161–275	84	276–520	98+	521–2500	100
Cobalt	10–45	78+	46–95	98+	96–120	100		
Nickel	0–35	50	36–55	84	56–85	97.5	86–190	100
Silver	0–1	98+	2	99+	3	100		
Uranium	0–1.8	25+	1.9–3.0	95+	3.1–4.3	100		
Molybdenum	0.5–2	50	3–4	90+	5–14	100		
Panned concentrate								
Copper	0–19	50	20–64	84	65–229	97.5	230–1454	100
Lead	1–50	82+	51–245	95+	246–2595	100		
Zinc	1–100	50	101–190	91+	191–1114	100		
Nickel	1–34	50	35–91	92+	92–998	100		
Barium	10–139	50	140–629	92+	630–2199	97	2200–56 659	100
Antimony	1–4	50	5–8	90+	9–60	100		
Iron*	1.37–7.90	50	7.91–12.60	84	12.61–20	97	20.01–31.89	100
Tin	1–4	80+	5–14	94+	15–2051	100		
Cerium	0–63	80+	63–399	99+	399–1100	100		
Calcium*	0–1.74	40+	1.75–3.98	80+	3.98–20.99	100		
Manganese*	0–0.0692	15+	0.0693–0.19	80+	0.19–1.26	100		
Titanium*	0–1.05	15	1.06–2.189	50	2.19–4.0	84	4.1–13.48	100

All concentrations in ppm except *iron, calcium, manganese and titanium — in per cent.

+ inflection point.

provide the largest number of correlations. Because of a restriction, during the course of the investigation, on the number of elements determined, not all elements were sought in all the samples. These permutations restrict the number of samples that could be correlated from 1326 in the case of copper, lead and zinc in stream sediments to only 272 between uranium and most other elements. Thus, the significance level for each correlation coefficient may vary; but generally for such large sample numbers, most coefficients greater than 0.10 are significant at the 99 per cent level ($N > 500$).

R-mode factor analysis

This multivariate technique, to give groupings of elements, was performed on the analytical data. The computer programme used, unlike that for correlation coefficients, can ignore absent data, but was utilised on two sets of analytical data to give the largest possible number of records of element analyses available, in each set. The first set, 977 records, covers copper, lead, zinc, nickel, molybdenum (in sediments); and barium, antimony, tin, lead, zinc, copper and nickel (in panned concentrates) (12 fields). The second set covers 12 fields plus iron, cerium, calcium, manganese and titanium in panned concentrates (17 fields, 757 records). Silver was omitted because of the large number of results near the detection limit, along with cobalt and uranium, which were only determined in a few samples from small areas. All analytical levels were log-transformed in order to give a near normal population before beginning the factor analysis.

In the 12 field set of data, four factors have eigenvalues greater than 1.0, and the elements with the highest loadings (in brackets) in the rotated factor matrix are:

Factor I	Zn_c (0.89)	Ni_c (0.74)	Cu_c (0.46)
Factor II	Pb_c (0.78)	Ba_p (0.74)	Mo_c (0.65)
Factor III	Zn_p (0.81)	Ni_p (0.77)	Pb_p (0.61)
Factor IV	Sn_p (0.78)	Sb_p (0.75)	

c — sediment p — panned concentrate

These four factors are interpreted as: I — basic rock assemblages and sources of sulphide mineralisation; II — baryte veining and late stage hydrothermal mineralisation, and acidic-

Table 3 Correlation coefficients between elements determined in drainage samples

	Pb-c	Zn-c	Co-c	Ni-c	Ag-c	Mo-c	U-c	Ba-p	Sb-p	Sn-p	Pb-p	Zn-p	Cu-p	Ni-p	Fe-p	Ce-p	Ca-p	Mn-p	Ti-p
Cu-c	0.05	0.34	0.38	*0.62*	0.31	0.09	0.07	-0.08	0.08	-0.05	0.07	0.29	*0.52*	0.28	0.49	-0.15	0.16	0.42	0.25
Pb-c		0.21	0.24	0.00	0.11	0.28	0.21	0.37	0.12	-0.01	0.24	0.00	-0.04	-0.22	-0.28	0.05	-0.31	-0.19	-0.23
Zn-c			*0.67*	*0.57*	0.31	0.11	0.04	0.00	0.02	-0.10	-0.02	0.37	0.15	0.15	0.27	-0.12	0.12	0.39	0.00
Co-c				*0.70*	0.13	0.01	x	-0.11	0.03	-0.09	-0.06	0.30	0.18	0.41	0.22	0.08	0.27	0.33	0.21
Ni-c					0.34	0.06	-0.11	-0.11	0.04	-0.07	0.00	0.30	0.38	0.47	0.40	0.01	0.20	0.37	0.16
Ag-c						0.25	-0.04	-0.01	0.09	-0.10	-0.03	0.05	0.15	0.03	0.18	-0.08	0.03	0.17	0.08
Mo-c							0.29	0.31	0.04	-0.01	0.08	-0.09	0.08	-0.17	-0.04	-0.05	-0.30	-0.01	-0.25
U-c								0.27	0.04	-0.12	0.01	0.03	0.16	-0.09	0.04	-0.05	-0.17	-0.02	-0.21
Ba-p									0.05	-0.08	0.16	0.20	0.09	0.09	-0.28	0.09	-0.56	-0.26	-0.45
Sb-p										0.24	0.08	0.05	0.04	0.03	0.02	0.04	0.00	0.01	0.02
Sn-p											0.25	0.08	0.01	0.10	0.08	0.04	0.21	0.04	0.21
Pb-p												0.36	0.35	0.34	0.28	0.09	0.04	0.15	0.08
Zn-p													0.32	*0.58*	*0.50*	-0.10	0.26	0.43	0.16
Cu-p														0.42	0.42	-0.10	0.01	0.29	0.08
Ni-p															*0.50*	0.17	0.33	0.35	0.21
Fe-p																-0.10	0.49	*0.83*	*0.50*
Ce-p																	-0.04	-0.10	-0.01
Ca-p																		0.49	*0.68*
Mn-p																			0.44

x — No correlation coefficient computed as U was analysed only in samples collected in the early part of the reconnaissance and Co only in the later part. No sample was analysed for both elements.

Strongest correlations (⩾0.5), which are all significant at the 99 per cent level, are shown *italic.*

Table 4 Class intervals and percentile limits for greyscale isopleth maps

	Class I	upper percentile	*Class II*	upper percentile	*Class III*	upper percentile	*Class IV*	upper percentile
Stream sediment								
Copper	0–20	50	21–37	84	38–62	97	>62	100
Lead	0–43	50	44–68	84	69–100	97	>100	100
Zinc	0–160	50	161–275	84	276–400	97	>400	100
Nickel	0–35	50	36–55	84	56–85	97.5	>85	100
Uranium	0–2.0	50	2.0–2.4	84	2.5–3.9	97	>3.9	100
Molybdenum	0–1	50	2–3	84	4–6	97	>6	100
Panned concentrate								
Copper	0–19	50	20–64	84	65–229	97.5	>229	100
Lead	0–50	82	51–90	90	91–245	95	>245	100
Zinc	0–79	40	80–190	91	191–575	99.2	>575	100
Nickel	0–34	50	35–39	84	60–129	97	>129	100
Barium	0–139	50	140–629	92	630–2199	97	>2199	100
Antimony	0–2	40	3–7	84	>7	100		
Tin	0–2	50	3–4	80	5–14	94	>14	100
Iron*	0–7.9	50	8.0–12.6	84	12.7–19.9	97	⩾20	100
Cerium	0–42	40	43–109	97	>109	100		
Calcium*	0–0.64	10	0.65–2.18	60	2.19–5.0	95	>5.0	100
Manganese*	0–0.129	60	0.130–0.359	95	>0.359	100		
Titanium*	0–0.959	10	0.96–2.189	50	2.19–3.019	80	>3.019	100

All concentrations in ppm except *iron, calcium, manganese and titanium — in per cent.

intermediate igneous rocks; III — sulphide mineralisation; IV — contamination such as dumped tin cans.

In the 17 field set of data, four factors have significantly high eigenvalues. The elements with significant loadings (⩾0.4) on the factors are:

Factor I	Ni_c (0.86)	Zn_c (0.82)	Cu_c (0.63)
Factor II	Ba_p (0.78)	Pb_c (0.58)	Mo_c (0.45)
	$-Ca_p$ (-0.83)	$-Ti_p$ (-0.77)	$-Fe_p$ (-0.58)
	$-Mn_p$ (-0.54)		
Factor III	Sb_p (0.73)	Sn_p (0.64)	Pb_c (0.45)
Factor IV	$-Pb_p$ (-0.76)	$-Zn_p$ (-0.74)	$-Ni_p$ (-0.69)
	$-Cu_p$ (-0.56)	$-Fe_p$ (-0.52)	$-Mn_p$ (-0.40)

Factors I and II are the same associations as in the 12 field set of data, although in this set of data the high negative loadings in Factor II emphasise an antipathy with iron and other oxides in the panned concentrates such as in the more basic parts of the Glen Fyne igneous complex. Factor III represents contamination with the addition of lead derived from solder, car batteries and lead shot. Factor IV represents sulphide mineralisation, with the addition of iron and manganese.

GREYSCALE MAPS

A computer programme was used to produce regional distribution maps of all the elements determined. The method is a slight modification of the programme of Howarth (1971) and uses a moving average in which the mean of all the data points within a cell is calculated. The size of the cell is a square with side 2.54 mm, which on the scale of the final map, here 1:250 000, is equivalent to about 0.635 km. A symbol is plotted at the map co-ordinate and varies in accord with pre-selected class division.

The symbols on the maps were contoured by hand to link up areas of equal concentation. Generally, six or seven classes were selected for each element from the cumulative frequency plots, this being about the maximum number easily assimilated. These classes differ from the three or four chosen on the basis of anomalous populations using the methods of Parslow (1974), mainly by an increase in the number of lower classes. The greater number of classes emphasises geochemical controls at lower levels, and large scale regional patterns of, for example, below-background concentrations. Because the method is a smoothing technique, it follows that the overall variance will be reduced by $\sqrt{n}$, where n = the number of data points in the cell, and extreme levels will have less effect on the pattern than in the similar class interval maps. Because of the technical strictures of map presentation, only three or four classes are shown on the greyscale maps, and the limits are listed in Table 4.

Results from both the preliminary and the later detailed drainage surveys are used in the plotting of the maps, as these provide a larger population and thus statistically more precise maps. The problem of bias caused by the generally higher metal concentrations in the detailed drainage samples is overcome by the design of the programme to average a number of samples within close proximity, which detailed drainage samples generally are, and to plot as one symbol.

The maps (Figures 7, 8, 11, 12, 15, 16, 19, 20, 22–31) show the isopleths superimposed on the outline geology, and are referred to in the following section. The results of all the statistical analyses are also discussed below. All element analyses for each sample are available for inspection on open file as computer listings at the Institute's office at Keyworth, Nottingham. Specific levels of potentially economic interest are dealt with in succeeding sections.

REGIONAL GEOCHEMICAL VARIATION OF ELEMENTS

COPPER

The populations for copper in stream sediment (Figure 7) and copper in panned concentrate (Figure 8) are virtually lognormal, although analytical imprecision at lower levels causes a departure from normality, as does a small highly anomalous sub-population. Class divisions were therefore chosen at the mean, the mean plus one standard deviation, and the upper inflection point (indicating the highly anomalous class). The distribution of the classes selected is illustrated on the larger-scale maps (Figures 5 and 6), where individual sample sites are shown. The same class divisions were used for the greyscale maps (Figures 7 and 8), except that the boundary of the highly anomalous group of copper in stream sediment would represent too few samples, and so a boundary at the mean plus two standard deviations (≏97%) was chosen instead (= 62 ppm).

The generally high levels of copper, compared with other areas of the Highlands, are probably due to the high incidence of copper mineralisation and volcanic-derived rocks such as Green Beds and epidiorites. Concentrations reach 170 ppm in stream sediment and 1454 ppm in panned concentrate in the preliminary reconnaissance samples.

The longer dispersion train of copper in the sediment is caused by chemical transport in solution and mechanical transport in finer and lighter fractions over greater distances before precipitation, especially in upland areas with acid groundwater. In contrast, the heavy copper minerals of the panned concentrate samples are mechanically transported over shorter distances before being trapped, or they break down and go into solution or finer fractions.

The greyscale maps show a broadly similar areal pattern of sources of copper, also indicated by the correlation coefficient. The large area of

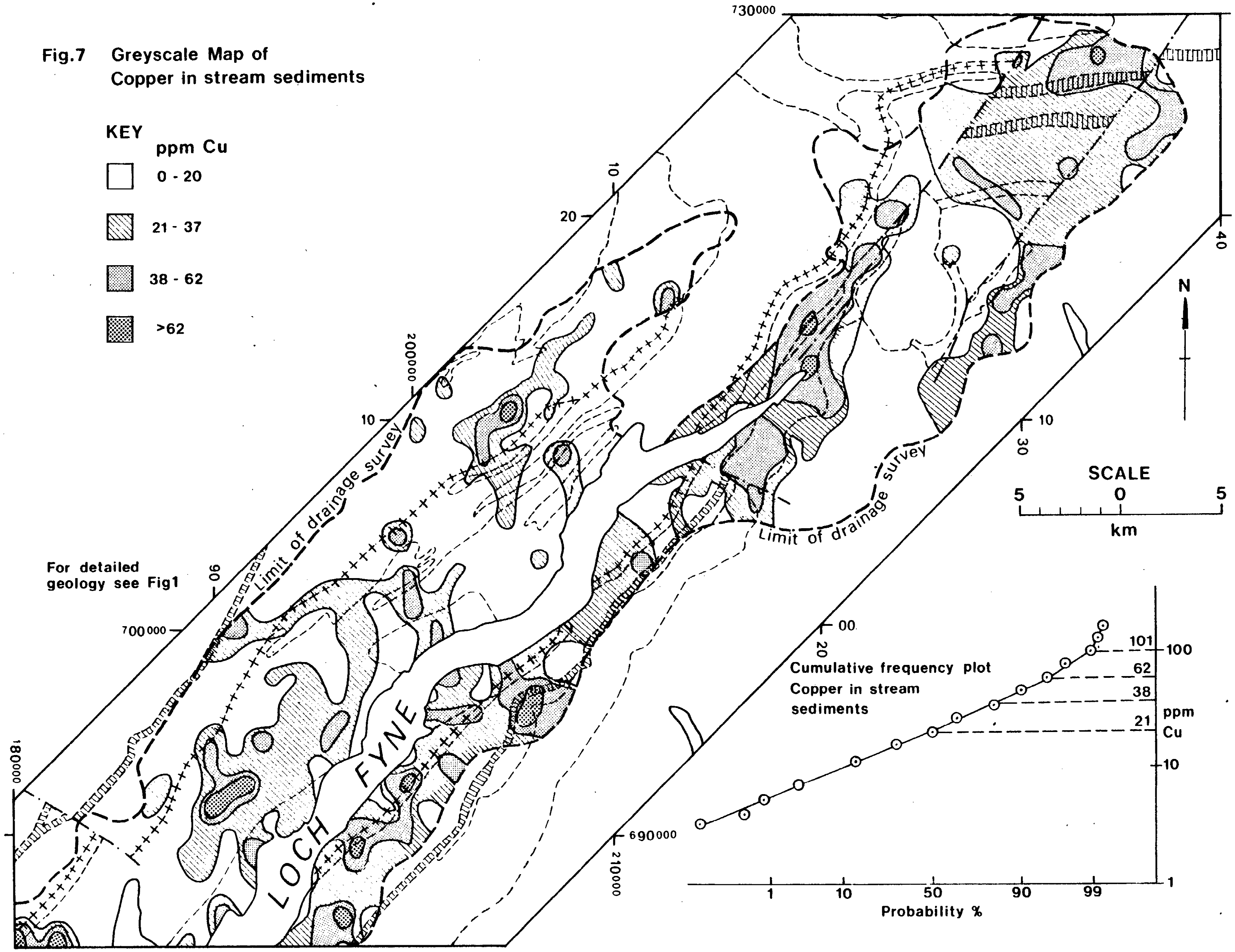
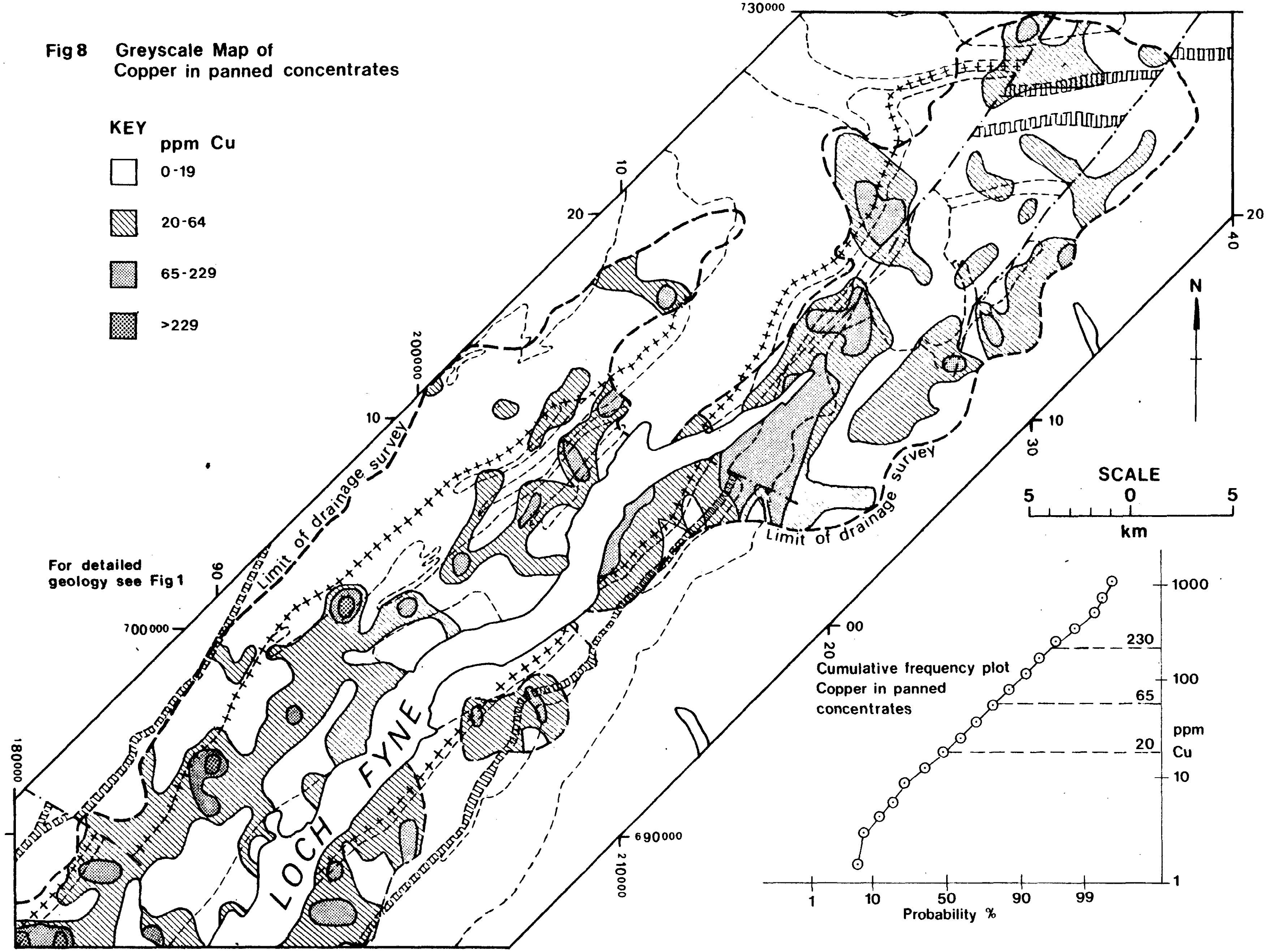


Fig.7 Greyscale Map of Copper in stream sediments

Fig 8 Greyscale Map of Copper in panned concentrates



21–37 ppm copper in sediment in the north-east indicates slight enhancements of copper (possibly derived from the faulting which affects the Green Beds and the Tayvallich Subgroup). The enclosed higher levels (38–62 ppm) indicate more confined sources in an outcrop of Green Beds, which is corroborated by the coincidence of an isolated zone of 20–64 ppm on the panned concentrate map. The previously mined Cononish area shows low concentrations of copper in sediment, but is better delineated on the panned concentrate map, as is the Pyrite Zone just to the south-west.

Both greyscale maps show the paucity of copper within the Garabal Hill–Glen Fyne igneous complex, and emphasise the higher levels around its eastern and western margins. The anomalies on the eastern margin are probably derived from minor mineralisation associated with the faulting; but a combination of Green Beds, Loch Tay Limestone subgroup and epidiorites, as well as the Glen Fyne fault, may influence contents on the western margins.

Just north-west of Loch Fyne, an almost continuous zone above 19 ppm (especially in panned concentrates) extends from near Inveraray (Coille-bhraghad mine) for some 40 km along the strike of the Ardrishaig Phyllites to the extreme south-western corner of the map. The isolated richer zones on the greyscale maps correspond with known or suspected mineralisation.

The Pyrite Zone to the north-west of Loch Fyne, in contrast, is hardly represented, except at Garbh Achadh (especially in stream sediments) and at points further south-west. It is, however, better delineated to the south-east of Loch Fyne, especially around and to the south-west of McPhun's Cairn.

The Crinan Grits yield low copper values (<20 ppm), but the Ben Lui Schist is masked by the dispersal of higher concentrations of copper from the overlying Loch Tay Limestones and associated epidiorites.

The concentration of copper in streams draining the Green Beds generally exceeds 38 ppm in the sediment and 65 ppm in the panned concentrate. The overlying Beinn Bheula Schists generally show low levels.

Most sites CZ685–CZ3384 with anomalies of ⩾50 ppm Cu in sediment and ⩾100 ppm copper in panned concentrate were sampled upstream in greater detail, as the results became available. These are described in the section on 'Detailed drainage surveys'. Known mineral localities were generally not resampled. No anomalies in samples CZ6000 and above were resampled, as the analytical results were not available during the follow up phase.

LEAD

The cumulative frequency plots of lead in both stream sediments (Figure 11) and panned concentrates (Figure 12) show mixing of populations. The curves indicate at least three separate populations, which, on replotting by the method of Parslow (1974), exhibit nearly lognormal distributions.

Only three per cent of sediment samples are anomalous (>100 ppm Pb), and the most highly anomalous group (>360 ppm) represents only one per cent. These levels are used in the plotting of the larger-scale map (Figure 9). The large background group (0–100 ppm) replots as one single lognormal population. For the purposes of the greyscale maps (Figure 11), however, this background group is divided at the mean and mean plus one standard deviation of the replotted curve to illustrate the distribution at lower levels. The division at the mean, 43 ppm, is the lowest level at which a significant pattern emerges from the greyscale map. Concentrations lower than this are probably affected by analytical precision producing a more random pattern.

Lead in panned concentrate has a smaller background population, 0–50 ppm (up to the 82 percentile). The anomalous groups range from 51–245 ppm (95 percentile), and up to 2595 ppm above this level. These class divisions are used on both the large-scale and greyscale maps (Figures 10 and 12). Subdivision of the background group fails to produce a significant pattern on the greyscale map.

Although the areas of highest concentration of lead in both sediments and panned concentrates broadly correspond, the higher levels in sediment are more widespread (as in the case of copper). Galena, the most common lead mineral, is probably stable for only a short distance downstream from the source and either enters the fine fraction, or breaks down chemically and is precipitated with iron and manganese oxides, or is absorbed by clay mineral particles. The anomalous population, the top three per cent (101–1050 ppm) in sediment, corresponds largely to areas of known or suspected lead mineralisation. The larger (18 per cent), but spatially more restricted, anomalous classes in panned concentrates also have a greater range (51–2595 ppm), but probably represent more precisely the distribution of galena.

