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 The information contained herein must not be published without reference to the Director, Institute of Geological Sciences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. 51

A reconnaissance geochemical survey of Anglesey

INSTITUTE OF GEOLOGICAL SCIENCES

Natural Environment Research Council

Mineral Reconnaissance Programme

Report No. 51

A reconnaissance geochemical survey of Anglesey

Geochemistry
D. C. Cooper, BSc, PhD

Geology and mineralisation
M. J. C. Nutt, BSc, PhD

Mineralogy
D. J. Morgan, BSc, PhD

London 1982

A report prepared for the Department of Industry

Mineral Reconnaissance Programme Reports

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

51 A reconnaissance geochemical survey of Anglesey

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
Cooper, D. C. and others. 1982. A reconnaissance geochemical survey of Anglesey. *Mineral Reconnaissance Programme Rep. Inst. Geol. Sci.*, No. 51

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

CONTENTS

FIGURES

TABLES

SUMMARY

A reconnaissance geochemical survey of Anglesey was based on a drainage survey (at one sample per km^2) supplemented by low-density soil sampling. A field survey of known mineralisation was carried out to aid data interpretation and assessment of mineral potential.

The reconnaissance field survey indicated that the non-ferrous mineralisation of Anglesey may be divided into three groups: (a) copper, (b) copper (lead, zinc) and (c) baryte (lead). Economically, group (b) is the most important and its occurrence is virtually confined to the Lower Palaeozoic rocks. Groups (a) and (c) are small vein occurrences, within the Mona Complex and adjacent to the basal Carboniferous unconformity respectively.

The drainage survey encountered major difficulties from the lack of surface drainage, contamination, subdued topography, variable background geology and extensive drift deposits. At least 35% of the island was not effectively covered by the drainage sampling but this figure was reduced by the collection of soil samples from three areas of poor drainage and thin drift cover. Problems were further countered by collecting water, stream sediment and panned concentrate samples at all drainage sites, mineralogically examining anomalous concentrates, and resampling streams with sites found to be contaminated. 440 drainage sites were sampled. Cu, Pb, Zn, Ba, Fe, Mn, Co, Ni and Mo were determined in sediment samples and Cu, Pb, Zn, Ba, Fe, Mn, Ti, Ni, Sn, Sb and Ca in panned concentrates. Cu, Pb and Zn were determined in soil and water samples.

Large-scale regional variation of the drainage results was examined using computer-generated greyscale maps. Variation was related to bedrock geology, mineralisation and contamination. The comparison of statistical analyses and mineralogical observations indicated that all high Sn and Sb levels were related to contamination and that, in this area, factor analysis was an effective means of discriminating between anomalies caused by contamination and those due to mineralisation. Inter-element relationships also indicated the presence of two chemically distinct types of mineralisation: a Cu-Pb-Zn-Fe sulphide type and a Ba type, which correspond to groups (a + b) and (c) of those defined by the field survey.

Threshold levels were established using cumulative frequency plots, and eighteen anomalous areas related to sulphide or baryte mineralisation were delineated. Four of these, at Carmel Head, Llandyfrydog, City Dulas and Llanbadrig were the subject of further study. Other areas considered worthy of investigation are the basal Carboniferous between Dulas and Malltreath, the Gwna rocks around Cerrigceinwen, and the area east of Parys Mountain; the latter area has been investigated by mining companies without success. Further areas not adequately covered by the survey, for example the basic rocks around Rhoscolyn, may also be worthy of further consideration.

INTRODUCTION

Anglesey is an island of about 750 km^2, forming the extreme north-west corner of Wales and separated from the mainland by the narrow Menai Strait (Figure 1). In contrast to the mainland, the island is characterised by a very subdued topography, with a few isolated hills rising to a maximum height of 220 m on Holyhead Mountain. The drainage is poor and the weak trellis pattern is dominated by north-east and south-west trending streams, directions resulting from a combination of the south-westerly direction of glaciation and the strong Caledonian trend of many major structures in Anglesey. Almost all the land is farmed; most of it is under grass, but the highest ground and a few other areas of poor soil development are heather covered; only a small proportion of the island is forested (Roberts, 1958).