A zone of high lead levels in sediments within and east of the Garabal Hill igneous complex (Figure 11) is not closely matched by high levels in panned concentrates (Figure 12). This contrast could be caused by the particular geochemical conditions in this zone, where many of the streams flow rather sluggishly across peat in which lead might have accumulated by co-precipitation, adsorption or organic fixing. These processes are confirmed by higher manganese levels and organic content (loss on ignition) in these samples. The panned concentrates indicate only slight lead mineralisation. An alternative explanation may be that some of the lead is held in the potash-feldspars of the igneous rocks, which are largely absent from

Fig.11 Greyscale Map of Lead in stream sediments

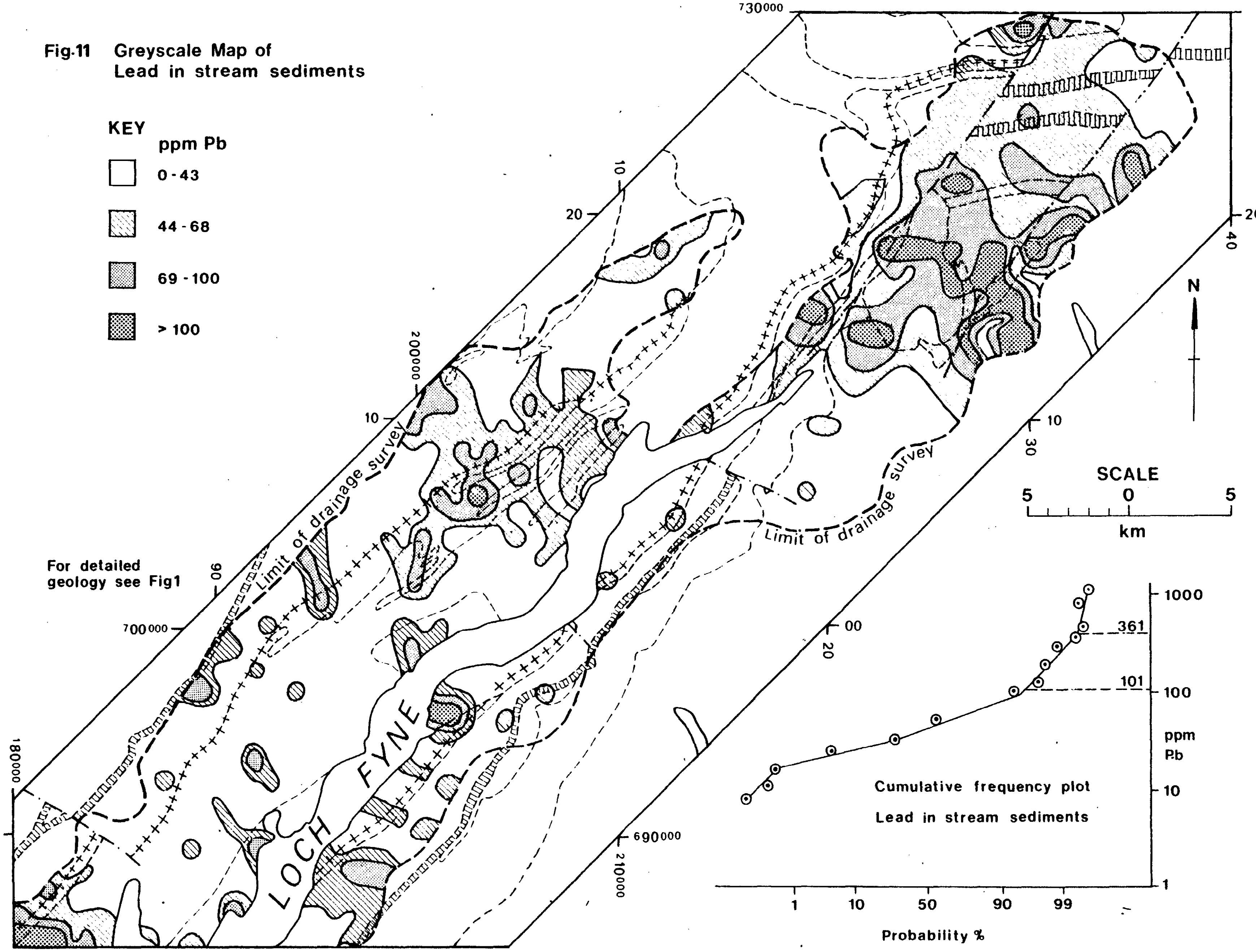
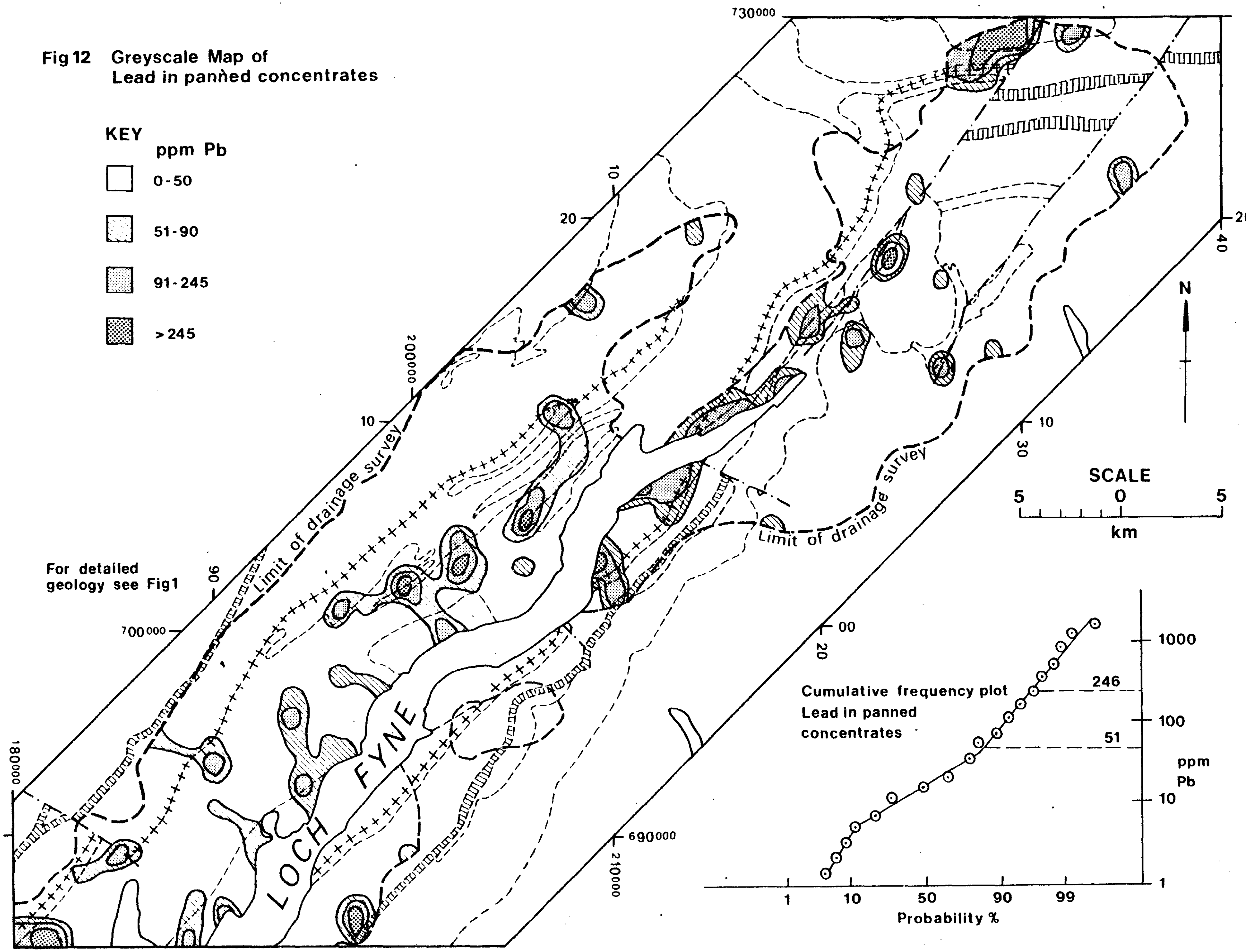


Fig 12 Greyscale Map of Lead in panned concentrates



the heavy mineral concentrates.

Elsewhere, both greyscale maps reflect the known mineralisation at Cononish, Eagle's Fall (but, contrarily, not Achadunan), Clachan Beag, Coille-bhraghad, McPhun's Cairn, Creggans, Craignure, Kaimes and north of Inverneil. Other areas of interest are in Glen Fyne, the Garabal Hill–Glen Fyne igneous complex and areas to the east, parts of the Pyrite Zone, the Loch Tay Limestone south of Loch Fyne, and the potentially mineralised belt of the Ardrishaig Phyllites south-west of Coille-bhraghad. Lead, however, corresponds less to litho-stratigraphic units than copper does, especially in sediments.

ZINC

The cumulative frequency plot of zinc in stream sediment is nearly lognormal (Figure 15), although an inflection at the 98 percentile delineates the most anomalous class (>520 ppm). Replotting of the lower class produces a lognormal curve, which is divided at the mean (160 ppm) and the mean plus one standard deviation (275 ppm) to produce the other classes represented on the large-scale map (Figure 13). More detailed subdivision to produce the greyscale map (Figure 15) fails to reveal any significant patterns below 160 ppm. Thus the original class divisions are retained, except that the isopleth of the most anomalous class is redefined at 400 ppm.

The curve of panned concentrates (Figure 16) is influenced by analytical imprecision below 10 ppm, and the inflection at the 91 percentile defines the uppermost class (>190 ppm). The other class division at the mean (100 ppm) is used on the large-scale map (Figure 14). The isopleths at 80, 190 and 575 ppm, however, produce the most significant patterns on the greyscale map (Figure 16).

The highest concentrations of zinc in sediment are more widespread than those in panned concentrate. This may be due to a greater dispersion of zinc before finer fractions enter the sediment phase, and some contrast between levels and distribution of zinc in sediments and panned concentrates emerges.

Such a contrast is in the Cononish area, where lead-zinc mineralisation is reflected in the high zinc levels in panned concentrates, but zinc is generally lacking from the stream sediment. The higher levels in panned concentrates can be accounted for by known or suspected mineralisation, whereas those in stream sediments generally cannot because of the much greater dispersion. South of Loch Fyne, the distributions correlate more closely, such as on the upper boundary of the Green Beds, although the Pyrite Zone is better delineated by panned concentrates. Further south, anomalies in sediment lie generally west of those in panned concentrate, indicating some breakdown of zinc minerals downstream from sources in the Loch Tay Limestone.

To the north-west of Loch Fyne, the highest panned concentrate levels are lacking (>575 ppm), although the 80–190 ppm class is extensive. More effective weathering, transport and comminution of zinc minerals may account for this, resulting in higher concentrations in stream sediment delineating known or suspected mineralisation in the Crinan Grits (with epidiorites), the Tayvallich Limestone, the Pyrite Zone, at Kaimes and north of Inverneil.

NICKEL

The curve of nickel in stream sediments (Figure 19) is almost lognormal, except for an inflection at the 97.5 percentile defining the most anomalous class (>85 ppm). The mean (35 ppm) and the mean plus one standard deviation (55 ppm) of the replotted lower class separate the other classes used on both the large-scale map (Figure 17) and the greyscale map (Figure 19). The plot of panned concentrates (Figure 20), conversely, reveals a mixing of populations. Analytical imprecision causes the inflection below 10 ppm, and the inflection at the 92 percentile determines the upper limit of the background class (<92 ppm). This break and the mean of the replotted background class define the class limits used in the large-scale map (Figure 18). The most significant patterns on the greyscale map, however, emerge at class boundaries of 35 ppm, 60 ppm and 130 ppm.

Contents of nickel in stream sediment and panned concentrate are similarly distributed, possibly indicating some equilibrium, especially at the lower levels. The known or suspected localities of nickel mineralisation are few, but anomalies also correlate with copper and zinc mineralisation. Such anomalies are in Glen Fyne, on the eastern margins of the igneous complex, in the Green Beds, the Pyrite Zone and Loch Tay Limestone south of Loch Fyne, around Garbh Achadh and adjacent parts of the Pyrite Zone, at Coille-bhraghad and potentially mineralised horizons in the Ardrishaig Phyllites to the south-west.

Certain contrasts in the distribution of nickel in sediments and panned concentrates emerge in the north-east, where, like copper, levels of nickel in sediment are in a higher class than those in panned concentrate. This is also probably due to minor enhancements of nickel in the epidiorites associated with Loch Tay Limestone. Sediment levels are low in the Beinn Bheula Schists, and panned concentrates define the Pyrite Zone and Loch Tay Limestone south of Loch Fyne more markedly, which is probably a function of a bias towards coarser fractions of nickel minerals in the shorter swiftly flowing streams. Panned concentrate levels in the Ardrishaig Phyllites south-west of Coille-bhraghad and in parts of the Crinan Grits are also higher. Stream sediments

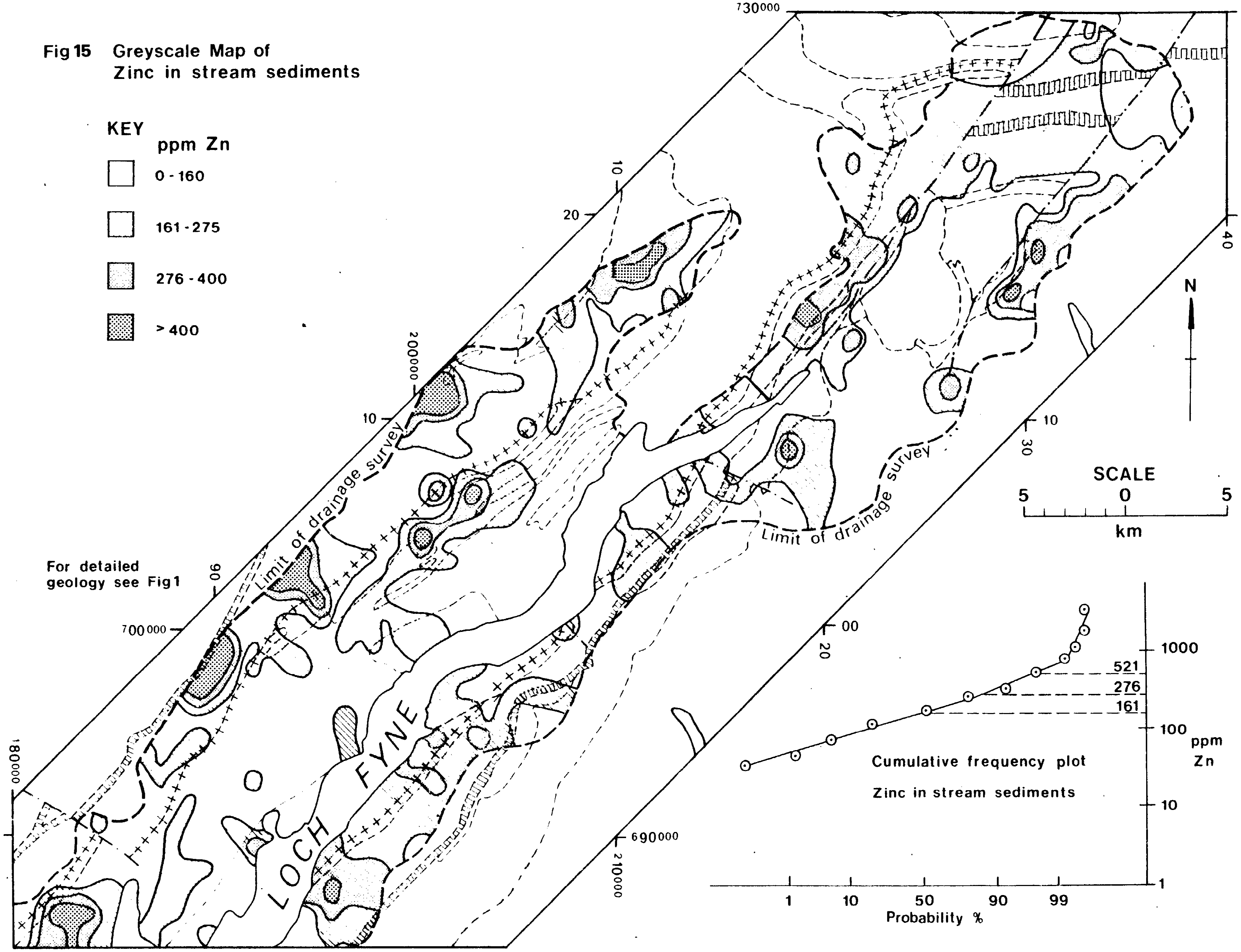
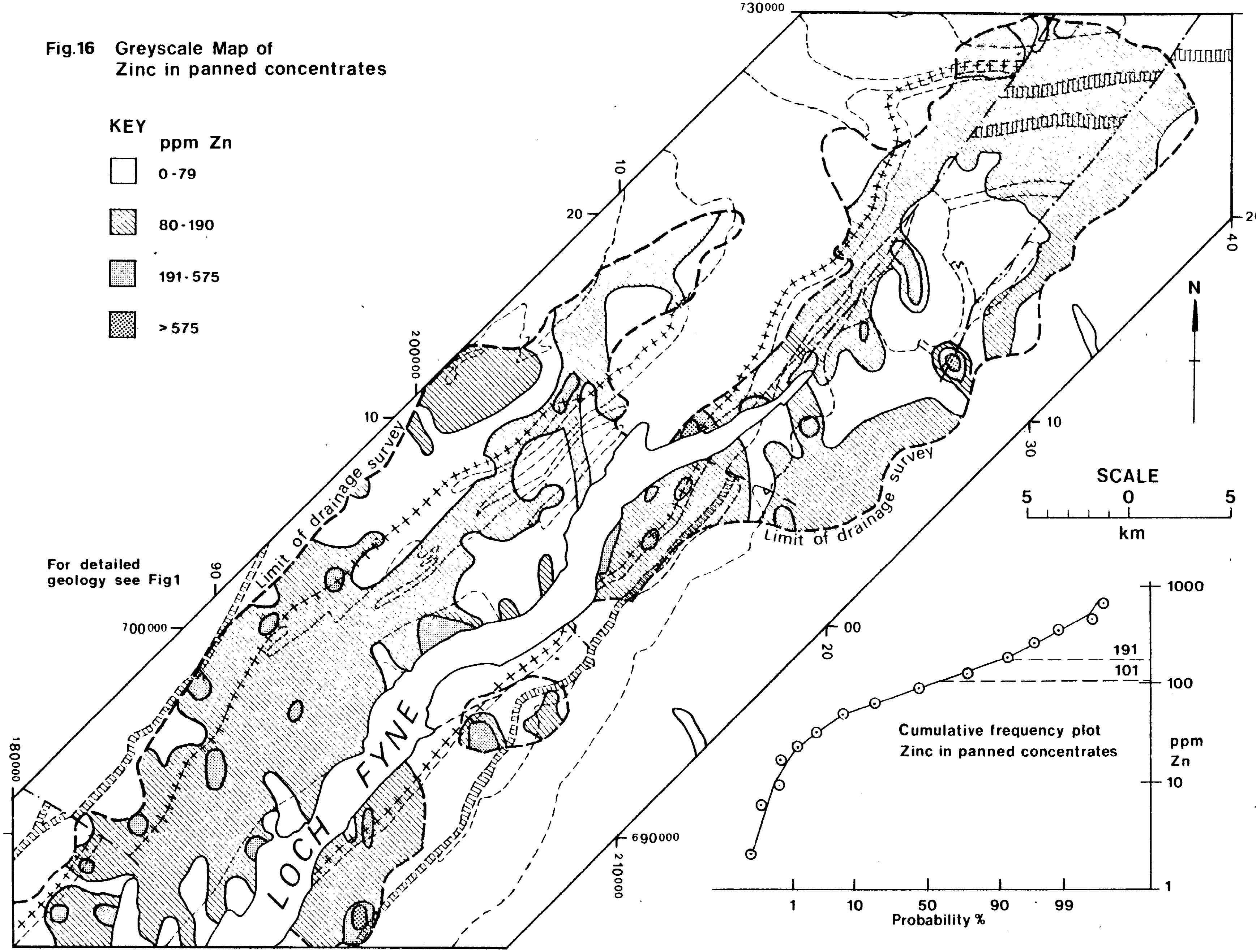


Fig 15 Greyscale Map of Zinc in stream sediments

Fig.16 Greyscale Map of Zinc in panned concentrates



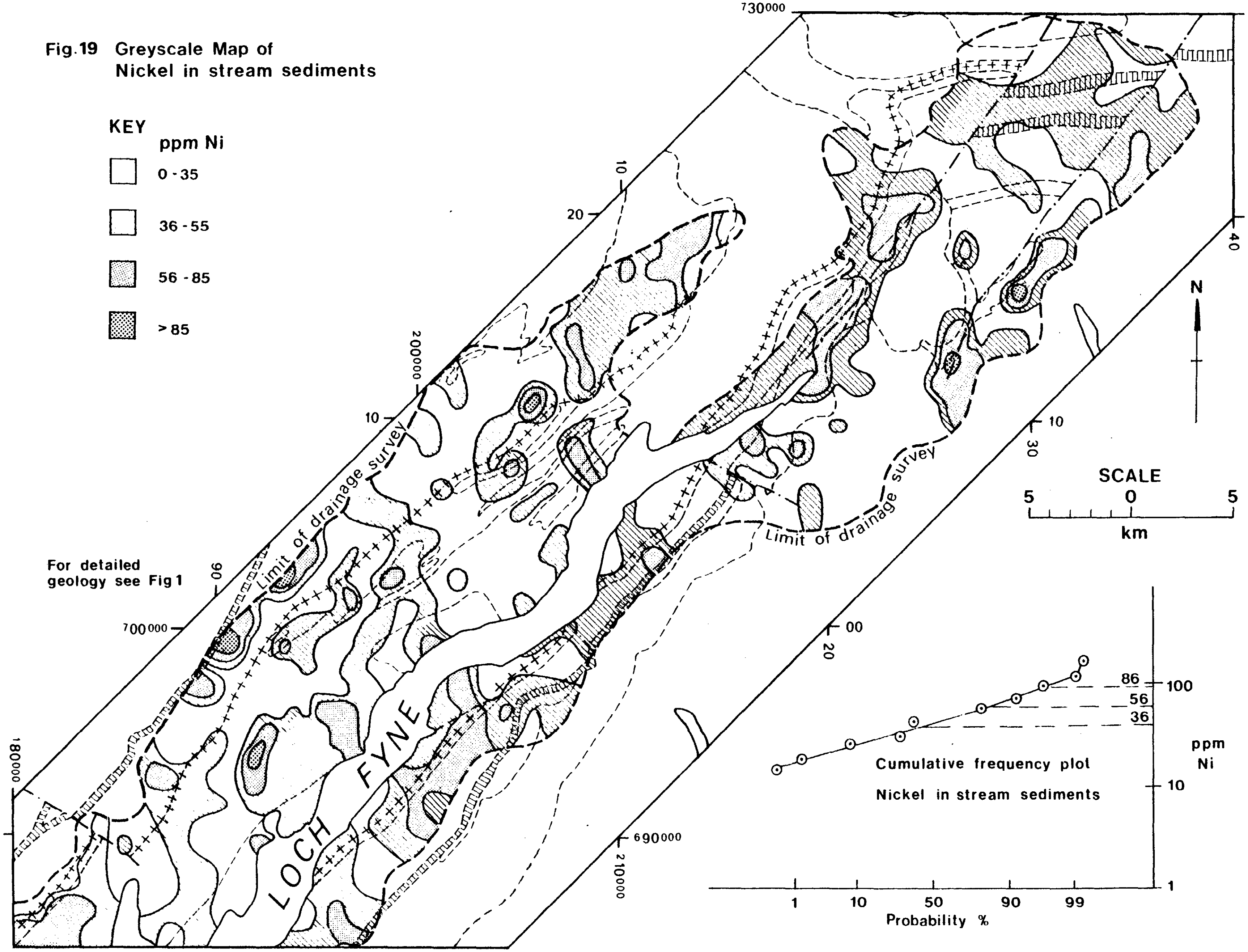
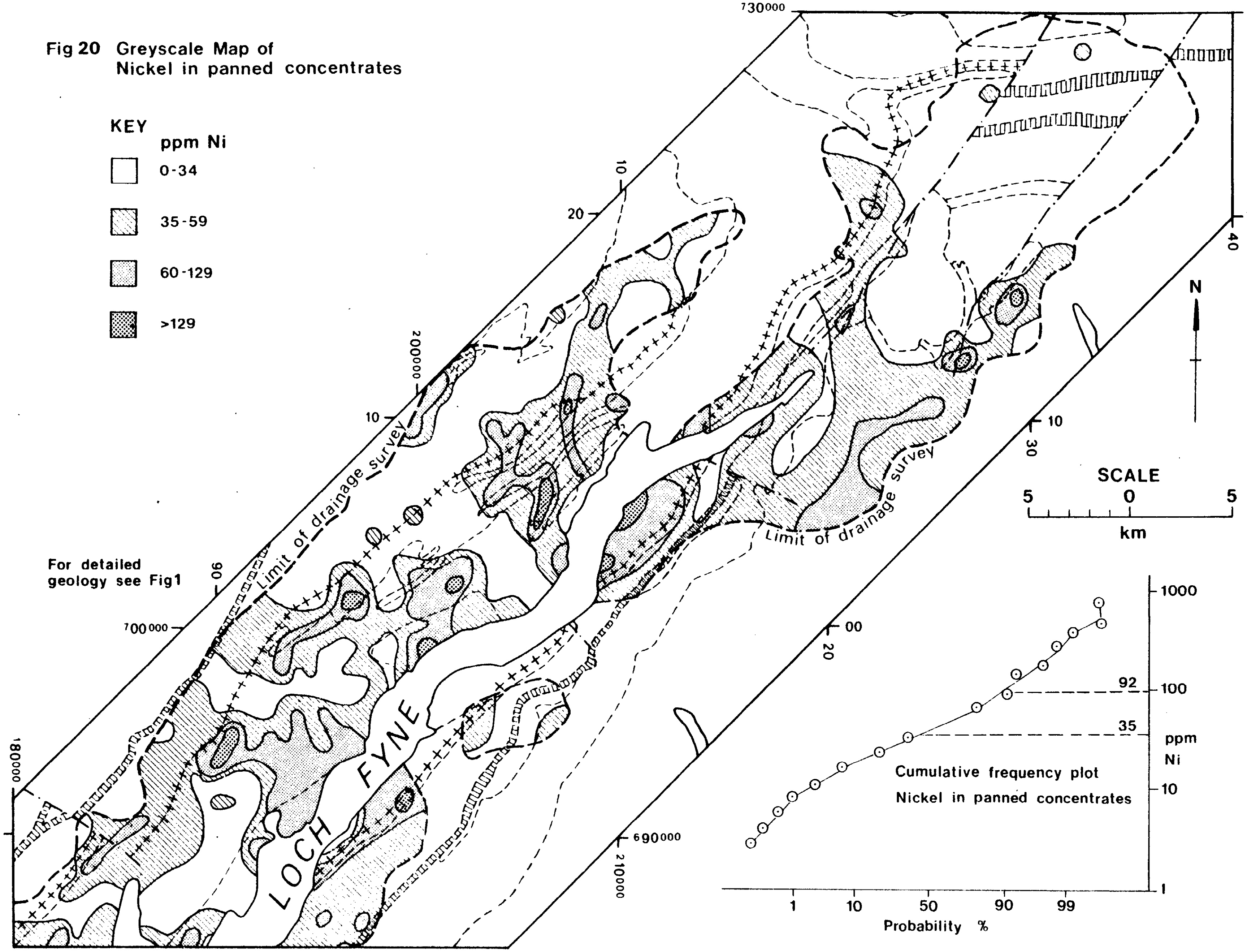


Fig.19 Greyscale Map of Nickel in stream sediments

Fig 20 Greyscale Map of Nickel in panned concentrates



alone typify mineralisation however, as in the case of zinc, where effective breakdown of nickel minerals probably causes displacement sediment anomalies derived from potential sources in the areas north of Loch Fyne.

COBALT

Only samples CZC 6045 to CZC 8021 (613) were analysed for cobalt. Of these, 209 samples were collected in the preliminary drainage reconnaissance of 1976, and were not resampled. The sites are along the north-western margins of the area, and the distribution and variation of levels is too restricted to represent on a large-scale plot or greyscale map. The remaining 404 samples were collected in the detailed drainage survey in isolated stream courses throughout the area.

Because of the restricted area sampled, mainly that of the Crinan Grits along with a small part of the Pyrite Zone and the Ardrishaig Phyllites, few deductions can be made about the likelihood of cobalt mineralisation, but an anomalous population, above 95 ppm cobalt, can be identified.

Of the preliminary samples, CZC 6047 (100 ppm), 6048 (120), 6161 (105), 6165 (115), 6324 (105) and 6812 (110) are anomalous. Cobalt has a strong affinity for zinc (correlation coefficient 0.67) and nickel (0.70) in stream sediment. The enhanced cobalt may correspond to basic rocks or potential zinc or nickel mineralisation; but secondary precipitation of cobalt, zinc and perhaps nickel with iron and manganese oxides is also a possibility.

In the detailed drainage survey, cobalt anomalies were found at: Loch Sloy, 100 ppm (upstream from CZ 1127), on the margin of the igneous complex; Ardkinglas, 130 ppm (upstream from CZ 1152) in Green Beds; and Eagle's Fall, up to 190 ppm (upstream from CZ 1131) in a marginal porphyrite phase of the igneous complex (where cobalt may be related to pyroxene and amphibole).

BARIUM

Barium was determined only on panned concentrates. Baryte is a common gangue mineral in the vein-style mineralisation associated with the Tyndrum–Glen Fyne and Garabal faults, and the Garabal Hill–Glen Fyne igneous complex. Panned concentrates from these areas commonly contain abundant visible baryte. The maximum level in the preliminary survey is 5.67 per cent, and in the detailed drainage survey it reaches 13.84 per cent.

The cumulative frequency plot (Figure 22) displays two anomalous classes defined by inflections at 2200 ppm (97 percentile) and 630 ppm (92 percentile). The lowest inflection, at 10 ppm, which is caused by analytical imprecision, is ignored, and the background class is defined by the mean (140 ppm). The distribution of these classes is plotted in Figure 21. The same classes also produce the most significant patterns on the greyscale map (Figure 22).

The highest barium levels correspond with baryte mineralisation spatially associated with the Glen Fyne igneous complex. Alteration of the igneous body by hydrothermal fluids entering along the two major wrench faults probably caused the breakdown of the feldspars and removal of the barium towards the veins (Wedepohl, 1972). Similarly, high barium levels which are associated with faulted dolerite dykes of Permo-Triassic age are probably derived from hydrothermally leached wall-rocks. Other, more moderate, barium levels are found near the margins of felsite intrusions exhibiting minor hydrothermal carbonate veining.

Barium shows a moderate correlation with lead and zinc, which is largely due to the association of such mineralisation in baryte veining near the igneous complex and elsewhere.

URANIUM

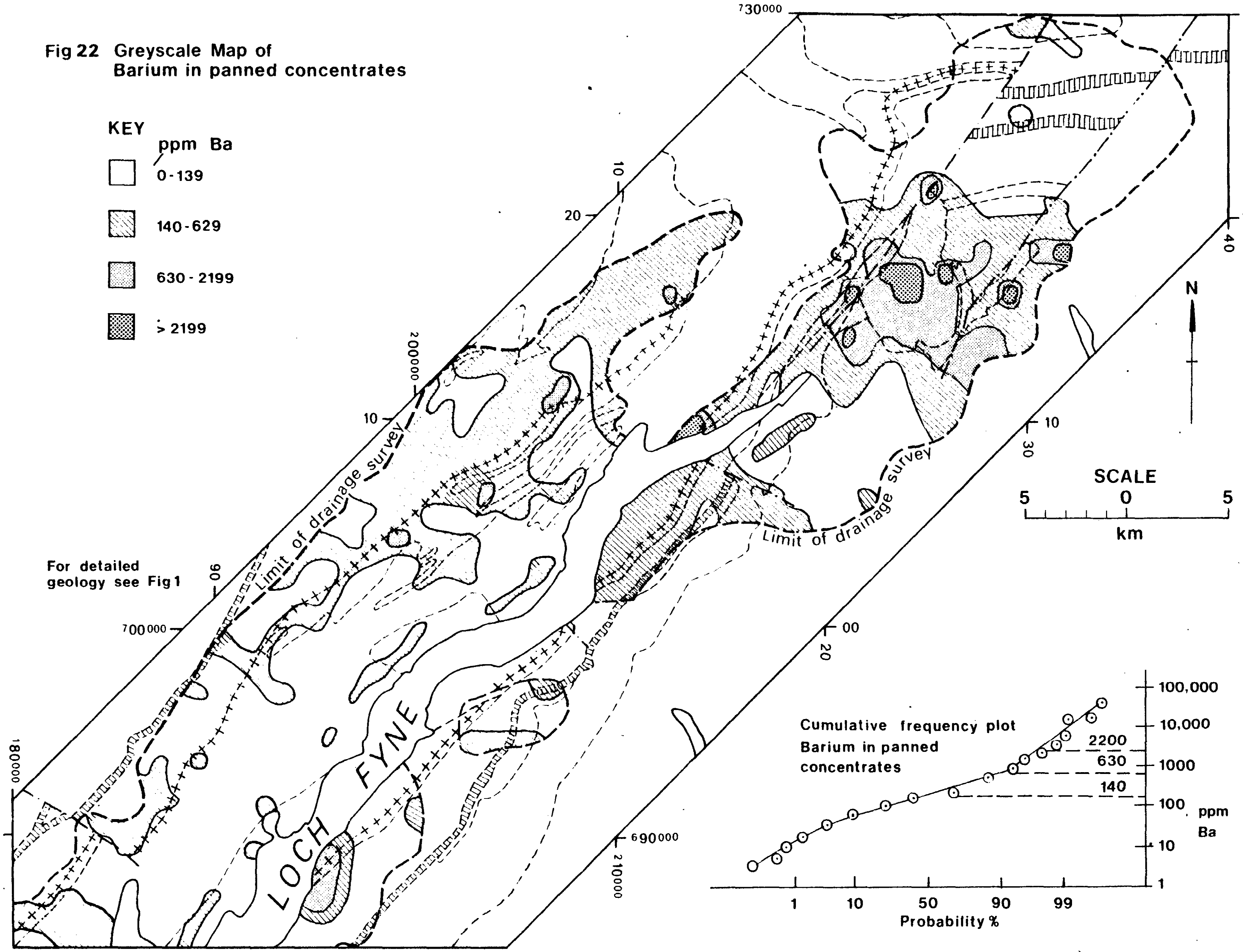
Uranium was analysed in only CZC 686 to CZC 3384, a total of 659 samples collected during the preliminary reconnaissance of 1975, which covers a sufficiently large area of sampling to enable a cumulative frequency plot and greyscale map to be produced (Figure 23). The north-western part of the area sampled during 1976 is not represented.

Although barium and uranium are significantly correlated at the 99 per cent level ($r = 0.27$) due to their coincidence in samples from the intrusion and faulted zones, this may be caused by later introduction of uranium into pre-existing fractures which contain barium (and lead) mineralisation. Similarly, along the Glen Fyne fault in the Cononish area, moderate enhancements of uranium are correlated with lead in sediment ($r = 0.21$). Some pitchblende accompanies galena in the numerous veins associated with the fault further north at Tyndrum (Wilson, 1921; Darnley, 1962), and has been shown to be significantly younger than the main lead mineralisation (Ineson and Mitchell, 1974).

Elsewhere, uranium concentrations correspond to the upper boundary of the Green Beds southwards from Glen Fyne, the Pyrite Zone south of Loch Fyne, the felsite bodies north of Loch Fyne (possibly syngenetically related to the intrusion), and the lead and copper mineralisation at Kaimes and Castletown and nearby parts of the Pyrite Zone and Ardrishaig Phyllites.

Although potentially economic concentrations of uranium are unlikely (the highly anomalous class rarely exceeds 10 ppm), the sites of some extremely high levels may be of interest. They are:

Fig 22 Greyscale Map of Barium in panned concentrates



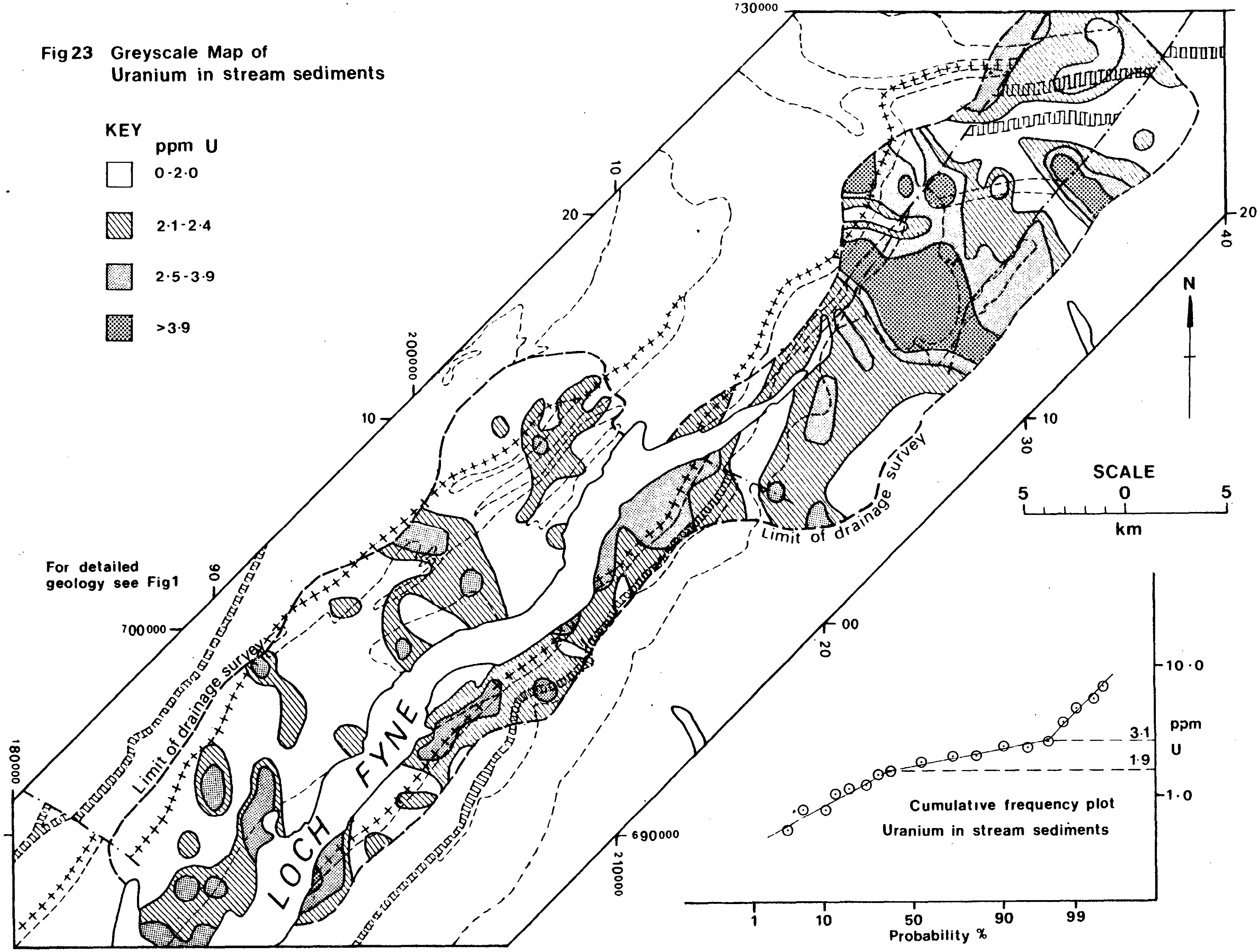


Fig 23 Greyscale Map of Uranium in stream sediments

Sample number CZC	NGR	Uranium ppm	Comments
1215	22540 71762	18.3	Streams drain faulted porphyritic granodiorite, associated with barium anomalies. See p. 40.
1234	22447 71700	43.2	
1239	22443 71712	19.0	
1253	22329 71705	14.2	

MOLYBDENUM

The cumulative frequency plot of molybdenum in stream sediments (Figure 24) has slight inflections at 3 ppm (90 percentile) and 5 ppm (96 percentile), and reaches a maximum of 27 ppm. The most significant patterns on the greyscale map, however, emerge at the levels shown.

The greatest concentration of molybdenum is in and around the Garabal Hill–Glen Fyne igneous complex, probably caused by traces of molybdenite, but it has only slight indications of any economic potential. The slight enrichment along the Tyndrum–Glen Fyne fault may be due to a remobilisation of molybdenum associated with the lead mineralisation. The moderate correlations with lead in sediment (r = 0.28) and barium in concentrate (r = 0.37) indicate that these three elements are all enhanced near the Glen Fyne complex and the major faults.

Specifically, the highest levels of molybdenum (⩾10 ppm) are in: CZC 1105 (NGR 22425 72015), 14 ppm in the River Fyne where it drains the north-west margins of the igneous complex (porphyritic granodiorite) along the line of the Glen Fyne fault; two sites coinciding with Loch Tay Limestone and epidiorite at CZC 1115 (NGR 22363 71927), 14 ppm in a tributary of the River Fyne; and CZC 3415 (NGR 23370 72773), 11 ppm in Allt Gleann Achrioch (see p. 35). CZC 3422 (NGR 19905 70110) and CZC 3424 (NGR 19713 70098), both 10 ppm, are in streams draining limestone horizons in Ardrishaig Phyllites near Craignure Mine, and CZC 3438 (NGR 21721 70605), is in the Green Beds at Hell's Glen, with 10 ppm.

Several molybdenum anomalies (up to 27 ppm) in parts of the Garabal Hill–Glen Fyne igneous complex near Loch Sloy, in Allt na Lairige, Allt Arnan and at Eagle's Fall are described below (p. 40). Elsewhere, CZC 6862 (NGR 22365 71670), in a tributary of the River Fyne draining the western margin (porphyritic granodiorite), contains 13 ppm molybdenum; and three samples (CZC 7074, 7075 and 7078) range from 10 to 12 ppm molybdenum, in a stream draining the southern margin of the porphyritic granodiorite near NGR 22467 71316.

SILVER

Silver was determined only in stream sediments. In 738 preliminary samples, it reaches a maximum of 3 ppm. Because of the generally low levels and the relatively high limit of detection (2 ppm) little can be said about the distribution of silver and no greyscale map has been plotted.

The highest levels of silver are at:

Sample No. CZC	NGR	Silver ppm	Copper ppm	Nickel ppm	Comments
3156	19218 69277	3	100	60	Drains epidiorite
6639	22004 71433	6	80	80	Resampling of CZ 1107 in Lower Glen Fyne (see p. 40).
6642	22026 71451	3	80	80	

The moderately anomalous levels of copper and nickel underline the slight association with silver (r = 0.29 and 0.24 respectively). The anomalous silver levels in Glen Fyne may be derived from a possible extension of the mineralised Loch Tay Limestone at Clachan Beag Mine, 3 km to the south-west, where a ?metasomatic replacement carries traces of silver (Wilson, 1921). The stratum-controlled mineralisation at McPhun's Cairn, which contains trace silver (Smith and others, 1977b), is not reflected in any sediment samples taken along strike. Extensive silver mineralisation here, or elsewhere in the area, is unlikely.

ANTIMONY

Antimony was determined only in panned concentrates by X-ray fluorescence. The detection limit is 20 ppm, and the maximum level in the preliminary samples is only 60 ppm. Despite the analytical imprecision, significant patterns emerge at the isopleths shown on the greyscale plot (Figure 25).

Antimony correlates with lead in sediment (0.12) and tin (0.24). Combined high levels of these metals usually indicate contamination from sources such as solder in tin cans, and car batteries. The coastal areas of population are sources of such contamination. Examples are at Furnace – CZP 1479 (20 ppm Sb, 116 ppm Pb and 355 ppm Sn), and Achnagoul – CZP 1485 (23 ppm Sb, 2595 ppm Pb, 104 ppm Sn).

As an element associated with the later stages of hydrothermal mineralisation, the coincidence of antimony with such zones at Cononish and in Glen Fyne may be expected. This coincidence partially accounts for the slight correlation (0.12) with lead in sediments.

Instances of high antimony levels possibly related to mineralisation are at Coille-bhraghad Mine in CZP 1000 (60 ppm); Eas Riachain in CZP 1060 (22 ppm), in a stream draining Beinn Bheula Schists and porphyrites marginal to the igneous complex; Upper Glen Fyne in CZP 6756 (23 ppm), in a stream draining a mineralised ?Permo-Carboniferous dyke (see p. 37); and Allt na Lairige in CZP 6968 (20 ppm) associated with lead and barium anomalies in granodiorite (see p. 40); economic antimony mineralisation is unlikely, however. Levels of up to 100 ppm are

Fig 24 Greyscale Map of Molybdenum in stream sediments

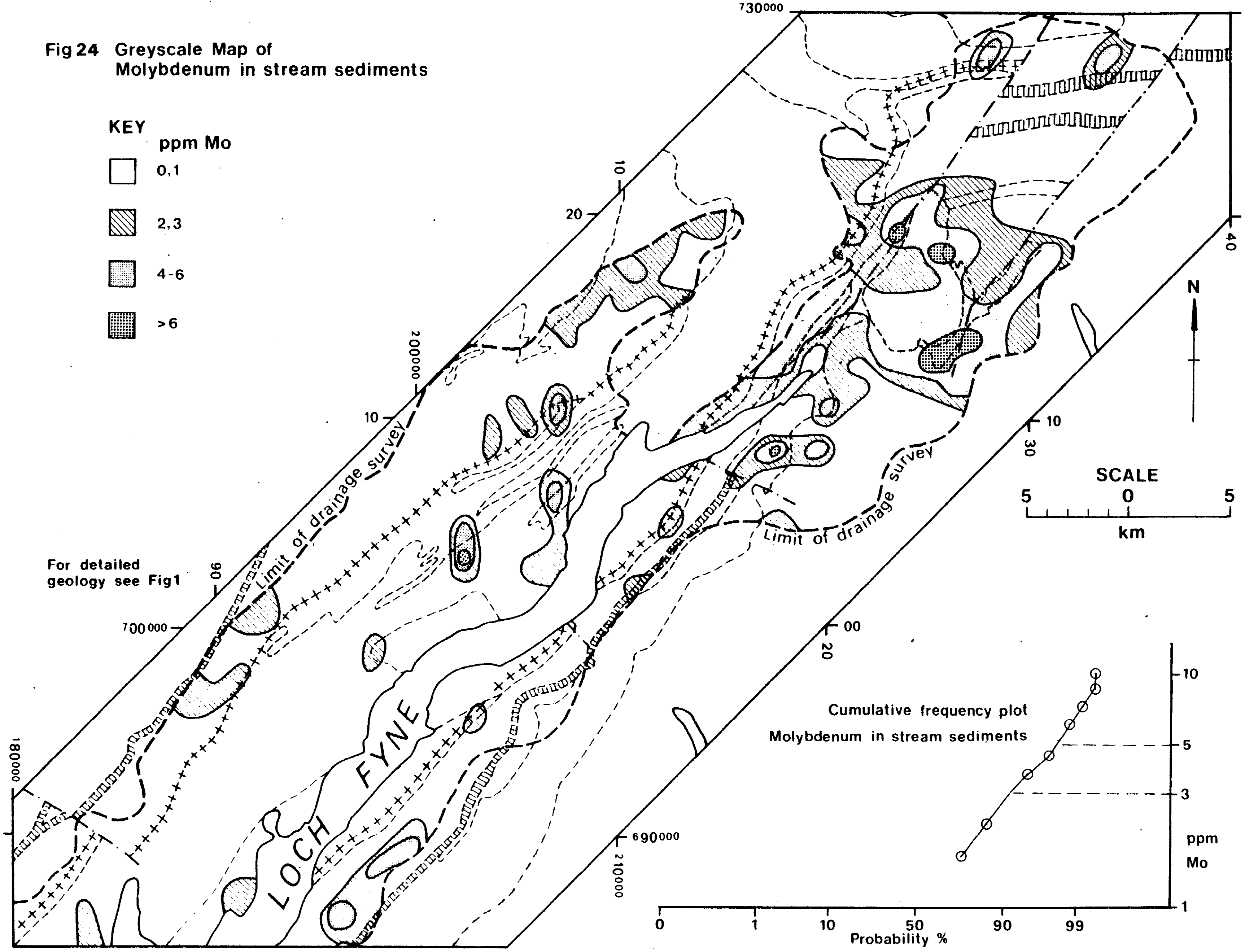
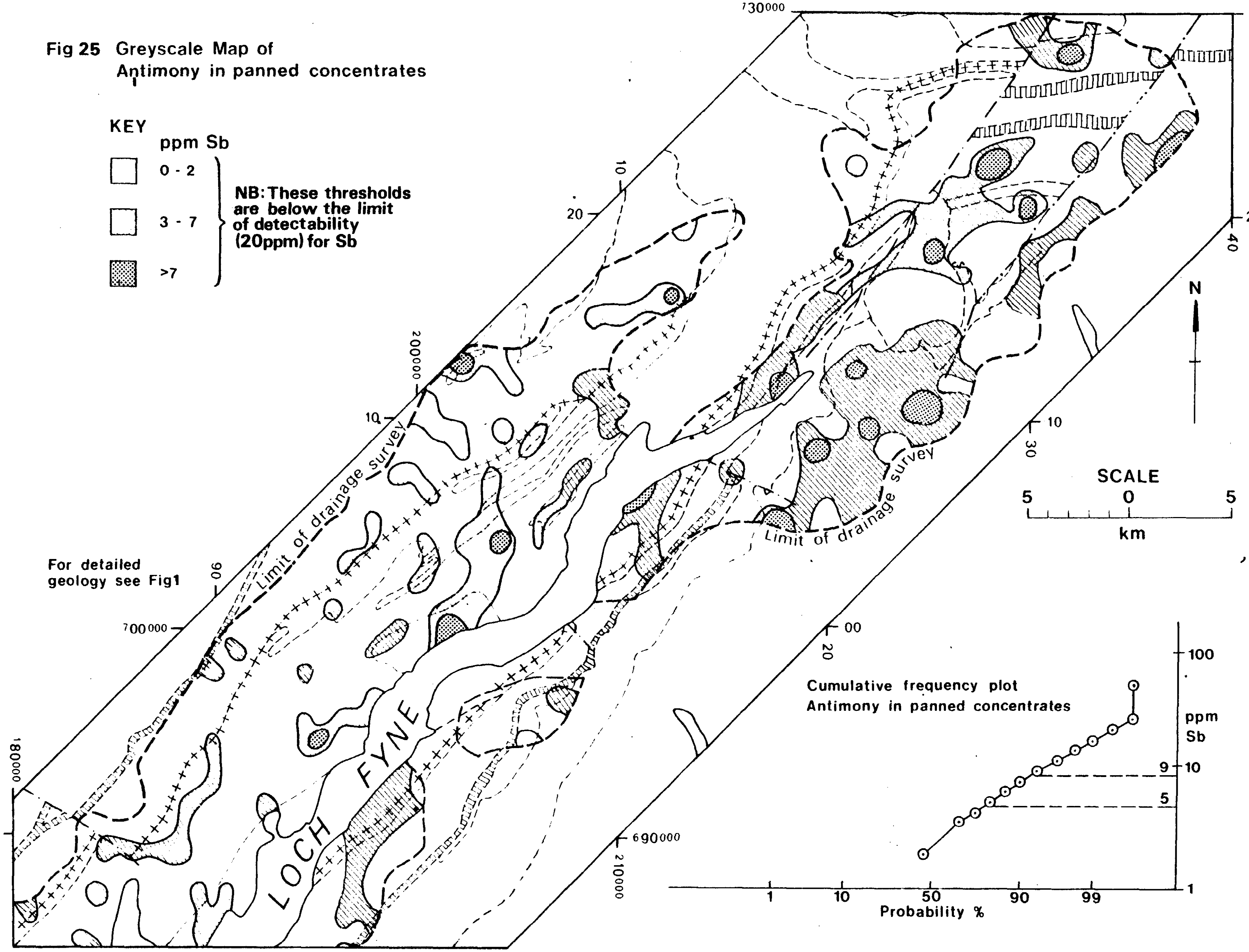


Fig 25 Greyscale Map of Antimony in panned concentrates



recorded in similar environments at Meall Mhor, just to the south-west of this area, associated with copper mineralisation (Coats, *in* Smith and others, 1978), but no antimony mineralisation has been identified.

TIN

Tin, determined only in panned concentrates, reaches levels of up to 2051 ppm, but has a mean of only 2 ppm and modes of 1 ppm and 6 ppm (Figure 26). The steepness of the curve above an inflection at 15 ppm (94 percentile) accounts for the range of the highly anomalous class, which is due almost entirely to contamination. The limit of detection of the analytical method is 9 ppm and this is probably greater than the level of tin derived from natural sources. No panned concentrates from this area were examined mineralogically, but experience elsewhere in the Highlands and in neighbouring districts, such as Meall Mhor (Smith and others, 1978), has shown that, where tin exceeds the detection limit, particles of metal indicating contamination can be found in the concentrate.

The distribution of tin derived from urban and agricultural contamination coincides mainly with the populated coastal strip and around the settlements at Lochgilphead, Lochgair, Minard, Furnace, St Catherine's and Inveraray. Inland, higher levels usually coincide with roads. Such zones are usually the dumping ground for tin cans, and association with high antimony, lead and nickel (correlation coefficients of 0.24, 0.25 and 0.10 in panned concentrates respectively) indicates contamination from this source and from dumped car batteries and car bodies. Concentrations in isolated areas usually correlate with intensive forestry activity and hydro-electric power schemes. Elsewhere, the known mineralisation at Eagle's Fall, Achadunan, Creggans, Kaimes and Castletown, and associated human activity, provide sources of contamination.

Instances of tin indicating contamination which may influence levels of other metals are described in the detailed drainage survey. No tin mineralisation is suspected in the area.

IRON

The cumulative frequency plot of iron (Figure 27), determined only in panned concentrates, is virtually lognormal. Class divisions are selected therefore at the mean, mean plus one and mean plus two standard deviations as shown. These are also the most significant levels on the greyscale map.

Iron levels reach 31.89 per cent in the preliminary samples and 40.37 per cent in detailed drainage samples, and it is the major constituent of nearly all panned concentrate samples. The strongest control of iron seems to be the incidence of mineralisation, and all of the known mineral localities are represented by high iron levels. Because of the active erosion which is taking place in most of the streams, and the removal of the fine fraction during panning, the levels of iron are probably due to discrete iron minerals rather than coatings of secondary iron oxides on the mineral grains.