Following the decision to include Anglesey in the Mineral Reconnaissance Programme it was decided that reconnaissance geochemical and geophysical surveys were needed to provide basic information on the island, so that small areas of particular interest in terms of mineralisation could be defined. The geology of Anglesey is well known through the work of Greenly (1919), and although modern developments have altered his interpretations his map remains more than adequate for reconnaissance purposes. In contrast, published geochemical and geophysical information is limited; the only available data covering the island being the 1:250 000 scale aeromagnetic map (IGS, 1964). It was therefore, decided to carry out an airborne geophysical survey across the part of the island outlined on Figure 1 (Smith, 1979) and a reconnaissance scale stream sediment survey.

It was known from orientation studies carried out prior to the main drainage geochemical survey

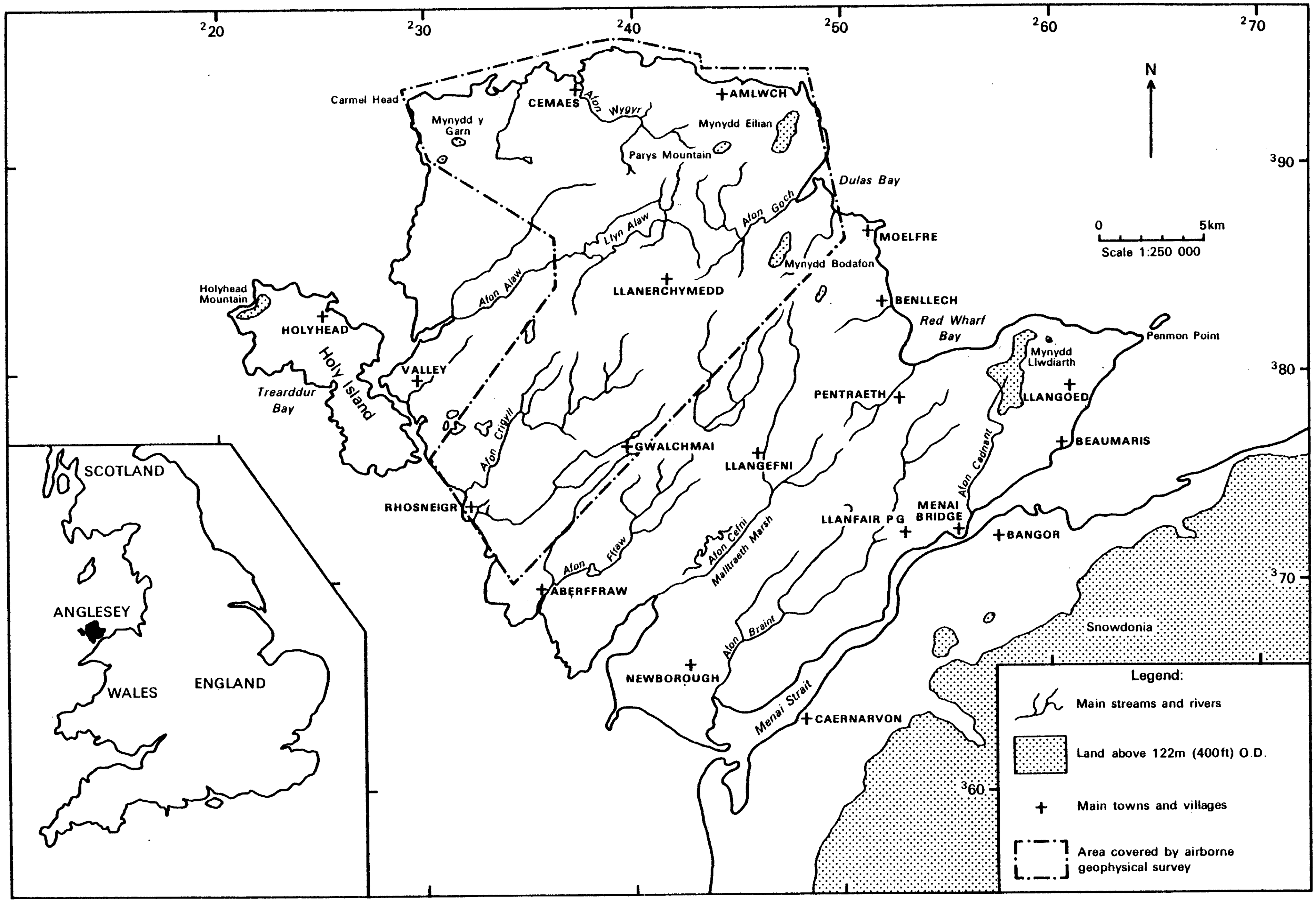


Fig.1 Location of the survey area

that several features of Anglesey made the island unsuitable for a stream sediment survey, but there was no viable alternative for obtaining the information required. The main problems concerned:

(a) Lack of surface drainage. Because of poor or non-existent surface drainage several areas could not be effectively covered. An attempt was made to overcome this problem by collecting soil samples over three of the most sparsely drained areas where drift cover was thin (Figure 4).