The correlation coefficients of iron with copper (0.49 and 0.42 in sediment and panned concentrate respectively), zinc (0.27 and 0.50), and nickel (0.47 and 0.50), are probably due to an association in basic rocks and in sulphide mineralisation. Almost all of the zones with high levels of these metals also have high iron levels. Iron is present in the concentrates as pyrite and magnetite, the latter being the more common phase near basic rocks. Pyrite, as may be expected, is abundant in the concentrates from streams draining the Pyrite Zone.

High levels of iron coincide with the two major faults associated with the hydrothermal mineralisation. The epidiorites associated with areas of Loch Tay Limestone are probably another source of iron. Only parts of the Pyrite Zone, a potential source of iron, are delineated by high iron levels. Higher pyrite concentrations in the Pyrite Zone correspond to higher levels of other metals indicating the close association between the iron mineralisation and the other metals such as copper and zinc.

CERIUM

The cumulative frequency plot of cerium in panned concentrates (Figure 28) indicates three main populations divided at 63 ppm (80 percentile) and 399 ppm (99 percentile). The most significant patterns on the greyscale map, however, emerge at the levels shown.

Allanite, which is usually associated with the calc-alkaline igneous intrusions, is probably the main source of cerium. Part of the most basic phase of the Garabal Hill—Glen Fyne intrusion is associated with high cerium levels. Elsewhere, many of the higher levels correspond to felsite intrusions, especially the larger bodies lying at the boundary of and within the Crinan Grits. The other cerium anomalies are more scattered and are difficult to explain.

Cerium shows little correlation with other elements. The strongest correlation is 0.17 with nickel in panned concentrates, and this association may be due to the high cerium and nickel levels in the more basic parts of the Garabal Hill—Glen Fyne complex.

CALCIUM

The frequency distribution of calcium in panned concentrates (Figure 29) is almost lognormal, but two slight inflections at 1.74 per cent (37 percentile) and 3.98 per cent (78 percentile) define three classes. Different class intervals are used on the

Fig 26 Greyscale Map of Tin in panned concentrates

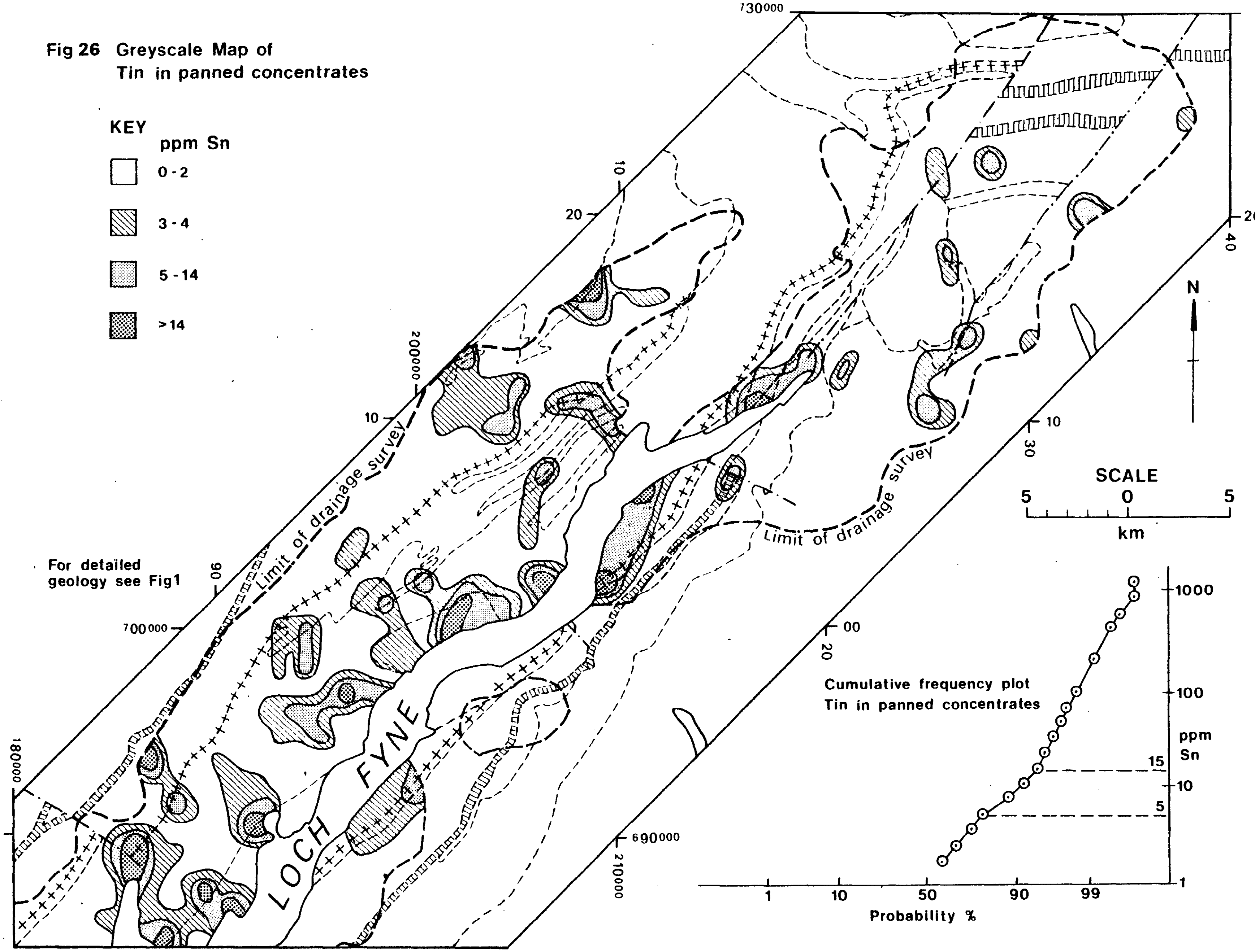


Fig 27 Greyscale Map of Iron in panned concentrates

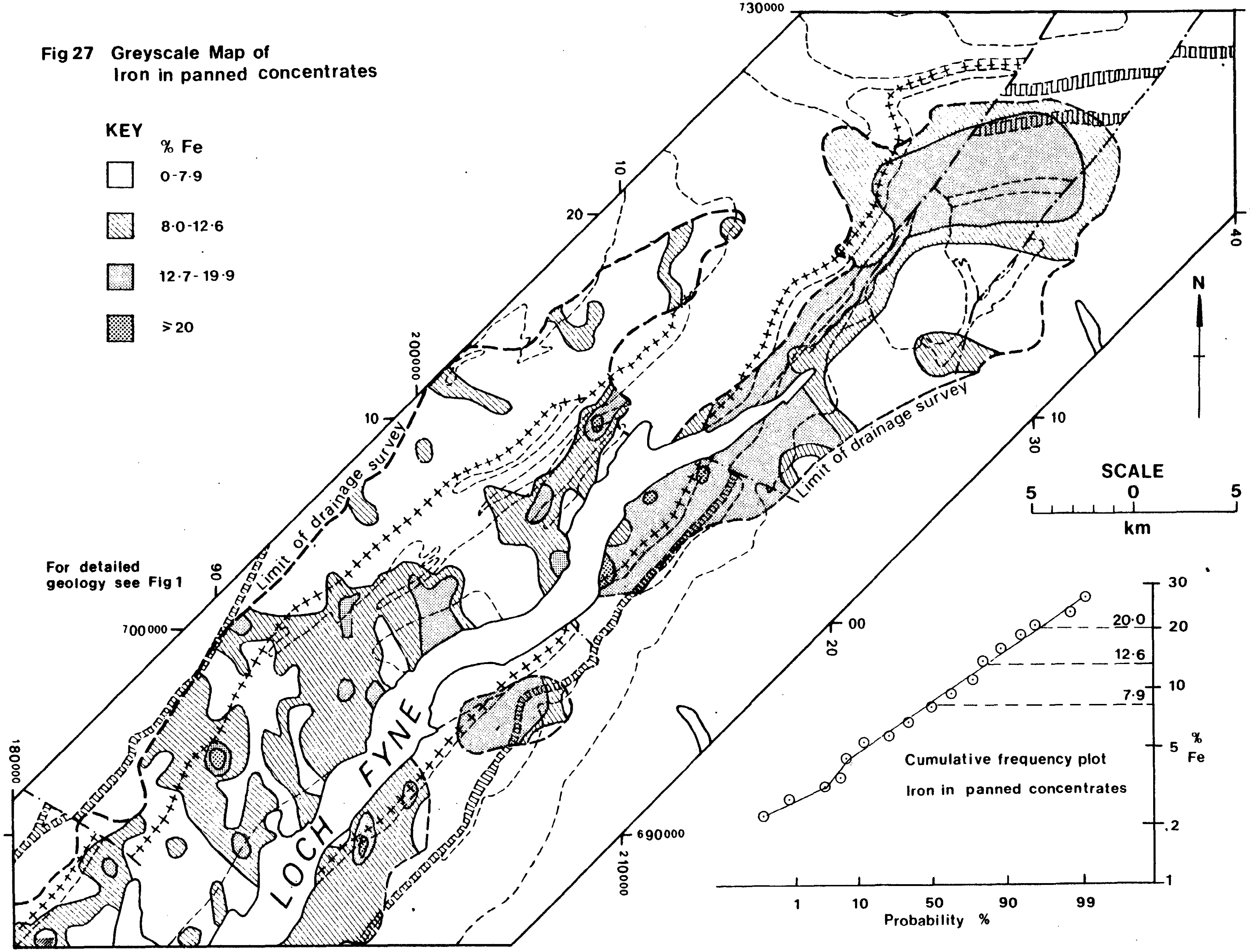
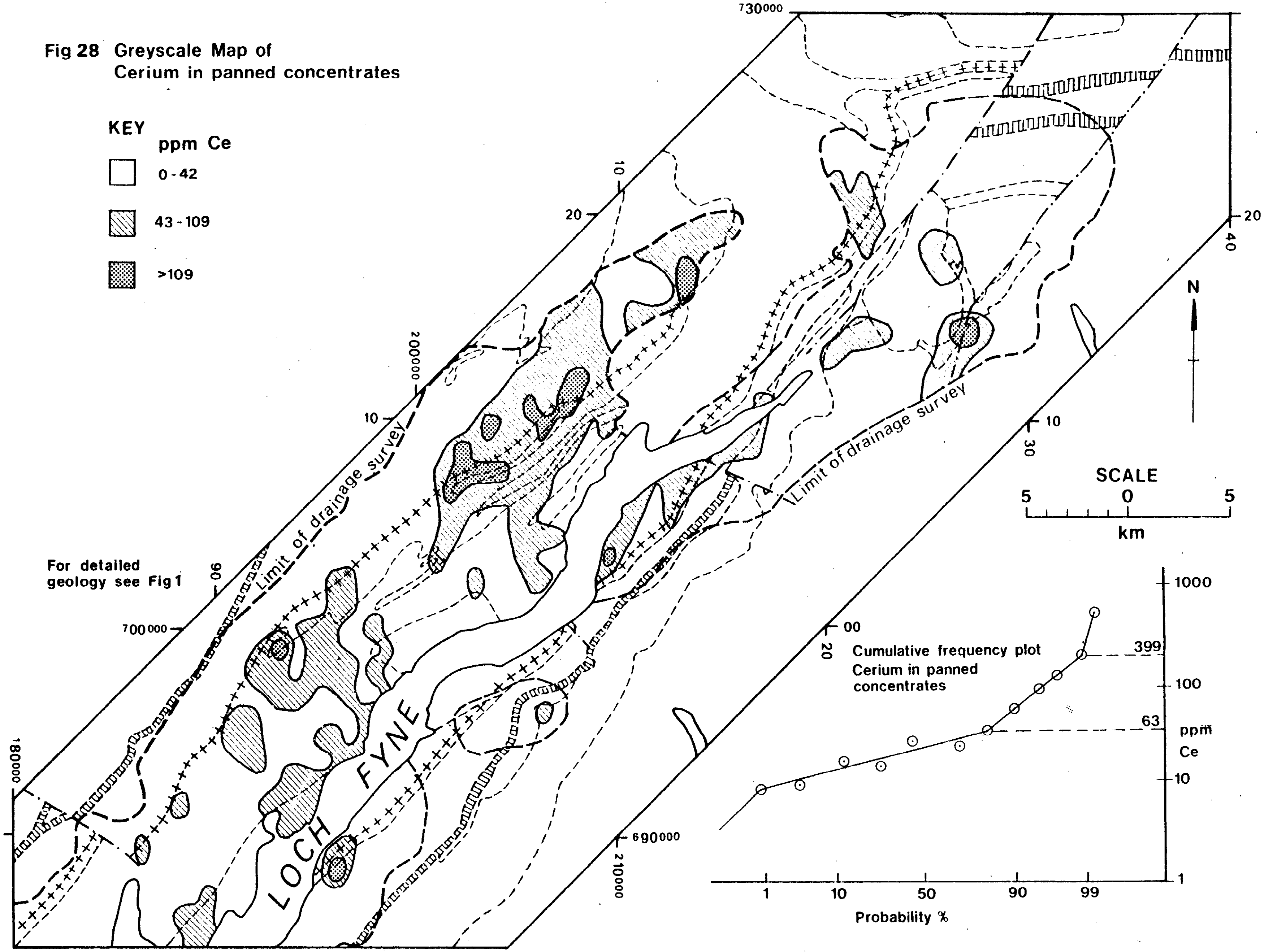


Fig 28 Greyscale Map of Cerium in panned concentrates



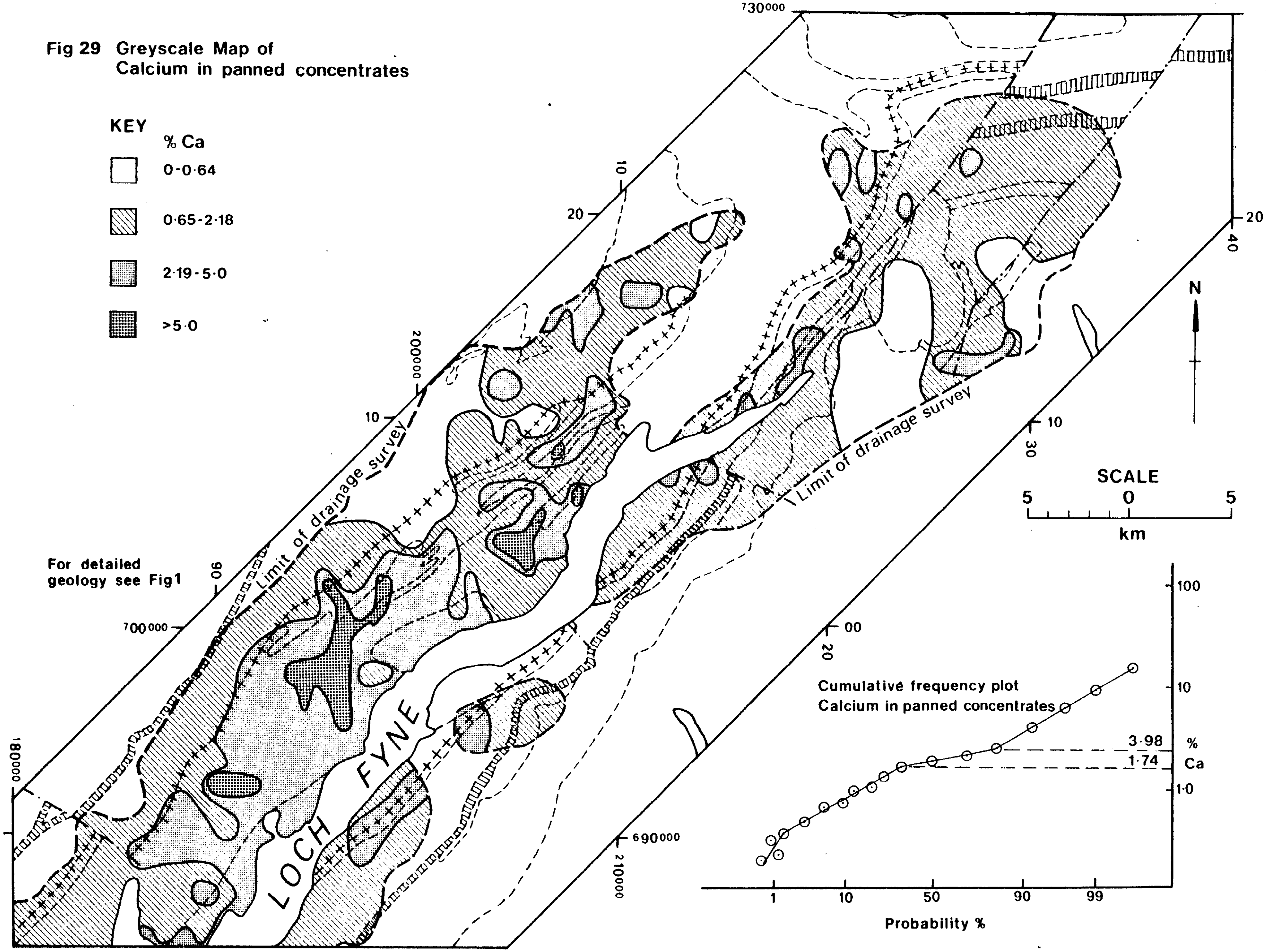


Fig 29 Greyscale Map of Calcium in panned concentrates

greyscale map, however, in order to outline more clearly the areas of low and high calcium levels, especially as the inflections are relatively minor.

Calcium is probably present in several minerals in panned concentrates. It can be derived from the more basic calc-alkaline igneous rocks, and higher levels in the eastern part of the Garabal Hill–Glen Fyne igneous complex are probably of this origin. Abundant hornblende in the epidiorites probably partly produces the highest calcium concentrations in the heavy mineral concentrates north-west of Loch Fyne. Calcium is also present in other minerals of metamorphic origin in the greenschist facies, such as zoisite, calcite, dolomite and tremolite, throughout the area. The abundance of lime-rich rocks and calc-sericite phyllites would add to the calcium concentration north-west of Loch Fyne. The relatively lime-free Crinan Grits and Beinn Bheula Schists are devoid of high calcium levels in the panned concentrate.

On a local level, higher concentrations of calcium correspond to the limestone at Clachan Beag and other outcrops of Loch Tay and Tayvallich Limestones in the area. The strong correlations with iron, titanium and manganese are probably due to the association of these elements in basic igneous rocks, and the heavy mineral phases, such as hornblende and spinels, derived from them.

MANGANESE

The cumulative frequency plot of manganese in panned concentrates (Figure 30) indicates three classes divided at 0.0692 per cent (18 percentile) and 0.19 per cent (70 percentile). The upper class is large, and the distribution of manganese is most significantly shown by the class intervals used on the greyscale map.

Manganese is strongly correlated with iron, calcium and titanium in the panned concentrates, and this is clearly the association derived from basic rocks. The availability of manganese due to the breakdown of basic rocks is not the only factor in its distribution, as it is found predominantly in the fine fractions as a coating of secondary manganese oxides. Co-precipitation of iron and manganese colloids can enhance the levels of trace elements such as cobalt, zinc and copper, but as the manganese content of the fine fraction was not determined, the contributions of the co-precipitated trace elements to the total geochemical variation cannot easily be found. In the heavy mineral concentrates, however, manganese is predominantly found in minerals such as spinel, pyroxene and hornblende, which are derived from the breakdown of basic rocks such as the epidiorites, the Green Beds and the more basic portions of the Garabal Hill–Glen Fyne igneous complex.

TITANIUM

The frequency distribution of titanium in panned concentrates (Figure 31) is almost lognormal although slight inflections at 1.05 per cent (20 percentile) and 2.19 per cent (50 percentile) define the two lowest classes. The most significant patterns on the greyscale map are produced by the two classes below and above the mean, as shown.

Titanium minerals are present in all the panned concentrates. Titanium reaches a maximum of 18.78 per cent in CZP 6729 (NGR 22838 71411), on the more basic south-eastern margin of the Garabal Hill–Glen Fyne igneous complex. In such rocks, ilmenite ($FeTiO_3$) and related spinels are disseminated throughout. The association of titanium with iron in this basic zone partly accounts for the high correlation of 0.5. Elsewhere in the igneous complex, where ilmenite, rutile (TiO_2) and sphene ($CaTiSiO_5$) could be expected as accessory minerals, titanium levels are lower. The highest titania content (2.49 per cent) of the complex is found in a hornblendite from Lochan Beinn Damhain (Nockolds, 1940).

Higher levels in Glen Fyne and on both sides of Loch Fyne are probably due to rutile and sphene (with some ilmenite) in schists and epidiorites. The streams draining the Ardrishaig Phyllites have noticeably higher titanium levels, and this is also a characteristic of the Ben Lawers Schists, the stratigraphic equivalents to the north-east of this area.

DETAILED DRAINAGE SURVEYS

INTRODUCTION

Sites sampled during the preliminary survey of 1975 which contained anomalous levels of copper, lead, zinc, nickel and barium were resampled at closer intervals further upstream in 1976 in order to locate the causes of the anomalies. A total of 101 stream sections were resampled in this way.

Because of the lack of complete analytical and statistical data at the time, thresholds were set at arbitrary levels based on experience elsewhere in the Highlands. These levels, in stream sediments and panned concentrates respectively, were 50/100 ppm copper, 100/100 ppm lead, 400/200 ppm zinc, 90/100 ppm nickel, and 2000 ppm barium in panned concentrate. Levels above these were judged as anomalous and such anomalous sites were considered for further sampling.

Shortage of time meant that not all the anomalous sites could be investigated. Priority was given to the copper anomalies with co-incident anomalies of other elements, followed by the anomalies of lead, zinc, nickel and barium. Geological observations were made at the same time and recorded on field sketch maps.

Assessment of the detailed stream sampling, and geological interpretation of the results, enable the anomalies to be grouped according to

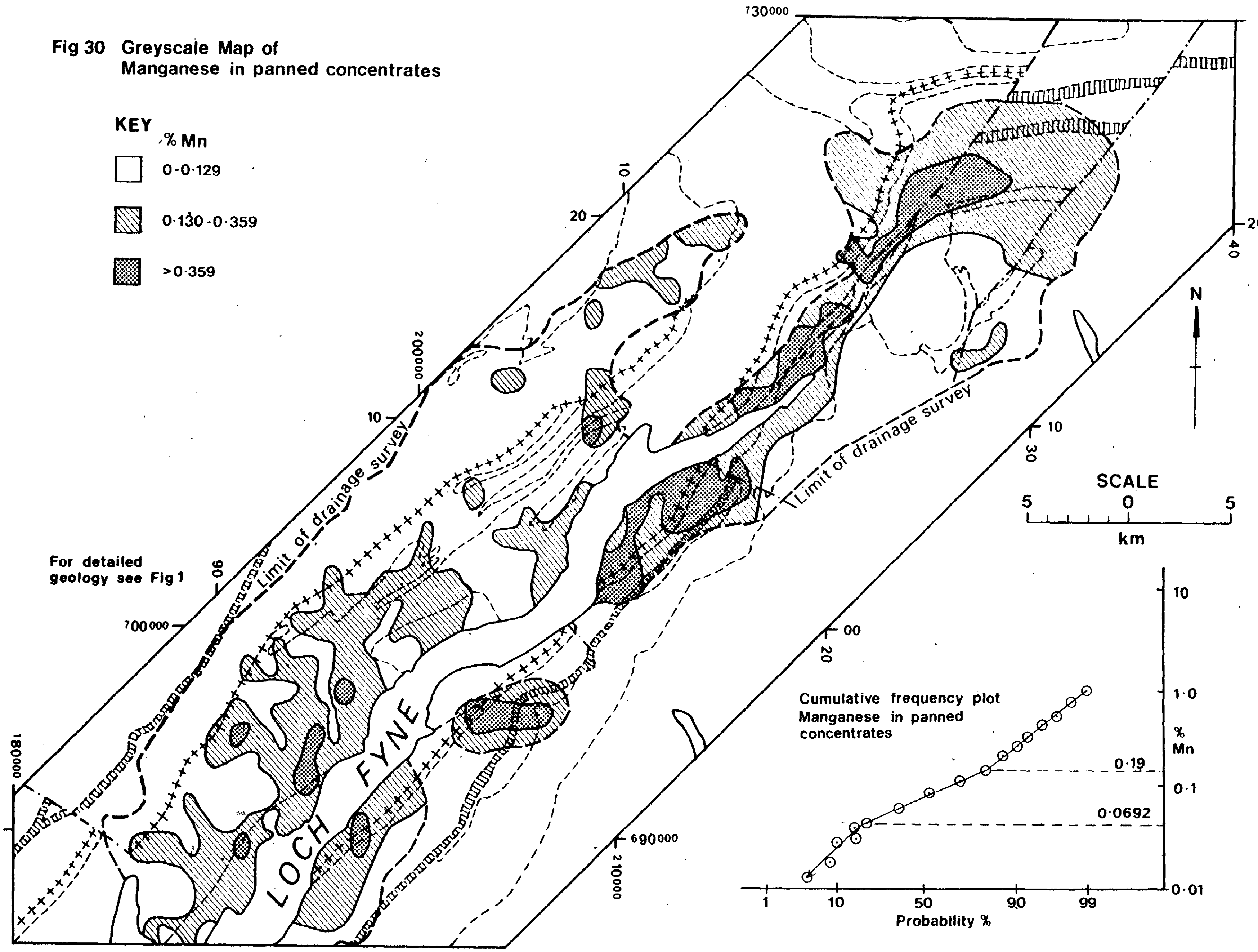
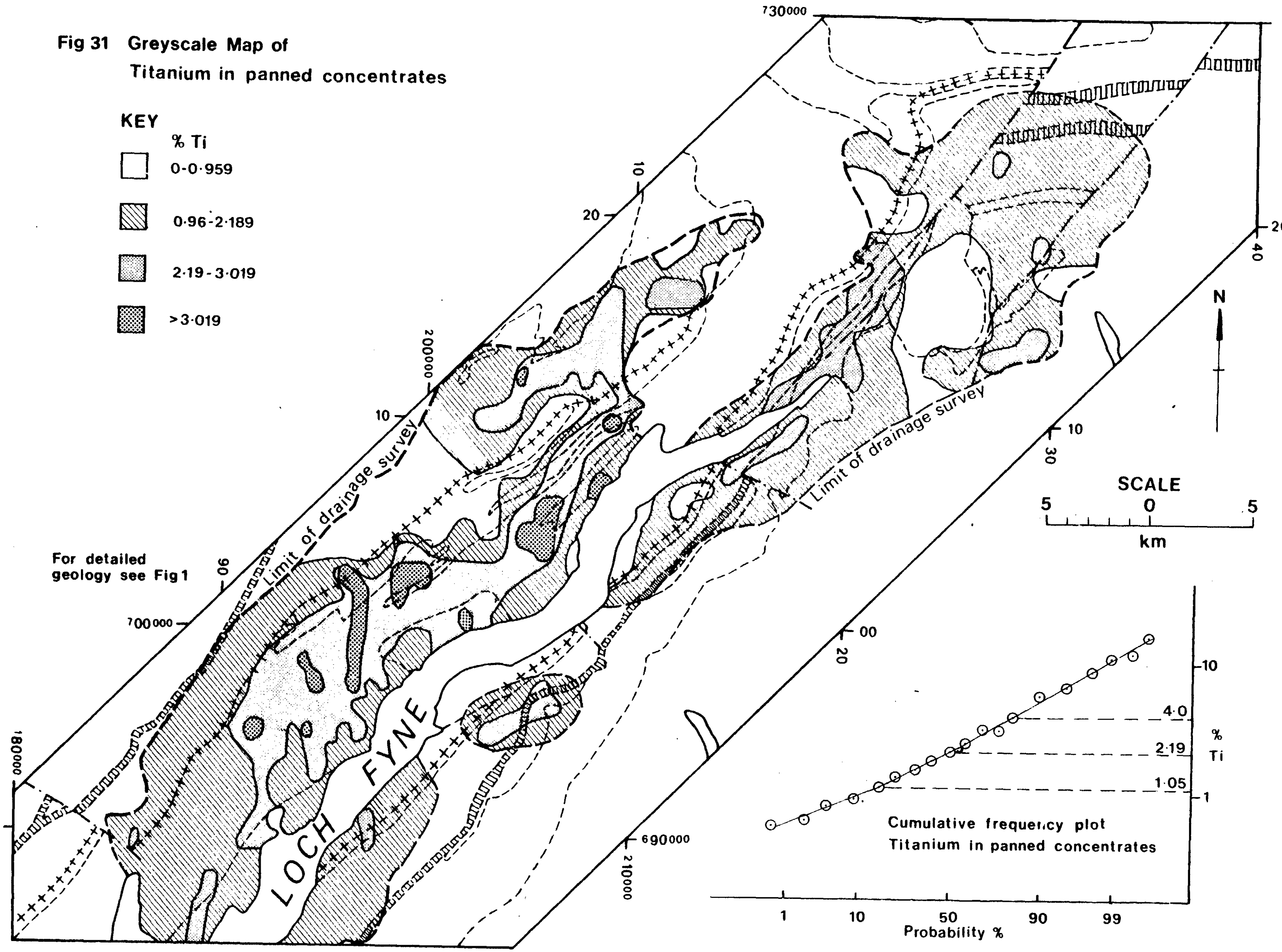


Fig 30 Greyscale Map of Manganese in panned concentrates

Fig 31 Greyscale Map of Titanium in panned concentrates



structural and lithological controls. These controls are the major faulting, the Garabal Hill–Glen Fyne igneous complex, mineralised horizons within the Ardrishaig Phyllites, the Pyrite Zone, the Loch Tay Limestone and associated epidiorites, and certain horizons within the Green Beds. At some localities, a combination of two or more such features may act as controls.

The anomalies which have been sampled in more detail are described according to the major controls, and, within these groups, from the north-east to the south-west of the area. Reference should be made to Figures 3 and 4, which give the location of the original sample sites, and on which the streams which were sampled in greater detail can be identified.

TYNDRUM–GLEN FYNE FAULT SYSTEM

This major fault system extends for 110 km from Loch Rannoch in the north-east, through Tyndrum, to Cowal in the south-west, and is one of a set of similar faults which traverse the Southern Highlands. It has been interpreted as a sinistral wrench fault (Tectonic Map of Great Britain and Northern Ireland, 1966) and is marked within the area of this survey (Figure 1) by a conspicuous topographic depression. In the Tyndrum mining area, which lies on the northern border of the survey, the fault is the major control of mineralisation and is probably of Caledonian to Hercynian age; the marginal, clay mineral alteration has been dated (potassium-argon method) at 315 Ma (Ineson and Mitchell, 1974), and the minor, cross-cutting, uranium mineralisation at 230 Ma (uranium-lead method, Darnley, 1962).

Although the fault acted as the major pathway for hydrothermal fluids, the varied lithologies intersected have acted as controls, either as suitable host rocks for the mineralisation or as sources for the metals.

Cononish

Samples at CZ 1273 (NGR 22985 72863) and CZ 1278 (NGR 22982 72859), at the south-western end of the Tyndrum mineralised area, have anomalous lead contents, and the stream courses were further sampled to reveal any unknown mineralisation.

CZ 1273, at the base of a stream from the north, contains 150 ppm Pb in sediment and 353 ppm Pb in panned concentrate. Although the Tyndrum fault system consists of a massive quartz vein (the Mother Reef) about 500 m upstream, lead in samples taken upstream from the original sample site diminishes to background levels. High lead contents of 240 ppm in sediment and 1006 ppm in panned concentrate are found, however, at 22967 72871, in a north bank tributary, and presumably provided the source of the original anomalies downstream. This tributary also drains the Mother Reef, but at a point some 300 m north-west of where the main stream intersects it, thus indicating lead mineralisation may be restricted in this particular zone, and is absent from the Mother Reef in the main stream.

Site CZ 1278 is in a stream draining Eas Anie Mine. Concentrations, in detailed sampling, increase markedly upstream to the position of the veins, beyond which they generally decline:

Site CZ	Pb (ppm in sediment)	Zn	Cu (ppm in panned concentrate)	Pb	Zn	Ba	Location
1278	350†	120	146†	1398‡	375‡	754†	22982 72859
5814	779‡	230	160†	701‡	1100‡	678†	0*
5816	1220‡	300†	412‡	1810‡	2126‡	1162†	500*
5818	960‡	300†	362‡	3456‡	1101‡	1055†	700*
5820	630‡	270	99†	11441‡	6023‡	757†	800*
5822	140†	250	1	59†	92	88	1000*
5824	130†	260	0	49	95	73	1200*
5826	190†	320†	1	36	107†	171	1400*

† moderately anomalous
‡ highly anomalous
* m upstream of CZ 1278

Mineralisation, in the form of galena, sphalerite and chalcopyrite in 15–25 cm thick quartz veins, is found near CZ 5816 and 5818. The main mine levels are located in the steep cliffs just above sample site CZ 5820, and probably contribute most of the lead and zinc, but not copper, to the stream sediment. The relatively thin and irregular veins are unlikely to be economic. One vein at this locality, strike 203° (true), dip 60°W, assays at 1.3 per cent Cu, 8.5 per cent Pb and 7.7 per cent Zn over 0.1 m.

Upstream of the known mineralisation, some element levels do increase:

Site CZ	5814	5816	5818	5820	5822	5824	5826
Arsenic ppm	9	16	13	15	12	20	32
Cobalt ppm	25	36	36	34	48†	42	63†

† moderately anomalous

This possibly indicates minor arsenic and cobalt mineralisation similar to that recorded on the cross courses of the Tyndrum Mine (Darnley, 1962).

Allt an Rund

CZ 1072 (NGR 22820 72725) lies just upstream of the confluence of this stream with the River Cononish. Three samples were subsequently taken further upstream of the lead and zinc anomalies at CZ 1072. Two of the samples (CZ 3410 and 3411) are duplicates taken at the same site. Results are as follows:

Site CZ	Pb (ppm in sediment)	Pb (ppm in panned concentrate)	Zn	Location
1072	150†	2530‡	758‡	
3410	450‡	12126‡	582‡	250 m Upstream of CZ 1072
3411	n.d.	18489‡	490‡	250 m Upstream of CZ 1072
3412	40	79	92	450 m Upstream of CZ 1072

† moderately anomalous
‡ highly anomalous
n.d. not determined

Abundant galena and sphalerite in CZP 3410 and 3411, from just downstream of the abandoned Ben Lui Mine, are the obvious sources of the anomalies. The mine lies on a mineralised branch of the Mother Reef, which also passes through the Eas Anie Mine some 1500 m to the north-east. No sources of metals upstream of the mine are indicated.

A sample of quartz vein material carrying galena and sphalerite, from the mine tip, contains 130 ppm Cu, 5.04 per cent Pb, 11.3 per cent Zn and 14 ppm Ag.

Allt Gleann Achrioch
In the lowest right bank tributary of this stream, CZC 1292 (NGR 23332 72797) contains 70 ppm Cu. Three additional samples were collected upstream:

Site CZ	Cu (ppm in sediment)	Location	
3413	65†	100 m	Upstream of CZ 1292
3414 (pyrite recorded in pan)	85†	200 m	
3415	55†	300 m	

† moderately anomalous

Copper scarcely increases, and the anomalies may be related to epidiorite associated with the Loch Tay Limestone lying further upstream. The epidiorite contains minor disseminated sulphide (?pyrite), and one sample assays at 300 ppm Cu. A molybdenum level of 11 ppm in CZC 3415 is highly anomalous and cannot be easily related to the known geology.

The Loch Tay Limestone also occupies the course of a left bank tributary of Allt Gleann Achrioch. Sampling upstream of the original site (CZ 1267) produced the following results:

Site CZ	Cu (ppm in stream sediments)	Zn	Co	Ni	Zn (ppm in pan)	Location
1267	70†	220	n.d.	40	129†	23299 72689
5865	65†	200	51†	61†	136†	same site
5867	95†	260	58†	67†	135†	200*
5869	120‡	290†	59†	70†	151†	400*
5871	70†	260	67†	64†	127†	600*
5873	50†	250	56†	54	101†	800*

† moderately anomalous
‡ highly anomalous
n.d. not determined
* m upstream of site CZ 1267

Sites CZ 5867 and 5869 coincide with limestone cut by faults, and a rock sample with visible pyrite from site CZ 5869 assays at 270 ppm Cu, 580 ppm Pb, 200 ppm Zn, 35 ppm Co and 30 ppm Ni. The limestone has probably reacted with solutions moving along the fault planes which may have leached the metallic elements (especially those related to basic volcanic rocks, such as copper, cobalt and nickel) from the associated volcanic rocks.

Allt Coire Dubhchraig
Samples collected at the confluence of this 4 km long stream with the Allt Gleann Achrioch (CZ 1284 – NGR 23319 72798) and at points upstream (CZ 1212 – NGR 23259 72771, CZ 1244 – NGR 23171 72710 and CZ 1265 – NGR 23170 72700) all contain anomalous copper and zinc.

Additional samples were taken at 200 m intervals between the original sites:

Site CZ	Cu (ppm in stream sediments)	Zn	Co	Ni	Zn (ppm in pan)	Location
1284	45†	420†	n.d.	50	176†	
5879	50†	480†	51†	74†	152†	App. 200 m intervals upstream
1212	55†	350†	n.d.	45	167†	
5877	55†	550‡	61†	85†	177†	
5875	65†	510†	53†	72†	141†	
1244	35	150	n.d.	40	110†	N. tributary
1265	65†	400†	n.d.	45	160†	Mainstream

† moderately anomalous
‡ highly anomalous
n.d. not determined

The source of metals is indicated near CZ 5877 and 5875, where a north-easterly trending fault determines the course of the stream. Upstream of CZ 1265, the fault intersects Loch Tay Limestone and metal contents decrease to background levels, indicating that mineralisation controlled by the fault is probably limited.

Dubh Eas
Resampling of an anomaly in an upper tributary of this stream was restricted by stream drought. Anomalous levels of 50 ppm Cu are repeated in sediment samples taken up to a limit of 400 m upstream of CZ 1172, but zinc diminishes from 360 to 280 ppm. Panned concentrate levels of lead and zinc fall drastically from 179 to 5 ppm and 171 to 22 ppm respectively. Lack of stream water may have resulted in poor sampling and affected panning efficiency. The stream drains a narrow, faulted, outcrop of Loch Tay Limestone and epidiorite just 1000 m east of the main Glen Fyne–Tyndrum fault where it passes north of the Garabal Hill–Glen Fyne igneous complex.

Upper Glen Fyne
Samples from two streams in this area (Figure 32) contain anomalous metal values. CZP 1071, in the northern stream, contains 144 ppm Pb and 168 ppm Zn. These levels increase only gradually upstream, to a point, 300 m from the original sample site, where lead sharply increases to 2628 ppm. The stream sediment at this site also has a high lead level. A source of lead such as galena may lie between this site and the next site upstream, within pyritiferous quartz veins, or in the quartzites and quartz-schists, bearing disseminated pyrite, further upstream. The Glen Fyne fault and the Garabal Hill–Glen Fyne igneous complex, lying

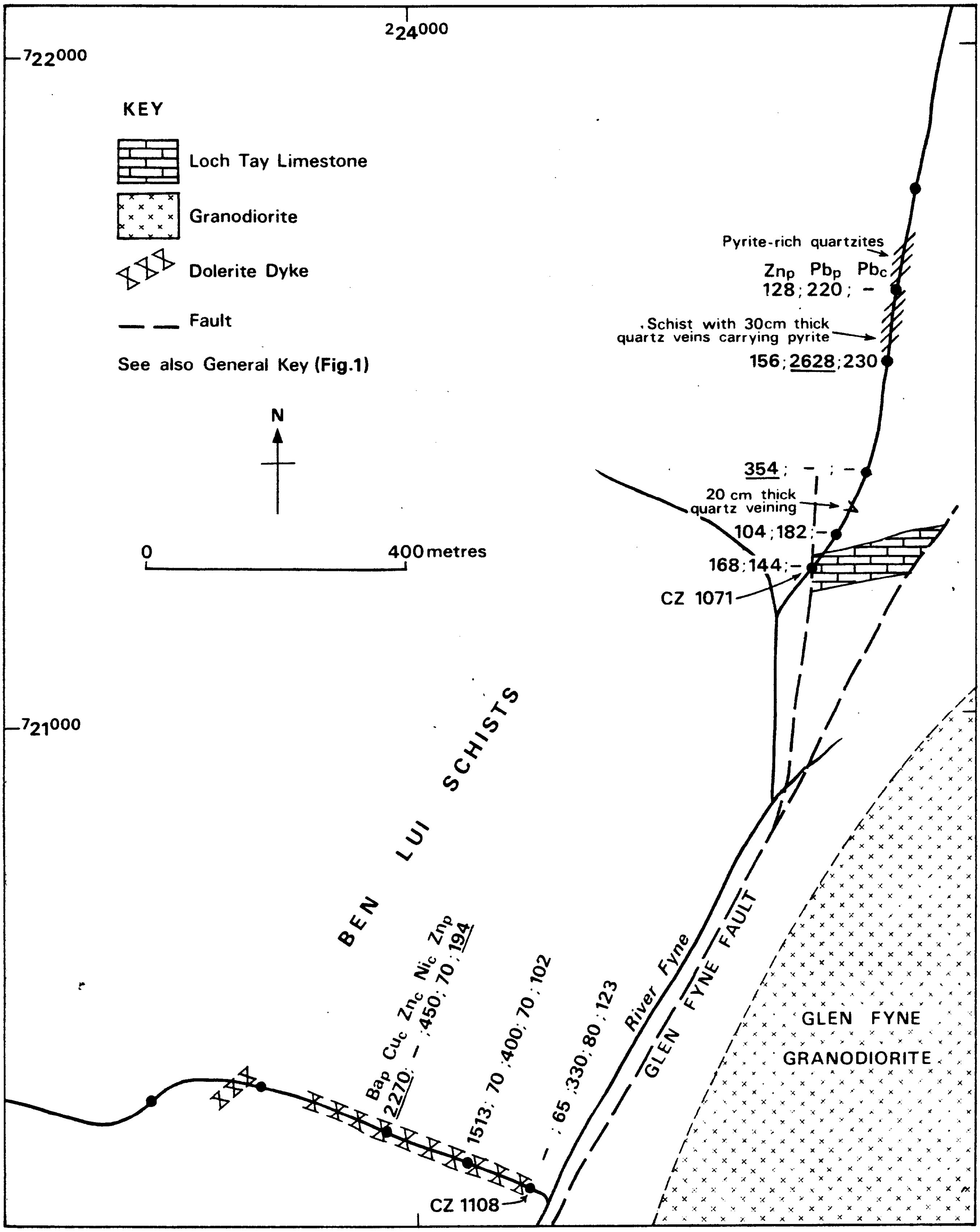


Fig.32 Anomalies in Upper Glen Fyne

close to the east, may be sources of the lead and zinc.

Further south, CZC 1108 contains 65 ppm Cu, 80 ppm Ni and 330 ppm Zn. Although two sediment samples upstream (Figure 32) are only slightly enhanced in these metals, the corresponding panned concentrate samples contain up to 2270 ppm Ba (compared with 446 ppm in the preliminary sample), and up to 194 ppm Zn, and the source lies presumably just upstream of these sites. A dolerite dyke of possible Permo-Carboniferous age extends along part of the stream (through Ben Lui Schists) and the barium-zinc mineralisation may be developed in a shatter zone coincident with the dyke.

Invercorachan

The northernmost of four sample sites (Figure 33), CZ 1089, contains 140 ppm Pb in the sediment; and 144 ppm Cu, 210 ppm Zn, 1298 ppm Pb and 2168 ppm Ba in the panned concentrate. Lead in sediment, and lead and zinc in panned concentrate increase to highly anomalous levels 200 m upstream (Figure 33). This panned concentrate contains abundant galena, and, after it was collected, a 25 cm wide vein carrying galena and minor chalcopyrite was discovered some 30 m upstream, which is presumably the source of the large lead anomaly, especially as no further anomalies are recorded from samples further upstream.

The vein lies near a narrow outcrop of the Loch Tay Limestone, between the Ben Lui Schists and the Green Beds, at the same horizon as the lead-zinc mineralisation at Clachan Beag some 8 km along strike to the south-west, where the limestone is metasomatically replaced (Wilson, 1921). Although exact field relations were not investigated, the mineralisation could be of a similar type. The close proximity of the Glen Fyne fault and of the Garabal Hill—Glen Fyne igneous complex could also have influenced mineralisation.

At the confluence of the next tributary with the River Fyne to the south, CZ 1093 contains 45 ppm Cu, 280 ppm Zn, 60 ppm Ni in sediment; and 88 ppm Cu, 85 ppm Pb, 42 ppm Ni and 2011 ppm Ba in panned concentrate. Zinc occurs at the highly anomalous level of 424 ppm in the panned concentrate (Figure 33) and rises to 552 ppm 100 m upstream. Other element levels also show an increase upstream. Further upstream, where the tributaries which meet just west of sample site CZ 1087 were also resampled, zinc levels are only moderately anomalous (Figure 33), with little or no increase in the other metals. A dispersed source for the zinc is indicated, but no mineralisation was observed in the field.

Although no record of mining in the Invercorachan area is known, a possible mine dump was found at NGR 22265 71775, where a 15 cm wide vein carrying galena and minor chalcopyrite, in a shatter belt of the Glen Fyne fault, crosses the stream (Figure 33). This vein was discovered in the detailed resampling of CZ 1124, which contains 50 ppm Cu, 120 ppm Pb and 360 ppm Zn in sediment and highly anomalous levels of 328 ppm Pb, 310 ppm Zn and 8529 ppm Ba in panned concentrate. These values were broadly confirmed in the resampling of the same site, the lowermost on this tributary (Figure 33), except that lead in panned concentrate increased to 822 ppm, and are presumably due to the vein and mine dump material discovered some 200 m upstream.

Other anomalies further upstream, however (Figure 33), indicate additional sources of copper, lead and zinc, possibly within the Green Beds, which are the source of the anomalies in the stream to the north, although the Loch Tay Limestone also outcrops in the headwaters of the tributaries, and may also be a contributary factor.

Anomalies in both stream systems are probably influenced by the Glen Fyne fault, and mineralisation in the intervening ground would produce a mineralised belt up to a maximum of 1200 m length.

Lower Glen Fyne

Another group of anomalies is located just south-west of the Invercorachan area.

In the west bank tributary of the River Fyne immediately to the north-east of Figure 34, detailed sampling upstream of CZC 1113 (Figure 3) gave the following results:

Site CZ	Cu	Zn	Ni	Cu	Zn	Ba	Location
	(ppm in sediment)			(ppm in panned concentrate)			
1113	55†	220	60†	n.a.	n.a.	n.a.	22263 71374
6745	80†	310†	75†	154†	161†	5469‡	300*
6746	45†	210	55	49	99	417	500*
6747	65†	230	65†	63	112†	1980†	600*
6748	55†	200	55	60	171†	483	800*
6749	60†	300†	80†	58	94	148	1100*
6750	60†	240	60†	52	128†	1495†	1200*
6751	60†	300†	60†	200†	185†	3020‡	1400*
6752	55†	340†	65†	71†	119†	632†	1800*

† moderately anomalous
‡ highly anomalous
n.a. no analysis
* m upstream of CZ 1131

CZC 1113 was collected at the base of the main stream, which flows from the north-east. CZ 6745—6750 are each at the base of tributaries flowing from the north-west, and CZ 6751 and 6752 are in the upper reaches of the main stream.

Although only CZP 6750 is anomalous in lead (174 ppm), the generally high levels of other elements indicate a continuation of the belt of mineralisation along the line of the Glen Fyne fault, which coincides with the upper 1300 m of the main stream course. The upper reaches of the tributaries drain the Loch Tay Limestone and epidiorites, although most of the stream course is in the Green Beds (intruded by felsite and granodiorite). A continuation of the mineralised zones

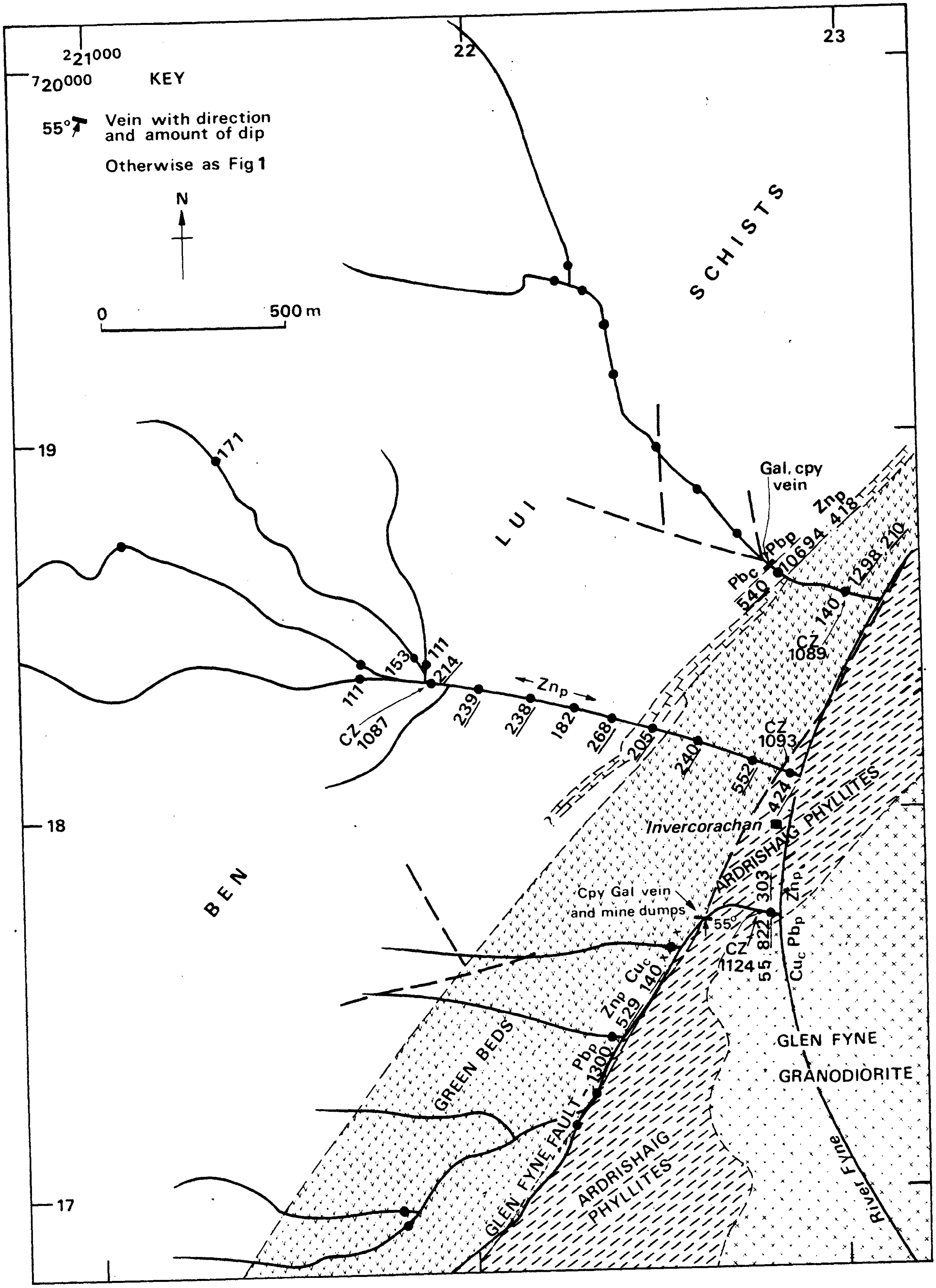


Fig 33 Anomalies at Invercorachan

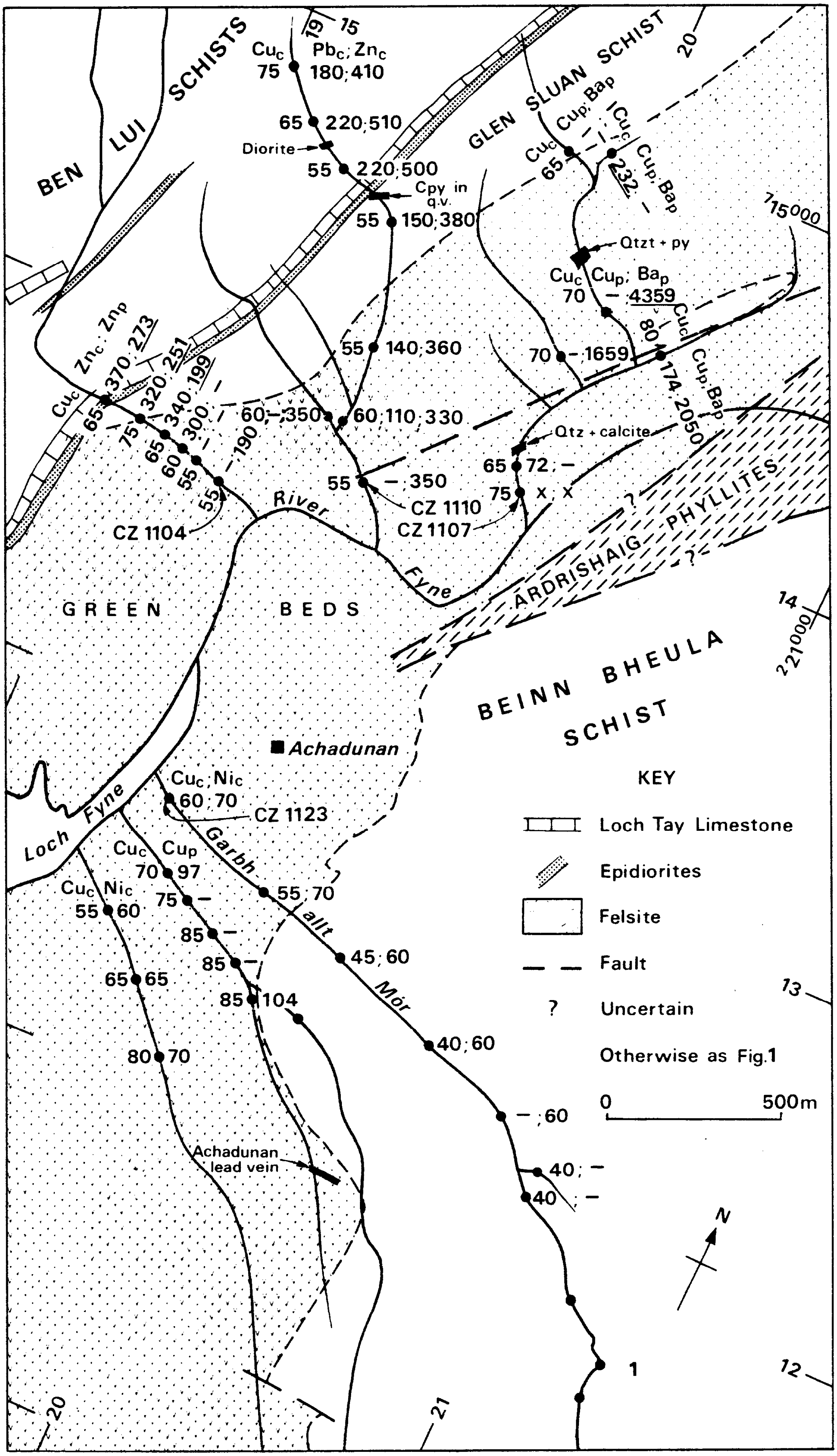


Fig.34 Anomalies in Lower Glen Fyne

postulated at Invercorachan south-westwards to this area would produce a total length of about 3500 m of potential mineralisation.

A copper content of 75 ppm, in CZC 1107 at the base of the next stream to the west (Figure 34), which is confirmed and extended by detailed sampling upstream, along with some anomalous copper and barium in panned concentrates, is evidence of yet further south-westward continuation of a mineralised belt. Nickel and zinc levels are also moderately anomalous. The only observed mineralisation is quartz and calcite veining and a quartzite in the Green Beds carrying disseminated pyrite.

In the next steam to the west, anomalous levels of copper, lead and zinc in CZC 1110 generally increase in samples upstream (Figure 34), with similar increases in panned concentrates, in the same weakly mineralised environments as those at Invercorachan (Glen Fyne fault, Green Beds and Loch Tay Limestone with associated epidiorites). The only observed field evidence of mineralisation, however, is a small amount of chalcopyrite in 30 cm wide quartz veins.

The same strata also pass through the sites of samples collected upstream of CZ 1104 in the westernmost of the right bank tributaries of the River Fyne (Figure 34), which exhibit anomalous copper, lead and zinc. No field evidence of mineralisation was observed in this section however.

Lying some 1500 m along strike from the end of the mineralised zone is the known mineral locality at Clachan Beag. In the intervening ground, CZ 1095 (Figure 3) and samples collected for detailed resampling have moderately anomalous copper contents of 55–60 ppm in sediment and zinc contents of 164–208 ppm in panned concentrate.

The mineralisation at Clachan Beag may therefore extend for 8 km as a weakly mineralised zone from lower Glen Fyne, through Invercorachan, and along the same strike as far as the anomalous areas in upper Glen Fyne (although the zone is probably terminated by the Glen Fyne fault in this area).

The mineralisation in suitable horizons adjacent to the Tyndrum–Glen Fyne fault seems to be controlled predominantly by the faults, as the mineralisation is found in several stratigraphic units. The fault has presumably acted as a channelway for hydrothermal fluids which may have been derived by dewatering of the Dalradian rocks during metamorphism, or from the magmatic fluids expelled on crystallisation of the nearby Garabal Hill–Glen Fyne igneous complex. The fault itself could have provided the driving mechanism by seismic pumping of fluids, as in the model of Sibson and others (1975). The source of the metals, which have been deposited in the veins and replacements, is probably low grade disseminations within the Dalradian metasediments, the metals having been moved and concentrated by the influx of fluids near the fault.

GARABAL HILL–GLEN FYNE IGNEOUS COMPLEX

This composite intrusion, ranging from ultrabasic peridotites to acid pegmatites (Nockolds, 1940), lies between Glen Fyne and Glen Lomond. The intrusion might have contributed to mineralisation on the nearby Glen Fyne fault (discussed above) at upper Glen Fyne, Invercorachan and lower Glen Fyne. From evidence on the Aeromagnetic Map of Great Britain and Northern Ireland (1972), the complex extends, at depth, further west across the Glen Fyne fault. Similar wrench faulting on the Garabal fault might have influenced the location of a group of anomalies on the south-east margin of the complex near Loch Sloy.

The Garabal fault has displaced the generally more basic eastern portions of the complex to the north. The main mass consists of porphyritic granodiorite, which shows some signs of hydrothermal alteration (Nockolds, 1940, p. 479), and most of the anomalies are just within this phase, or within and marginal to a gabbroic phase in the south-east. Other anomalies are associated with the dyke phases on the south-west margin of the complex.

Allt na Lairige

The middle part of this tributary of the River Fyne has been dammed to provide a hydro-electric power reservoir. Lead and barium anomalies coincide with the points where two original tributaries of the Allt na Lairige join the reservoir.

Detailed sampling upstream of the lead in sediment anomaly (120 ppm) at site CZ 1120 (NGR 22585 71775) showed a gradual increase of lead to 260 ppm, 200 m upstream. Molybdenum in sediment reaches 11 and 12 ppm.

CZC 1097 (NGR 22229 72140) was resampled, and the lead in sediment anomaly showed an increase from 120 ppm to 160 ppm, with similar levels upstream. Barium in panned concentrate, however, increased to 27 860 ppm 100 m upstream of CZ 1097, along with highly anomalous values for lead (2198 ppm) and antimony (20 ppm). The major source of lead, antimony and barium (probably jointly in the same vein system) presumably lies between this point and the next sample site, 100 m upstream.

Both streams flow across a poorly exposed porphyritic granodioritic variant of the complex, just 800 m west of its eastern margin. No field evidence of mineralisation was observed.

In the area where the Allt na Lairige joins the River Fyne, three other barium anomalies, in CZP 1253, 1206 and 1234, were sampled. Sampling upstream of CZP 1253 gave the following results:

Site CZP	Ba ppm	Location	
1253	16046‡	22329 71705	
6685	4126‡	100 m	Upstream of CZP 1253
6686	5114‡	250 m	
6687	22776‡	450 m	
6688	5824‡	650 m	
6689	924†	800 m	

† moderately anomalous
‡ highly anomalous

Shattered porphyrite dykes just upstream of CZ 6687 may be a source of barium, although no baryte was observed.

Just upstream of CZ 6688, a tributary running along a north-west trending fault joins the Allt na Lairige from the south. CZP 1206, taken at the base of this stream, has a barium content of 16127 ppm, and further sampling produces these results:

Site CZP	Pb (ppm in panned concentrate)	Zn	Ba	Location	
1206	50	173†	16 127‡	22408 71693	
6650	545‡	660‡	123 839‡	0 m	Upstream of CZP 1206
6651	162†	1017‡	138 361‡	300 m	
6652	35	487‡	34 466‡	600 m	
6653	37	61	9402‡	800 m	
6654	16	36	1108†	900 m	

† moderately anomalous
‡ highly anomalous

Because of a deep gorge, caused by the fault, it was impossible to examine this stream section in detail, although fractures filled with, presumably, baryte were observed near the site of CZ 6651. The fault, which cuts porphyritic granodiorite, is probably the source of the anomalies in this tributary and possibly in the Allt na Lairige also.

Because of the dry state of the stream, detailed investigation of CZP 1234 (NGR 22448 71700), in the next tributary east, was restricted to resampling of the original site. The content of 6874 ppm Ba in the original sample increased to 15172 ppm. This site is also in the porphyritic granodiorite.

Allt Arnan

The copper, lead, zinc and barium anomalies, at CZ 1213 (NGR 23140 71858), 1201 (NGR 22962 71812), in this stream draining the more basic phases of the north-east of the Garabal Hill—Glen Fyne intrusive complex, are not substantiated in resampling, except by values of 560 ppm Zn in both CZC 7024 (NGR 23059 71862) and CZC 7025 (NGR 23041 71862). A molybdenum level of 20 ppm in CZC 6899 (NGR 22850 71800) is highly anomalous.

Eagle's Fall

A galena-bearing vein is known at this locality (Wilson, 1921) one km south-west of the igneous complex, but two sites in streams draining the area were resampled to test the possibility of further mineralisation. One northward-flowing stream drains ground 500 m to the east of the vein and the other stream flows north-west, to the River Fyne, 500 m south-west of the vein.

At site CZ 1131 (NGR 22263 71374), in the northward-flowing stream, the sediment contains 190 ppm Pb and the concentrate 781 ppm Ba. Barium shows little variation in samples upstream, but lead and cobalt in sediment rise to maxima of 550 ppm and 190 ppm respectively in a sample 200 m upstream of CZ 1131. Stream sediments also contain up to 11 ppm Mo. The site corresponds to a 300 m by 100 m, south-west trending, porphyrite intrusion lying one km south-west of the igneous complex. The intrusion was not examined but it may be the source of the anomalous metal values.

Site CZ 1118 is in the other stream south-west of the Eagle's Fall vein, and detailed sampling upstream produced the following results:

Site CZ	Pb (ppm in sediment)	Zn	Cu (ppm in panned concentrate)	Pb	Zn	Ba	Location
1118	130†	310†	No sample				22128 71441
6920	130†	300†	66†	53†	120†	5010‡	50*
6921	140†	300†	32	44	130†	1782†	150*
6922	130†	260	47	201†	119†	1254†	230*
6923	130†	220	181†	40	132†	2668‡	300*
7007	180†	320†	116†	959‡	248†	1567†	370*
7008	210†	300†	127†	465‡	391‡	3081‡	570*
7009	150†	410†	247‡	1192‡	373‡	4283‡	690*
7010	150†	240	136†	90†	700‡	2930‡	790*

† moderately anomalous
‡ highly anomalous
*m upstream of CZ 1118

A source of base metals lies in the upper sampled part of this stream in an extensively faulted section of its course, some 500 m south-west of the known lead vein. A mineralised zone may occupy the intervening ground, extending along the Caledonian strike and carrying copper, zinc and barium in addition to lead, but faulting and the intrusion of minor porphyrite and lamprophyre dykes are other possible controls for the mineralisation. The grade of the mineralisation from the evidence at hand would appear to be low.

Loch Sloy

There are three anomalous sample sites in streams draining into Loch Sloy (Figure 35). A fourth site is on a stream draining south-west into Kinglas Water, and a fifth site lies on a stream draining north to Strath Dubh-uisge. All of the sites lie near the margin of the gabbroic and granodioritic phases of the igneous complex.

CZ 1125 (NGR 22907 71492 – not on Figure 35) is in the headwaters of Strath Dubh-uisge (Figure 3). Copper and barium anomalies were not reproduced in resampling, but a lead anomaly in sediment was confirmed. The original level of

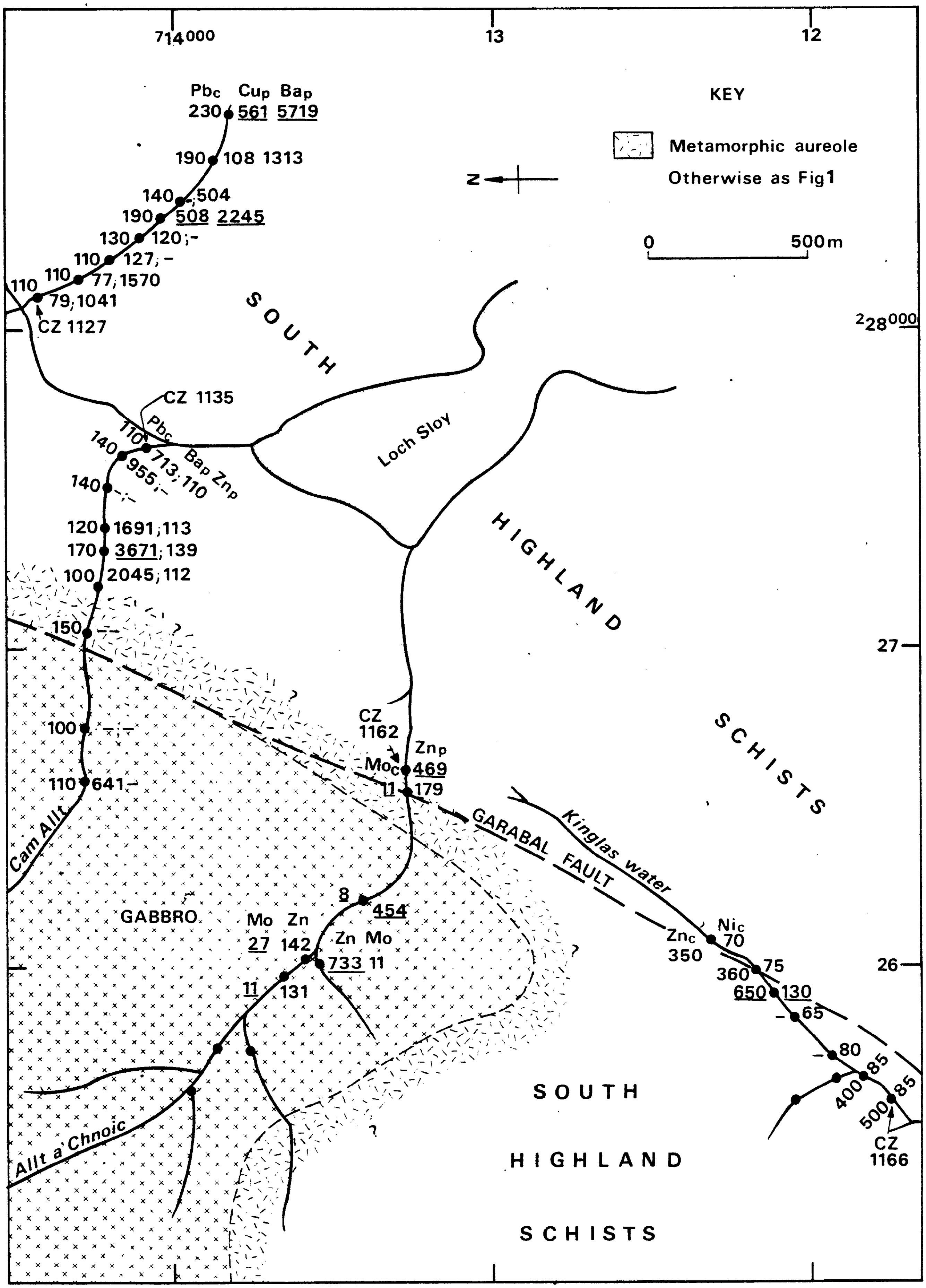


Fig.35 Anomalies near Loch Sloy

110 ppm was repeated in resampling the original site and the value increases to 150 ppm at a site 200 m upstream, before decreasing to 130 ppm 400 m upstream.

Further upstream, samples taken from two tributaries contain the following lead levels:

Left tributary	Distance upstream	Right tributary
80 ppm	500 m	120 ppm
150 ppm	60 m	80 ppm
120 ppm	700 m	110 ppm
	800 m	110 ppm

The stream system lies entirely within South Highland Schists, 1000 m to the south-east of the igneous complex, and a fairly widespread source of lead is indicated.

The easternmost site on Figure 35, CZ 1127, contains anomalous lead in sediment, and copper and barium in panned concentrate. The lead content of the sediment generally increases upstream to a maximum of 230 ppm, along with copper, barium and cobalt (561, 5719 and 100 ppm respectively). A high barium level of 2245 ppm at a midway point in the stream is associated with highly anomalous copper (508 ppm), lead (495 ppm) and zinc (225 ppm) in panned concentrate, this probably being a better heavy mineral concentrate than the other samples. A source of the metals near the headwaters of this stream is indicated, but field evidence is lacking.

Near a marginal, gabbroic phase of the intrusion, site CZ 1135, in Cam Allt, produced anomalous levels of 110 ppm Pb in the sediment, and 110 ppm Zn and 713 ppm Ba in the panned concentrate. All three metals rise fairly consistently to maximum contents at a sample site just 300 m east of the igneous contact (Figure 35). Upstream of this point, levels decline, and a source of metals near the margin of the complex is indicated. In addition, levels of molybdenum reach 14 ppm.

CZP 1162, collected on the next tributary south (Figure 35), also has a high zinc content (469 ppm), along with 149 ppm Cu, 168 ppm Ni and 1737 ppm Ba. Only one sample, on a small side stream within the gabbro, shows an increase in zinc concentration (to 733 ppm). Other zinc levels generally diminish upstream, indicating a localised richer source of zinc in the sidestream, which was not geologically examined. The overall high zinc levels, however, also indicate a general enhancement of this metal in the margins of the complex. Levels of molybdenum reach 27 ppm.

Another possible controlling factor in the location of the two groups of anomalies is the Garabal fault, which is mapped (Nockolds, 1940) as coinciding with a conspicuous depression, passing through the two groups of anomalies on the intrusive margin, and continuing down Glen Kinglas. The fault also appears as a strong lineation on the LANDSAT photographs.

The fault may control the source of anomalies in the headwaters of Kinglas Water to the south-west. Directly upstream of CZC 1166, the lowermost site on this stream (Figure 35), almost all of the sediment samples have anomalous zinc and nickel contents, reaching maxima of 650 ppm Zn and 130 ppm Ni. The overall distribution of anomalies indicates a general weak source of metals, possibly coincident with the course of the stream.

The anomalies lie in a similar situation, adjacent to the more basic portion of the complex where it is cut by the Garabal fault. Some minor pyrite and chalcopyrite mineralisation has also been noted on the south side of Lochan Srath Dubh-uisge, some 800 m to the north-west of the area of Figure 35 (R. T. Smith, personal communication), and sporadic zinc, nickel, lead and barium mineralisation could coincide with the fault for at least 3 km.

ARDRISHAIG PHYLLITES

Certain zones along the strike of the Ardrishaig Phyllites, between the former mines at Coille-bhraghad and Craignure, typified by thin limestones and epidiorites, seem to possess enhanced metal contents. Similarly, in central Perthshire, certain zones of the Ben Lawers Schists, the lateral equivalents of the Ardrishaig Phyllites, are enhanced in copper, although the greatest sulphide concentration is at the junction of this unit and the Ben Lui Schists (the Pyrite Zone). More detailed sampling of stream sections in the Ardrishaig Phyllites, both within the area between the abandoned mines and beyond, confirms an enhancement of metals.

Leacann Water

Three anomalous sites in close proximity on this stream were resampled. In the southernmost stream, resampling of CZ 3030 gave the following results:

Site CZP	Cu	Pb	Zn	Location	
	(ppm in panned concentrate)				
3030	117†	75†	118†	20196 70335	
3440	87†	73†	132†	0 m	Upstream of of CZ 3030
3441	77†	396‡	107†	300 m	Upstream of of CZ 3030
3442	54	25	131†	1000 m	Upstream of of CZ 3030

† moderately anomalous
‡ highly anomalous

A localised source of lead between sites CZ 3441 and CZ 3442 is indicated, and a sample of a calcite nodule, carrying pyrite and minor galena, in this tract at NGR 20205 70377 (about 400 m upstream of CZ 3441), contains 160 ppm Pb. The variation of copper and zinc implies a more dispersed source for these metals. Indeed, quartzitic bands carrying pyrite disseminations outcrop along the length of the stream. A sample of such a rock from NGR 20194 70333 contains, however, only 35 ppm Cu, 60 ppm Pb and 60 ppm Zn.

Resampling of CZ 3031 in the next tributary north gives the following erratic results:

Site CZP	Cu	Pb	Zn	As	Location
	(ppm in panned concentrate)				
3031	100†	241†	141†	442†	20197 70353
3452	6	15	45	n.d.	same site
3453	102†	611‡	110†	471†	400 m upstream
3454 R. trib.	54	421‡	85	75	20221 70418
3455 L. trib.	6	10	49	n.d.	20228 70417

† moderately anomalous
‡ highly anomalous
n.d. not determined

As in the case of the previous sample, localised sources of lead, such as a galena-calcite nodule near site CZ 3031/3452, may cause specific high lead levels. The erratic results may be due to variable panning efficiency.

In the next tributary north, only one additional sample was taken, 70 m upstream of the anomalous sample at CZ 3032 (NGR 20190 70354). Panned concentrate levels of 139 ppm Pb, 159 ppm Zn and 110 ppm As in CZ 3032 diminish to 93 ppm, 119 ppm and 60 ppm respectively.

The three anomalous streams lie within a zone of the Ardrishaig Phyllites containing thin limestone bands and intrusions of felsite, epidiorite and dolerite. This zone is probably the same as that at Douglas Water 4 km north-east, and reinforces the evidence for a general zone of sulphide mineralisation lying on strike between Coille-bhraghad 7500 m to the north-east and Craignure 3500 m to the south-west.

Furnace

Site CZ 3111 (NGR 20073 69955), just west of Furnace, produced 90 ppm Cu and 120 ppm Pb in sediment and 208 ppm Cu, 230 ppm Pb and 321 ppm Zn in panned concentrate. On resampling, metal contents diminished to background levels, except those of zinc. Although CZP 3111 has a high tin content, indicating contamination, none of the samples upstream contains significant tin.

Site CZP	Zn	Sn	Location
	(ppm in panned concentrate)		(m upstream of CZ 3111)
3111	321‡	387‡	
6659	382‡	7	200, in main stream
6660	403‡	0	200 } in first right bank
6661	129†	0	400 } tributary upstream
6662	122†	0 }	500, in left and right
6663	121†	0 }	branches of second trib.
6664	422‡	4	400, in main stream
6665	263‡	7	600, in main stream
6666	302‡	3	800, in main stream

† moderately anomalous
‡ highly anomalous

The part of the stream system that has been sampled is underlain by felsites, but the boundary with Ardrishaig phyllites and an epidiorite intrusion lies in the headwaters, and probably contributes zinc to the panned concentrate.

Abhain Bhuidhe and Crarae Burn

A small amount of resampling, encouraged by levels of up to 247 ppm Cu, 695 ppm Pb and 199 ppm Ni in samples CZP 1483, 1484 and 3073, generally failed to produce additional anomalies. It seems therefore that any extension of the mineralised zone in the Ardrishaig Phyllites to this area (2 km south-west of Craignure) is very limited, although localised minor enrichment may be associated with limestone outcrops and various intrusions in these stream sections.

Minor mineralisation in quartz and calcite veinlets is developed at the contacts of basalt dykes with phyllites. One particular quartz vein in phyllite, at NGR 29738 70122 in the Abhainn Bhuidhe, carries pyrite, chalcopyrite and galena, and contains 1570 ppm Cu, 300 ppm Pb, 530 ppm Ni and 245 ppm Co. A sample of schistose epidiorite from 400 m south-east (NGR 29778 70131) carrying pyrite, however, contains only 75 ppm Cu, 20 ppm Pb, 55 ppm Ni and 50 ppm Co. A sample of limestone from Crarae quarry (in the lower reaches of Crarae Burn at NGR 19850 69750), with green and blue secondary copper minerals and galena, contains 700 ppm Cu, 2890 ppm Pb and 70 ppm Zn.

Minard

Two short streams near this village were sampled in detail. On the northern stream, sample site CZ 1464 and samples upstream gave the following results:

Site CZ	Cu	Zn	Ni	Pb	Zn	Ni	Location
	(ppm in stream sediment)			(ppm in panned concentrate)			
1464	55†	200	70†	122†	184†	41†	19659 69534
6766	65†	210	70†	715‡	65	47†	same site
6767	25	380†	65†	19	75	37†	100*
6768	40†	270	95†	10	55	24	200*

† moderately anomalous
‡ highly anomalous
* m upstream of CZ 1464

Resampling of CZ 1496, on the southern stream, largely fails to produce further anomalies:

Site CZ	Cu	Ni	Cu	Pb	Zn	Ni	Location
	(ppm in sediment)		(ppm in panned concentrate)				
1496	40†	60†	167†	504‡	304‡	253‡	19650 69517
6869	30	80†	35	86†	93	75†	100*
6870	30	40	55	61†	143†	99‡	200*

† moderately anomalous
‡ highly anomalous
* m upstream of CZ 1496

Contamination at site CZ 1496 can probably be dismissed as the tin content is zero. Both of these streams intersect a large epidiorite body intruded into the Ardrishaig Phyllites. Small outcrops of limestone probably place this area at the same stratigraphic level as the limestones at Crarae Burn 4500 m to the north-east.

The high copper combined with high nickel contents of these samples is typical of the mineralisation at Coille-bhraghad and Craignure, and the mineralisation may possibly extend for all this 17 km distance. The lack of consistently high levels at sites in between, however, indicates that the enrichment is very patchy and localised in this stratigraphic zone.

PYRITE ZONE

The stratum-controlled pyrite mineralisation, the Pyrite Zone, lies at the boundary of the Ardrishaig Phyllites or its lateral equivalent, the Lower Erins Quartzite, in the south of the area, and the Ben Lui Schist (or its lateral equivalent to the north-west, the Crinan Grit).

Because the existing geological map of the area (Sheet 37) does not mark the Pyrite Zone, and lateral facies changes make the stratigraphy difficult to follow, some of the following anomalies may be related to other pyrite-bearing horizons within the Ardrishaig Phyllites. Because of the proximity of these anomalies to the Pyrite Zone, they are all described in the following section.

Allt an Taillir

Samples at three sites, CZ 1088 (NGR 22229 72140), CZ 1098 (NGR 22195 72169) and CZ 1101 (NGR 22178 72190) exhibit anomalous metal levels.

CZP 1088 has a moderately anomalous copper content (165 ppm), but resampling at the same site gives a lower, but still moderately anomalous level (89 ppm). Successive sampling at 100 m intervals upstream also produces lower levels ranging from 63 to 106 ppm Cu.

CZC/P 1098 contains 320 ppm Zn in sediment and 110 ppm Cu in panned concentrate. No additional anomalies are recorded upstream of a small concrete dam (constructed for hydro-electric purposes) 100 m upstream. A moderate level of only 12 ppm Sn in CZP 1098 indicates little contamination, and it is more likely that the metals have a limited source, near the original site.

CZP 1101 contains 218 ppm Cu, but samples taken further upstream range erratically from only 12 to 131 ppm. A zero tin content indicates that site CZ 1101 is probably not contaminated, and thus, as in the case of CZ 1098, copper may be only sporadically distributed.

All of these samples are located in the Ardishaig Phyllites close to the Pyrite Zone, and higher levels of copper in stream samples could be due to minor enrichments of copper in the phyllites or the epidiorite intrusions. No economic concentrations are indicated, however.

Dundarave

One isolated stream on the north shore of Loch Fyne, between the head of the loch and Loch Shira, was sampled in greater detail. The original sample, CZP 1243, and samples upstream produced results thus:

Site CZP	Cu (ppm in panned concentrate)	Pb	Zn	Ni	Ba	Location
1243	81†	191†	162†	51†	4554‡	21362 70972
6762	117†	49	347‡	65†	4083‡	same site
6763	300‡	392‡	817‡	113‡	8687‡	200*
6764	133†	65†	902‡	70†	5834‡	300*
6765	96†	286‡	2471‡	88†	18586‡	600*

† moderately anomalous
‡ highly anomalous
* m upstream of CZ 1243

The stream runs through a gorge, presumably caused by a fault, in the Ardrishaig Phyllites. Epidiorite intrusions outcrop in the stream, although their precise positions could not be identified. The anomalies may be due to the Pyrite Zone, but their source was not traced. High barium is not characteristic of the Pyrite Zone. The association here may indicate vein-type polymetallic mineralisation or possibly stratabound mineralisation similar to that at Aberfeldy (Coats, Smith and others, 1981).

Allt Bail a Ghobhain

Anomalies in this stream at site CZ 1474, lying 2 km north-west of Inveraray, were investigated.

Site CZ	Zn (sediment ppm)	Cu (ppm in panned concentrate)	Pb	Zn	Ba	Location
1474	120	124†	261‡	226‡	1348	20739 71019
3444	220	97†	133†	284‡	857†	400*
3445	160	122†	649‡	958‡	3787‡	1000*
3446	500†	46	35	144†	881†	1000 N. trib.*
3447	270	30	58	90	368	1350*
3448	170	12	24	57	278	1700 S. trib.*
3449	260	17	43	253‡	321	1900*
3450	220	11	18	67	464	1700 N. trib.*

† moderately anomalous
‡ highly anomalous
* m upstream of CZ 1474

Three rock samples were collected from the stream section. A sample of the Crinan Grits collected 250 m upstream of CZ 3444 is a fine-grained metasediment, with disseminated pyrite, which contains, however, only 75 ppm Cu, 20 ppm Pb and 90 ppm Zn. At the site of CZ 3445, a sample of thin quartz-banded phyllites in faulted Crinan Grits contains 95 ppm Cu, 450 ppm Pb, 200 ppm Zn and 60 ppm Ni. This outcrop may be the source of the anomalies in CZ 3445. A sample of carbonate vein material, from the site of CZ 3450, contains only 20 ppm Cu, 80 ppm Pb and 20 ppm Zn.

Two other rock samples were collected 500 m to the north of the stream section. A pyrite-mineralised felsite dyke at NGR 20678 71143 contains 40 ppm Cu, 20 ppm Pb and 130 ppm Zn and a pyrite-mineralised quartzose grit from NGR 20693 71059 contains 20 ppm Cu, 20 ppm Pb and 60 ppm Zn.

The whole stream section extends along a zone mapped as the boundary between the Crinan Grits and an elongated felsite intrusion. The Pyrite Zone may be present in this section, but a felsite is intruded at the boundary between the Crinan Grits and Ardrishaig Phyllites. This is the same stratigraphic level as the known mineralisation at McPhun's Cairn and Creggans, directly opposite across Loch Fyne, in the Pyrite Zone. Some of the mineralisation in the stream section – disseminated sulphides in banded quartz-schists – is typical of the Pyrite Zone, although the high barium and lead levels may indicate additional vein-style mineralisation related to the nearby felsite or Aberfeldy-type stratabound baryte (Coats, Smith and others, 1981).

Ardchyline

Sample CZP 1156, collected 600 m north-east of this farmhouse, contains anomalous copper, zinc and nickel. Resampling produces the following results:

Site CZP	Cu	Pb	Zn	Ni	Location	
	(ppm in panned concentrate)					
1156	379‡	64†	229‡	170‡	21174 70650	
6609	52	19	76	43†	100*	W. trib.
6610	140†	99†	107†	83†	300*	W. trib.
6611	61	31	99	50†	550*	W. trib.
6612	11	2	36	9	150*	E. trib.
6613	1	1	32	7	350*	E. trib.
6614	246‡	227†	248‡	318‡	550*	E. trib.
6615	285‡	240†	265‡	312‡	750*	E. trib.

† moderately anomalous
‡ highly anomalous
* m upstream of CZ 1156

Although slight anomalies coincide with the western tributary, the major source seems to be in the upper reaches of the shorter eastern tributary. The anomalously low levels in the middle reaches may be due to poor panning efficiency.

CZP 1156 is, however, on the faulted edge of an epidiorite body, and so the anomalies could have a local origin. Both tributaries flow over small epidiorite and diorite dykes, but the largest anomalies are upstream of these, within Ardrishaig Phyllites. The headwaters of the eastern tributary rise just 500 m north-east of the Ardrishaig Phyllites – Ben Lui Schist boundary, and the anomalies may therefore be derived from the Pyrite Zone.

CZ 1447 (NGR 21261 70606) lies in a stream 400 m east of the eastern tributary draining towards CZ 1156. Zinc declines from 290 ppm in CZC 1447 to only 160 ppm upstream. Lead in panned concentrate, however, reaches 138 ppm in a sample 200 m upstream, and a sample 100 m upstream contains 514 ppm Zn. Only a 300 m length of the stream was sampled. The panned concentrate samples contain pyrite and galena. Although the stream lies in the Pyrite Zone, faulting and a porphyrite dyke may be local controls of the mineralisation.

Strachur (South-east shore of Loch Fyne)

The Eas Dubh was resampled upstream of two original sites with anomalous metal contents, as far as other original sites with only background levels (which acted as a cut-off). CZP 1015 (NGR 20998 70184), at the lowermost site, contains 157 ppm Cu, 165 ppm Pb and 198 ppm Zn. Upstream, levels of copper and zinc generally diminish, except in preliminary sample CZP 1023 (186 and 214 ppm, respectively), 1100 m upstream of CZ 1015. Conversely, lead increases to the very high level of 2961 ppm, in CZP 6771, 250 m upstream of CZ 1015, beyond which point it generally diminishes.

The Eas Dubh runs along the strike of the Ben Lui Schists just east of the junction with the St Catherine's Graphitic Schist (equivalent to the Ardrishaig Phyllites). The Pyrite Zone coincides with this boundary and is represented by the known mineralisation at Creggans and McPhun's Cairn. Faulting and some thin outcrops of Loch Tay Limestone, Green Beds and epidiorite in the upper part of the stream section, if carrying minor mineralisation, may combine with the Pyrite Zone to produce the moderate anomalies along this stream section. The high lead anomaly, however, has a more localised source, and may be due to lead veining associated with a fault immediately upstream.

Cruach Mhor

A tributary of the Strathlachlan River draining Cruach Mhor produced anomalous contents of 60 ppm Cu and 80 ppm Ni in sample CZC 1435 (Figure 36). On more detailed sampling, however, copper in the sediment diminished to background levels, but nickel rose to a maximum of 110 ppm at the fifth sample site, 600 m upstream. Zinc in sediment also rises to 350 ppm, and in panned concentrates reaches a maximum of 532 ppm. One vestige of anomalous copper remains in the third concentrate sample upstream, which contains 364 ppm. All other levels are at background.

The stream course lies within the Ben Lui Schists (above the Pyrite Zone).

Lephinmore

Sample sites on two tributaries of a main stream flowing into Loch Fyne at Lephinmore were

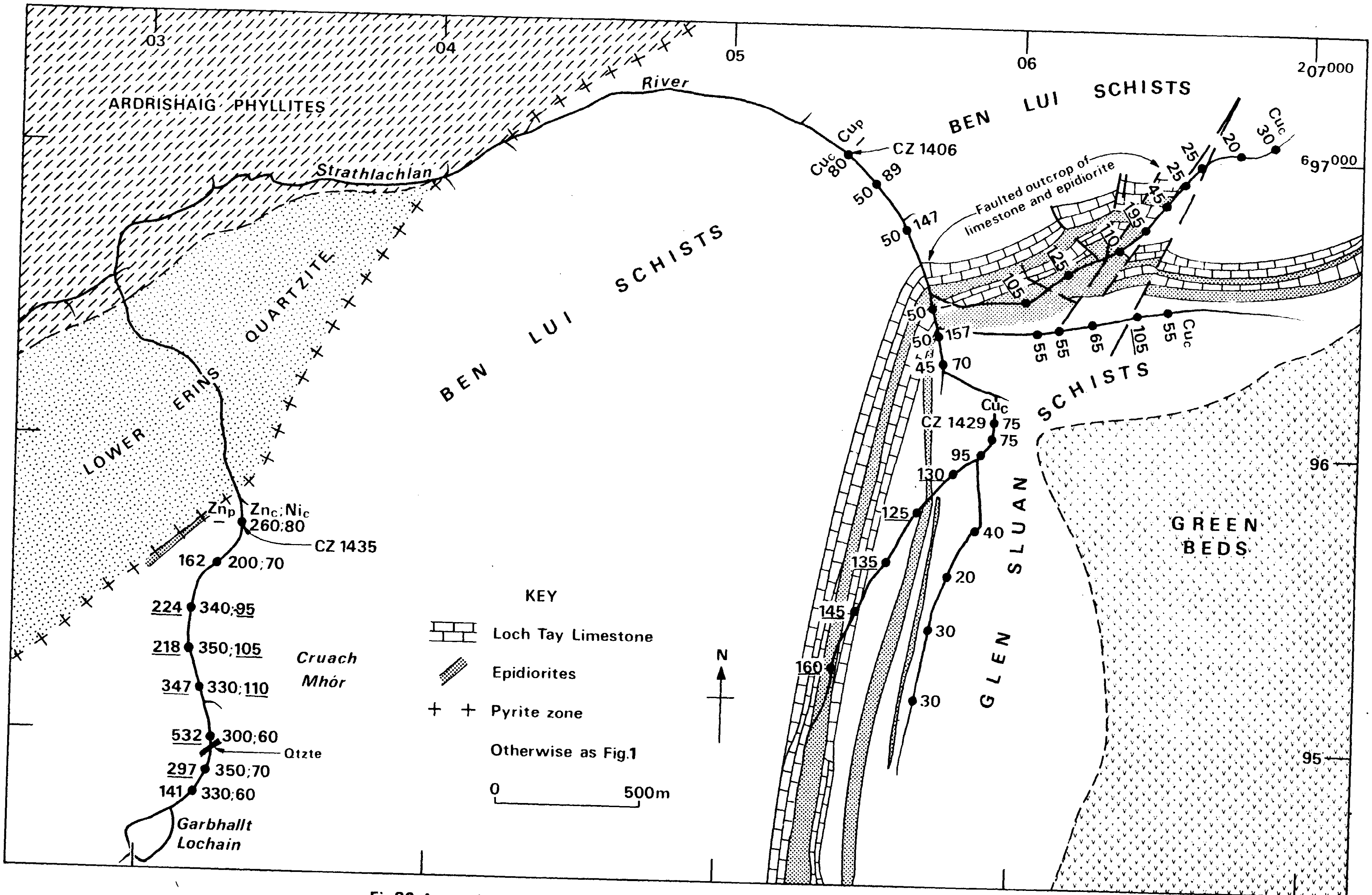


Fig36 Anomalies at Cruach Mhór and Upper Strathlachlan River

further investigated (Figure 37).

In the northern stream, copper and nickel in the stream sediment remained roughly constant, falling below threshold level only upstream from a zone of intense shearing which coincides with the outcrop of the Pyrite Zone.

Further south, levels of copper diminished upstream from the original site, except for an isolated 70 ppm at the penultimate site. At this site, and the next downstream, are the highest levels of zinc in sediment and panned concentrate, and copper in panned concentrate. Metal levels upstream from this site declined sharply. Nickel in sediment, however, reached a maximum of 75 ppm near an outcrop mapped as 'Green Beds' (probably hornblende schists), but diminished upstream.

The samples in the southern stream were collected at stratigraphic levels above the Pyrite Zone, at approximately the same level as the anomalies in the stream draining Cruach Mhor (Figure 36) 4 km along strike to the north-east. Intervening streams traversing these horizons are at generally background levels, which would indicate only sporadic mineralisation in the Ben Lui schists. The anomalies at Lephinmore are more closely related to the dolerite dykes, of presumed Permo-Carboniferous age, which extend along both streams.

Lephinchapel

Three samples with anomalous copper contents, CZC 1362, 1363 and 1364, were all collected from a stream system which enters Loch Fyne at Lephinchapel Farm (Figure 38a).

Detailed sampling reveals a general increase in copper in sediment upstream to a maximum of 190 ppm. High levels of 145 ppm Pb and 550 ppm Zn in sediment are isolated in the uppermost right bank tributary. Nickel was not analysed in all sediment samples, but generally increases to a maximum of 80 ppm, at the ninth sample site upstream. Zinc in panned concentrate rises to a maximum of 374 ppm, and nickel attains a level of 90 ppm.

Resampling the western stream, which contained 310 ppm Zn in CZ 1347, produced 370 ppm at the same site, and a maximum of 410 ppm in the next sample site upstream (Figure 38a), where a panned concentrate contained 90 ppm Cu. Zinc in sediment diminished upstream, although a panned concentrate contained 106 ppm Zn and 41 ppm Ni at the third sample site upstream. There appears, therefore, to be a source of zinc upstream from these sites which produces a long dispersion train in the stream sediment.

Both anomalous stream sections coincide with the junction of the Ben Lui Schists and Lower Erins Quartzite, the presumed position of the Pyrite Zone. The longer eastern stream, however, has anomalies at slightly higher stratigraphic levels, possibly corresponding to the stratigraphic levels of mineralisation at Lephinmore, 2 km to the north-east. Epidiorites intrude the area, and the longer stream partly coincides with a dolerite dyke. Either of these features could control mineralisation.

In the upper reaches of the longer stream, two samples of the dolerite dyke were collected (Figure 38a). CZR 2590 is a highly weathered, red-stained sample of the dyke, and contains 115 ppm Cu, 50 ppm Zn, 45 ppm Ni and 40 ppm Co. CZR 2591 is less weathered and carries disseminated sulphides (?pyrite). It contains 95 ppm Cu, 60 ppm Zn, 25 ppm Ni and 20 ppm Co. The source of the anomalies in the stream samples is most probably in this slightly enriched, weathered dyke.

Resampling of the 490 ppm Zn anomaly in CZC 1334 (NGR 19597 68860), 700 m south of CZ 1347, resulted in a diminution of zinc in samples upstream. Levels range from 340 to 380 ppm, but are still anomalous. The 400 m length of stream resampled lies in the Pyrite Zone, but also coincides with a dolerite dyke of probable Tertiary age.

LOCH TAY LIMESTONE

The thin persistent outcrop occupies the highest ground to the south-east of Loch Fyne, generally on or beyond the watershed. Although it is little represented in the area sampled, metal anomalies are generally associated with it. The limestones are commonly accompanied by thin pelites and epidiorite bodies, and exercise a strong control over mineralisation.

The epidiorites probably represent metamorphosed basic lavas and pyroclastic rocks, but are difficult to distinguish from intrusive sills and dykes. Epidiorites from the same stratigraphic horizon in the Tayvallich area, to the north-west, are of fairly low base-metal content, as determined by Wilson and Leake (1972), with mean contents in 31 samples of 33 ppm Cu, 164 ppm Zn and 21 ppm Pb. Further east, in the south Loch Tay area, however, the epidiorites at this level possess higher base metal contents, with copper up to 400 ppm.

Coire No

Zinc increases from 180 ppm in CZC 1053 (NGR 21539 70774), on this stream, to a highly anomalous 530 ppm some 500 m upstream. Further upstream, zinc in sediments remains in the range 290 to 330 ppm. Copper in panned concentrates, however, generally diminishes upstream from CZ 1053, although levels of 35 ppm and 50 ppm are attained in sediments at sites 400 m upstream. Copper in panned concentrate reaches a maximum of 245 ppm at the uppermost site, 1500 m upstream. The next site, 150 m downstream, contains 312 ppm Pb and 788 ppm Ba in panned concentrates, compared with low background levels elsewhere.

A north-west trending fault coincides with the northern end of the stream, and Loch Tay Lime-

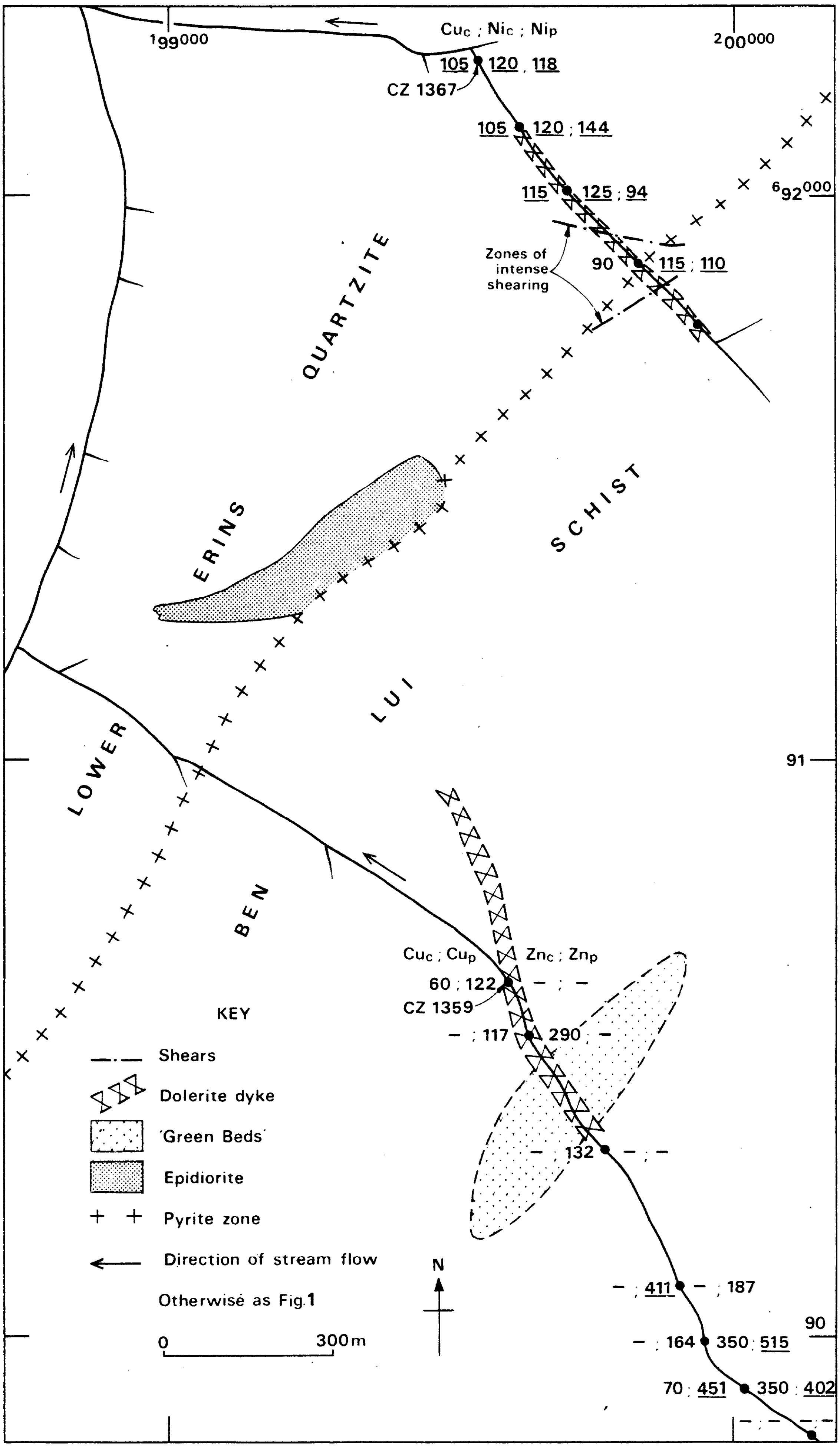


Fig.**37** Anomalies at Lephinmore

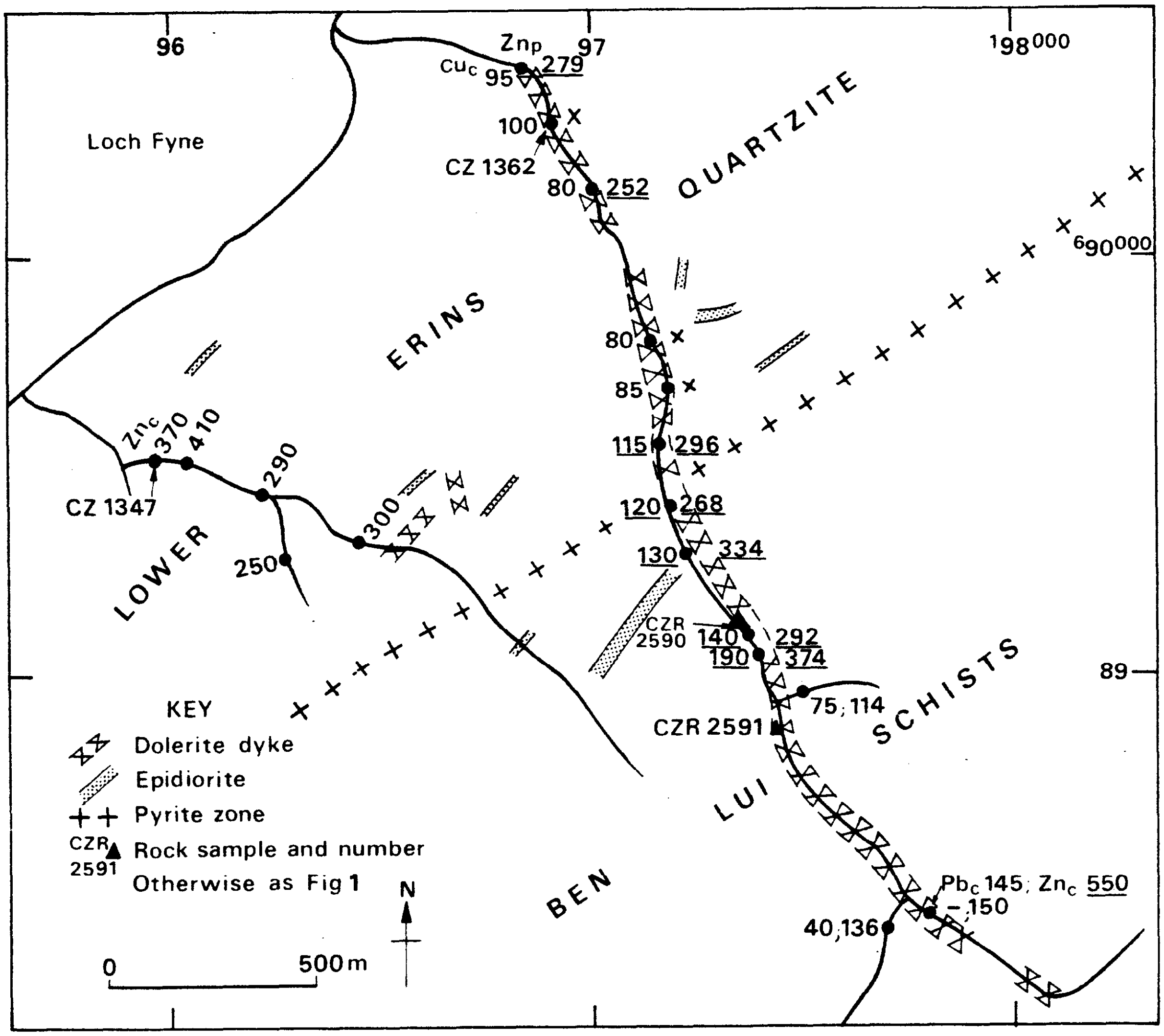


Fig.38a Anomalies at Lephinchapel

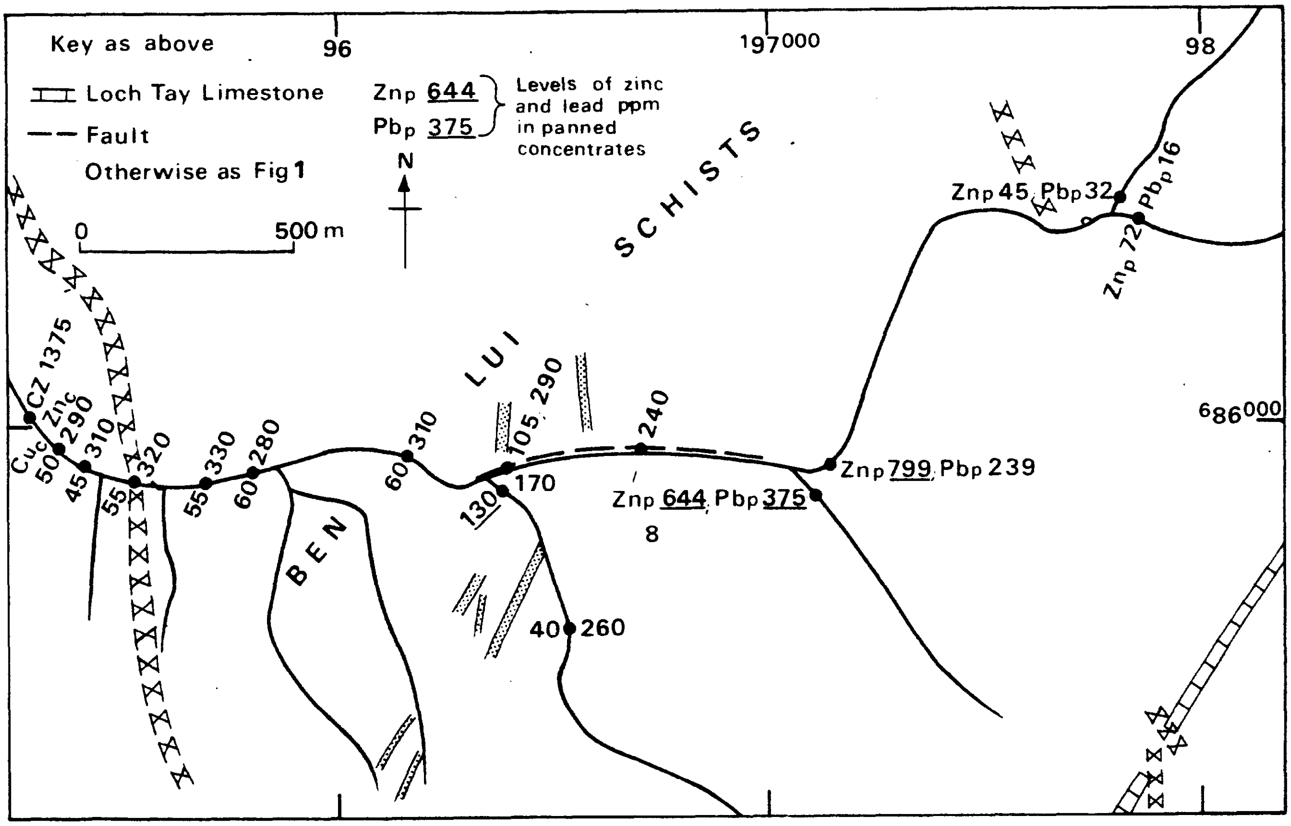


Fig.38b Anomalies at Evanachan

stone outcrops along its western side. Dolerite and felsite intrusions also occupy parts of the catchment. This area is only 5 km south-west, along the strike of the Loch Tay Limestone, of the ?metasomatic lead-zinc mineralisation at Clachan Beag. Sampling of the intervening ground is hampered, as the outcrop, displaced north-westwards by the fault, passes through the ornamental gardens of Ardkinglas House and beneath the northern end of Loch Fyne; but the extension of the postulated ?metasomatic (or ?stratiform) mineralisation between Lower Glen Fyne and Coire No, a further 5 km south-west, is a possibility.

Upper Strathlachlan River

Samples collected in the headwaters of this river (Figure 36) contain anomalous levels of copper. In the northern tributary, resampling upstream of CZC 1418, the lowermost site, resulted in an increase of copper to a maximum of 195 ppm in a sample 500 m upstream. Levels diminished further upstream. In a similar pattern, copper in panned concentrates reached a maximum of 106 ppm, also at the site 500 m upstream. At the next sample site upstream, the panned concentrate contained 242 ppm Pb and 736 ppm Ba.

In the next tributary south, resampling upstream of CZC 1417 also produced a gradual increase in copper to a maximum of 105 ppm and zinc to a maximum of 500 ppm in the third sample upstream.

The northern tributary is underlain by Loch Tay Limestone and epidiorite, whereas the southerly stream runs along the boundary of these rocks with Glen Sluan Schists. The differing geology probably accounts for the generally higher metal levels in the northern stream, and this implies a source for the metals within the limestone and epidiorite. The distribution of lead and barium, however, indicates a more local source for these metals, probably from veins along the faults.

A similar geological pattern controls levels in the resampling of CZ 1429 at the base of the southernmost stream system in this area (Figure 36). Copper in sediment and panned concentrate gradually increases upstream and in the left bank tributary, but levels in the right bank tributary decrease.

The left bank tributary coincides with an outcrop of Loch Tay Limestone, along strike from that in the course of the northern stream, whereas the right tributary is underlain by Glen Sluan Schist.

Levels of copper in sediment in the main stream diminish upstream of CZ 1406, but panned concentrate contents do generally increase towards the limestone and epidiorite outcrop.

These anomalies are the only indications of potential mineralisation in the Loch Tay Limestone between this area and Coire No 14 km to the north-east. Much of the limestone outcrop over this distance, however, lies on the watershed marking the boundary of the sampled area, and so would be poorly represented in stream samples. Thus the possibility of base metal enrichment in the Loch Tay Limestone over this distance remains untested. A metasomatic origin in areas far removed from the nearest large igneous intrusion is difficult to envisage, but smaller intrusions might be local sources, and faulting could provide channel-ways for hydrothermal fluids. Just to the south-west, the limestone outcrop crosses over the watershed and is not sampled except for a short tract which re-enters the sampled area 11 km away at Evanachan.

Evanachan

The southerly branch of a stream system flowing just south of this farm produced a panned concentrate sample (CZP 1375) containing 1056 ppm Cu, 456 ppm Zn and 146 ppm Ni.

Resampling resulted in zinc alone increasing, to 799 ppm in panned concentrates, in only the upper part of the stream section (Figure 38b). Lead increased to 375 ppm and was associated with the high zinc levels.

All stream sediment metal levels increase, however, especially copper, which reaches a maximum of 130 ppm, and zinc, which attains a maximum of 330 ppm. Zinc has a longer dispersion train in the stream sediment, and anomalous levels in the panned concentrates are found only in the upper part of the stream section near the presumed source. Copper, however, seems to show the reverse effect, although the differing panning efficiency between different collectors may be of influence.

Although the lower reaches of this stream probably traverse the same mineralised zones in the Ben Lui Schists as those at Lephinchapel and Lephinmore to the north, the main stream section occupies almost the whole width of the Ben Lui Schist outcrop. The headwaters rise just short of the outcrop of Loch Tay Limestone, which could be the source of the lead and zinc anomalies in panned concentrate samples from the upper reaches. Further downstream, small outcrops of epidiorite are common, especially in the area of the highest copper contents (where the stream also flows along the course of a fault). Dolerite intrusions may also be an influence.

If the Loch Tay Limestone is a source of anomalies, this would indicate that the enrichments suspected in the upper Strathlachlan River may also exist here.

GREEN BEDS

Most of the outcrop of the Green Beds lies outside of the area sampled, except for a tract around and north-east of the upper part of Loch Fyne. Anomalies in the Green Beds in Lower Glen Fyne have been described in previous sections. Further anomalies south-west of this tract are described below.

Achadunan
The three streams flowing northwards (Figure 34) drain the area of the Achadunan lead vein. The preliminary samples, however, are moderately anomalous in copper and nickel content. The western stream shows a gradual increase in copper and nickel content from 55 ppm and 60 ppm in CZC 1129 to 80 ppm and 70 ppm respectively at 200 m upstream, where resampling was terminated due to the stream becoming dry. Resampling upstream of CZ 1126 produced similar increases in copper in sediment and panned concentrates. Although field evidence is lacking, minor copper mineralisation may possibly be associated with the known lead mineralisation. Higher copper and nickel contents in sediment may also be due to enhancement of these metals in the Green Beds. This may account for the decline in levels in Garbh-allt Mor, where only Beinn Bheula Schist is sampled.

Ardkinglas
Seven copper, lead and zinc anomalies at sites CZ 1145, CZ 1128, CZ 1152, CZ 1154, CZ 1163, CZ 1160 and CZ 1046 were resampled. The copper (130 ppm) and zinc (184 ppm) anomalies in CZP 1145 (NGR 21966 70960) declined to 3 ppm and 105 ppm respectively on further sampling upstream. The stream drains Beinn Bheula Schists.

Moderately anomalous copper (115 ppm) and highly anomalous zinc (203 ppm) in CZP 1128 (NGR 21946 70962) are broadly reproduced in two additional samples, 500 m and 800 m upstream (93 ppm, 125 ppm Cu; and 165 ppm, 275 ppm Zn respectively). This stream drains Beinn Bheula Schists, lying just east of the boundary with the Green Beds, and intruded by dolerite dykes.

In the next stream west, copper generally diminishes upstream from 149 ppm in CZP 1152 (NGR 21769 70978), but slightly increases from 55 ppm in CZC 1152 to 80 ppm some 650 m upstream. Zinc in sediment, however, increases markedly from 120 ppm, in the preliminary sample, to 540 ppm, and cobalt reaches 130 ppm, in the ultimate sample, one km upstream. This upper part of the stream also drains the boundary of the Green Beds and the Beinn Bheula Schists just 850 m south-west of the anomalous zinc site in the stream draining towards CZP 1128.

In the remainder of the streams, anomalous levels of copper of up to 80 ppm in sediments and 286 ppm in panned concentrates vary little in the resampling of sites CZ 1154 and CZ 1163, although the westernmost stream has generally a slight increase from 40 to 65 ppm in sediment and 122 to 191 ppm in panned concentrate upstream from CZ 1160 (NGR 21658 70895) to the penultimate site 500 m upstream. The lead and zinc anomalies, 220 ppm and 490 ppm respectively, in CZC 1046 (NGR 21971 70982) decline markedly in resampling (to 20 ppm and 90 ppm respectively). Contrarily, copper increases from 25 to 65 ppm in resampling at the same site and attains 50 ppm at a site 500 m upstream.

The overall widespread distribution of moderate copper anomalies indicates a fairly dispersed source from the underlying Green Beds. Minor enrichments of copper, and, more specifically, zinc may be controlled by the faulting or the interface with a thin quartzitic band in the Green Beds and the Beinn Bheula Schists. No field evidence of mineralisation was observed, except in a sample of the Green Beds from NGR 21738 70840, upstream of CZ 1163, which contains pyrite and a green secondary ?copper mineral (?after chalcopyrite). This rock contains 310 ppm Cu and 90 ppm Zn. Another sample, of quartz vein carrying pyrite, from NGR 21980 71004, contains only 15 ppm Cu and 50 ppm Zn. No potentially economic sources in the Green Beds seem likely.

Hell's Glen
A fault extends south-eastwards through Hell's Glen, where moderate copper anomalies, 55–65 ppm in sediment and 70–127 ppm in panned concentrate, lie upstream of CZ 1274 (NGR 21774 70263). Further south, anomalies of up to 189 ppm Cu and 547 ppm Zn in panned concentrate were produced upstream in the resampling of CZP 1038 (NGR 21780 70605). Both of these short streams cross faulted Green Beds in a geological environment similar to that of the streams in the Ardkinglas area some 3 km to the north. The anomalies are probably of a similar origin, although quartz veins are possible sources, such as one at NGR 21760 70561 (400 m upstream of CZ 1036) which contains 105 ppm Cu and 90 ppm Zn.

The large barium anomaly (56 659 ppm) in CZP 1036 (NGR 21740 70665) diminished to only 53 ppm in a sample taken at the same site during detailed investigation in Hell's Glen. This may be due to poor panning efficiency on resampling, or the possible effects of drought. Other metal levels also declined. Although contamination rarely affects barium levels, this possibility is discounted by a tin content of zero in CZP 1038. Barium mineralisation is likely in the stream section, in faulted Beinn Bheula Schists marginal to the Green Beds, although no field evidence was observed.

CONCLUSIONS

The results of the survey indicate moderate prospects for the discovery of various types of mineralisation in well-defined zones:

Associated elements	Locality	Environment
Copper		
Cu, Mo	Allt Glean Achrioch	Loch Tay Limestones and
Cu, Pb, Zn, Ni, Ba	Invercorachan, lower Glen Fyne	Green Beds, Glen Fyne fault
Cu, Pb, Zn, Ba, Mo	Eagle's Fall, Loch Sloy (+ Co)	Glen Fyne igneous complex
Cu, Pb, Zn, Ni, Ba	Dundarave, Strachur (Pb only)	Pyrite Zone
Cu, Zn, Ni	Ardchyline, Lephinmore, Lephinchapel (Zn)	
Cu, Pb, Zn	Upper Strathlachlan River, Evanachan	Loch Tay Limestone
Cu, Pb, Ni	Achadunan	Green Beds
Cu, Pb	Ardrishaig	Ardrishaig Phyllites
Lead (apart from where it coincides with copper)		
Pb, Zn, Ni, Ba, Sb	Upper Glen Fyne	Glen Fyne fault
Pb	Dubh Eas, River Falloch	Garabal fault
Pb, Zn, Ba, Sb, Mo, U	Allt na Lairige	Garabal Hill – Glen
Pb, Zn, Mo	Allt Coir' an Longairt	Fyne igneous
Pb, Zn, Mo	Allt Arnan, Strath Dubh-uisge	complex
Pb	Leacann Water, Minard	Ardrishaig Phyllites
Pb	Douglas Water, Abhain Bhuidhe	
Pb, Zn, Ba	Allt Bail a Ghobhain	Pyrite Zone
Pb	Lower River Add	
Zinc (apart from where it coincides with copper and/or lead)		
Zn (+ minor Co, Ni, Cu)	Allt Coire Dubhcraig	Glen Fyne fault
Zn	Furnace	Ardrishaig Phyllites (intruded by felsites and epidiorites)
Zn (+ minor Cu, Ni)	Cruach Mhor	Pyrite Zone
Zn (+ minor Cu, Ba)	Coire No	Loch Tay Limestone
Zn (+ minor Cu, Ba)	Hell's Glen	Green Beds

Although the primary intention of the drainage survey was to examine the economic potential of the Pyrite Zone, it has demonstrated that other controls of mineralisation seem to be at least equally important.

The sub-economic stratiform mineralisation at Garbh Achadh, McPhun's Cairn and Creggans, in or near the Pyrite Zone, is well developed. Sporadic mineralisation is indicated at only a few additional isolated points through the remainder of the Zone, Dundarave, Ardchyline, Lephinmore and Lephinchapel being at isolated and widely separated points along the southern outcrop. The intervening tracts are only slightly enhanced in metal levels. A common control of local metal enrichment may be the intersection of generally south-easterly trending features: shearing and faulting at Dundarave, and epidiorites, sheared Permo-Carboniferous dolerite dykes and other intrusions at the other localities. Although such intersections are common along the Pyrite Zone, the capacity of the intersecting structure to react with and concentrate fluids (from a remobilised source of weak stratiform sulphide mineralisation) is variable and will determine the economic potential of the resultant mineralisation. The only positive indication of mineralisation on the northern outcrop of the Pyrite Zone is at Allt Bail a Ghobhain, where mineralisation may be controlled by a nearby felsite intrusion. Other parts of the outcrop are only slightly enhanced in metal content.

Of the other controls of mineralisation, the Tyndrum–Glen Fyne fault system is predominant. As well as controlling the lead-zinc distribution in the Cononish area, the fault may influence the location of mineral concentrations in Allt Glean Achrioch, Allt Coire Dubhcraig, upper Glen Fyne, Invercorachan and lower Glen Fyne. Although influenced by the proximity of the igneous complex and the presence of potentially favourable host rocks (limestones, felsites, epidiorites), the fault provides the genetic link between the mineralisation at Clachan Beag and that at Cononish. Sample analytical values are not consistent, but the almost unbroken continuity of multi-element anomalies for about 11 km along Glen Fyne emphasises the potential for economic mineralisation in this zone.

The Garabal Hill–Glen Fyne igneous complex presents a variety of isolated environments favourable for mineralisation. Hydrothermally altered parts of the porphyritic granodiorite phase control lead, zinc, molybdenum, antimony and barium mineralisation (Allt na Lairige); the more basic parts influence copper, lead, zinc, nickel, cobalt, molybdenum and barium enrichment (Allt Arnan, Loch Sloy, where mineralisation may extend for 3 km along the Garabal fault); and marginal intrusions probably control mineralisation at Eagle's Fall (copper, lead, zinc, barium, cobalt and molybdenum).

The continuity of mineralisation between

Coille-bhraghad and Craignure, and beyond in zones of Ardrishaig Phyllites typified by limestones and epidiorites, has been demonstrated. The mineralisation, however, is only sporadic, and lies at more than one stratigraphic level. Lead and zinc are the predominant forms of mineralisation, with minor amounts of copper, nickel, cobalt and arsenic. The general persistence of moderate multi-element anomalies in these zones, some of which were not investigated in detail, may indicate a genetic link between the ?stratiform mineralisation at Coille-bhraghad and Craignure, and the vein-style mineralisation at Kaimes, Castletown and possibly Inverneil.

The Loch Tay Limestone and associated epidiorites, wherever sampled, seem to be a focus of mineralisation, as at Coire No, in the upper Strathlachlan River, and Evanachan. The continuity of mineralisation is unknown, as much of the outcrop lies outside the area sampled. A stratum-controlled deposition similar to that at Clachan Beag is implied, but igneous metasomatic sources of the size and nature of the Glen Fyne complex are difficult to envisage, although the extent of metasomatism at Clachan Beag is uncertain. Local igneous sources and structural controls may be of influence in other parts of the outcrop, however, and the limestone is probably a chemically reactive interface for deposition of remobilised solutions under various conditions.

The Green Beds, of volcanic origin, are enhanced in many elements, probably syngenetically. Enrichments, such as lead (with ?associated copper and nickel) at Achadunan, are controlled by shear zones. Such controls are also probably partly responsible for the moderate anomalies at Ardkinglas and Hell's Glen.

RECOMMENDATIONS

Further detailed study, including geochemical soil sampling, geological mapping and geophysical surveys, is merited in the following areas identified by the detailed drainage survey;

1 Glen Fyne (upper, Invercorachan and lower). To establish the continuity of mineralisation from Clachan Beag in Loch Tay Limestone and epidiorites and to investigate other potentially mineralised controls such as faulting, felsite, dolerite and porphyrite intrusions.
2 The Garabal Hill–Glen Fyne igneous complex. To examine well-defined sources of anomalies such as baryte veining (Allt na Lairige), fault controlled mineralisation with basic igneous associations (Loch Sloy), and possible disseminations in marginal porphyrites and related veins (Eagle's Fall).
3 Pyrite Zone. To determine the extent of mineral concentration at Dundarave, Ardchyline, Lephinmore and Lephinchapel.
4 Loch Tay Limestone. To examine sources of high copper anomalies in this outcrop in upper Strathlachlan River, and in epidiorites at Evanachan.

Additional detailed stream sampling is required at those localities with anomalous sample levels which were not resampled.

ACKNOWLEDGEMENTS

The authors wish to thank members of the IGS Edinburgh Office, especially Mr G. S. Johnstone, for advice and assistance. Thanks are due to Mr K. Smith of the Metalliferous Minerals and Applied Geochemistry Unit (MMAGU), IGS, for the computing work; the other leaders of sampling parties of voluntary workers – Mr P. Green and Mr K. Jacobs (both MMAGU); and the Analytical and Ceramics Unit of IGS and AWRE Aldermaston for sample analyses.

REFERENCES

Coats, J. S., Smith, C. G. and others. 1981. Stratabound barium-zinc mineralisation in Dalradian schist near Aberfeldy, Scotland: Final report. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 40.

Darnley, A. G. 1962. A new analysis of pitchblende from Tyndrum, Perthshire. Age Determination Report. *Geol. Surv. G.B.*, No. 21 (Unpublished).

Ellis, R. A., Marsden, G. R. and Fortey, N. J. 1978. Disseminated sulphide mineralisation at Garbh Achadh, Argyllshire, Scotland. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 23.

Harris, A. L. and Pitcher, W. S. 1975. The Dalradian Supergroup. In *The Precambrian: A correlation of Precambrian rocks in the British Isles* (Harris, A. L. and others, eds.), *Geol. Soc. London Spec. Rep.*, No. 6, pp. 52–75.

Howarth, R. J. 1971. FORTRAN IV program for grey-level mapping of spatial data. *Math. Geol.*, Vol. 3, pp. 95–121.

Ineson, P. R. and Mitchell, J. G. 1974. K-Ar isotopic age determinations from some Scottish mineral localities. *Trans. Inst. Min. Metall. (Sect. B: Appl. Earth Sci.)*, Vol. 83, pp. B13–B18.

Institute of Geological Sciences. 1966. Tectonic map of Great Britain and Northern Ireland, 1:1 584 000 (one inch to twenty-five miles).

— 1972. Aeromagnetic map of Great Britain and Northern Ireland, 1:625 000, Sheet 1.

Jeffrey, K. G., Gill, E. M., Henley, S. and Cubbit, J. M. 1977. *G-EXEC System User's Manual.* Atlas Computing Division and Institute of Geological Sciences.

Johnstone, G. S. 1966. British Regional Geology: The Grampian Highlands. *Institute of Geological Sciences.*

Nockolds, S. R. 1940. The Garabal Hill–Glen Fyne igneous complex. *Q. J. Geol. Soc. London*, Vol. 94, pp. 451–511.

Parslow, G. R. 1974. Determination of background and threshold in exploration geochemistry. *J. Geochem. Explor.*, Vol. 3, pp. 319–336.

Roberts, J. L. and Treagus, J. E. 1977. The Dalradian rocks of the south-west Highlands – Introduction. *Scott. J. Geol.*, Vol. 13, pp. 87–99.

Sibson, R. H., Moore, J. Mc.M. and Rankin, A. H. 1975. Seismic pumping – a hydrothermal fluid transport mechanism. *J. Geol. Soc. London*, Vol. 131, pp. 653–659.

Smith, C. G. and others. 1977a. Investigation of stratiform mineralisation in parts of central Perthshire. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 8.

— 1977b. Investigation of stratiform sulphide mineralisation at McPhun's Cairn, Argyllshire. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 13.

— 1978. Investigation of stratiform sulphide mineralisation at Meall Mor, south Knapdale, Argyll. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 15.

Tait, B. A. R. and Coats, J. S. 1976. A rapid method for the analysis of trace elements in rocks, stream sediments and soils by photographic emission spectrography using a semi-automated method of plate evaluation. *Rep. Inst. Geol. Sci.*, No. 76/11.

Wedepohl, K. H. 1972. Behaviour during processes connected with magmatism. In *Handbook of Geochemistry*, (Wedepohl, K. H., ed.) (Springer-Verlag: Berlin–Heidelberg), Vol. II, Section 56–F-2.

Wilson, G. V. 1921. The lead, zinc, copper and nickel ores of Scotland. *Mem. Geol. Surv. Scotland: Special Reports on the Mineral Resources of Great Britain*, No. 17.

Wilson, J. R. and Leake, B. E. 1972. The petrochemistry of the epidiorites of the Tayvallich Peninsula, north Knapdale, Argyllshire. *Scott. J. Geol.*, Vol. 8, pp. 215–272.

Winchester, J. A. 1974. The zonal pattern of regional metamorphism in the Scottish Caledonides. *J. Geol. Soc. London*, Vol. 130, pp. 509–524.

Zachrisson, E. 1971. The structural setting of the Stekenjokk ore bodies, central Swedish Caledonides. *Econ. Geol.*, Vol. 66, pp. 641–652.

FIG. 3
DRAINAGE GEOCHEMICAL SURVEY
CENTRAL ARGYLL
LOCATION OF
STREAM SEDIMENT SITES


FIG. 4
DRAINAGE GEOCHEMICAL SURVEY
CENTRAL ARGYLL
LOCATION OF
PANNED CONCENTRATE SITES
LOCH FYNE
LOCHGILPHEAD
INVERARAY
SCALE

1

FIG. 5 DRAINAGE GEOCHEMICAL SURVEY
CENTRAL ARGYLL
COPPER IN
STREAM SEDIMENTS
KEY
ppm Copper
101 - 107
38 - 100
21 - 37
1 - 20
SCALE
0 1 2 3 Kilometres
0 1 2 Miles
LOCH FYNE
LOCHGILPHEAD
INVERARAY
Furnace
Strachur
Cairndow
Tyndrum
Crianlarich
Loch Gilp
Loch Goil
Lochgoilhead
Loch Lomond
Ardrishaig
River Goil
River Fyne

FIG. 6 DRAINAGE GEOCHEMICAL SURVEY
CENTRAL ARGYLL

COPPER IN
PANNED CONCENTRATES

FIG.9 DRAINAGE GEOCHEMICAL SURVEY CENTRAL ARGYLL

LEAD IN STREAM SEDIMENTS

FIG.10 DRAINAGE GEOCHEMICAL SURVEY CENTRAL ARGYLL

LEAD IN PANNED CONCENTRATES

FIG.13 DRAINAGE GEOCHEMICAL SURVEY CENTRAL ARGYLL

FIG.14 DRAINAGE GEOCHEMICAL SURVEY CENTRAL ARGYLL

ZINC IN PANNED CONCENTRATES

FIG.17 DRAINAGE GEOCHEMICAL SURVEY CENTRAL ARGYLL

NICKEL IN STREAM SEDIMENTS


FIG. 18 DRAINAGE GEOCHEMICAL SURVEY
CENTRAL ARGYLL
NICKEL IN
PANNED CONCENTRATES
KEY
ppm Nickel
92 - 998
35 - 91
1 - 34
SCALE
LOCHGILPHEAD
INVERARAY
LOCH FYNE
Furnace
Strachur
Lochgoilhead
Loch Gilp
Loch Lomond

FIG.21 DRAINAGE GEOCHEMICAL SURVEY CENTRAL ARGYLL

BARIUM IN PANNED CONCENTRATES