(b) Contamination. Two main groups of contaminants are found in Anglesey streams; firstly waste from roads, farms, villages and towns, and secondly the products of past mining activities. Strong anomalies generated by these sources were likely to mask anomalies caused by unknown mineralisation. This problem was countered by determining elements indicative of contamination and examining mineralogically panned concentrates, which were collected at every site.

(c) Variable background geology. The rocks on Anglesey are extremely varied, which made the determination of background levels difficult. 'Anomalies' were likely to be solely the product of the higher background of a given element found in some lithologies and, conversely, anomalies related to mineralisation were likely to be missed over areas of low background. Unsuccessful attempts were made to overcome this problem by dividing samples into groups according to their geological background.

(d) Subdued topography. Streams were generally sluggish, which tended to increase the effects of contamination and also meant that the samples were unlikely to be representative of the entire upstream catchment.

(e) Extensive drift deposits. Glacial and postglacial drift and alluvium cover much of the lower ground. In the first instance sediment was likely to be derived from these deposits rather than bedrock, and there was evidence (Greenly, 1919) to suggest that at least some of the drift deposits had travelled an appreciable distance from their source. This problem is accentuated by the rapid variations in background geology.

GEOLOGY AND MINERALISATION

GEOLOGY

The geology of Anglesey ranges from the most complex to the very simple and is amongst the most diverse in the whole of Britain relative to the size of the island. Ranging in age from the Precambrian through much of the Palaeozoic, there is a great variety of rock types and geological structures, together with a strong development of igneous rocks in all but the Upper Palaeozoic rocks. Exposure is at its best around the coastline and in certain inland areas chiefly in the north and east as well as on Holy Island. Much of Anglesey is covered by superficial deposits, especially those of glacial origin, boulder clay with sands and gravels. Alluvium, both marine and non-marine, is significant, while blown sand is a major deposit along the south-western seaboard.

Early research into the geology of Anglesey culminated in 1919 with the publication of the Geological Survey Memoir in two volumes and the one-inch geological map (now reprinted at 1:50 000 (Solid, 1980; Drift, 1975) and here simplified in Figure 2) by Greenly. The Memoir includes a comprehensive account and bibliography of previous research, but such was its authoritative stamp on the geology of Anglesey that further research has only taken place since the early 1950s particularly in the last fifteen years. Within this period the principal published papers are by Shackleton (1969), Maltman (1975, 1977), Barber and Max (1979) and Muir and others (1979) on the Precambrian, Bates (1968, 1972, 1974) on the Ordovician and Allen (1965) on the Old Red Sandstone. Recent work on the Carboniferous has yet to be published except for a short paper by Power and Somerville (1975). Dewey (1969), Baker (1973), Wood (1974), Thorpe (1974) and Virdi (1978) have discussed the development of the Precambrian and Lower Palaeozoic geology of Anglesey in relation to modern theories of plate tectonics and subduction. Nutt and Smith (1981a) have discussed the palaeogeographical position of Lower Palaeozoic Anglesey relative to the mainland of North Wales and have proposed pre-Carboniferous transcurrent faulting along the line of the Menai Strait to account for the present position of the pre-Carboniferous rocks of Anglesey.

For descriptive purposes in this report the rocks of Anglesey may be divided into five major groups, the Mona Complex, Ordovician (including minor Silurian), Old Red Sandstone, Carboniferous and igneous intrusions.

The Mona Complex, ranging in age from Precambrian to at least early Cambrian, occurs throughout Anglesey (Figure 2) and forms the largest tract of exposed metamorphic rocks in Britain south of the Scottish Highlands. Greenly (1919) and later Shackleton (1975) divided the Mona Complex into a Bedded Succession (the Monian Supergroup) and a gneissic group. The Bedded Succession is a thick sedimentary sequence of turbidite deposits, sandstones including quartzites, and mélanges (olistostromes, which involve limestones in the north), with associated extrusive volcanic rocks, tuffs and lavas. This succession has been metamorphosed into various metasediments and metavolcanics ranging from low greenschist to amphibolite facies. Greenly (1919) and later Barber and Max (1979), regarded the gneisses as the metamorphosed basement on which the sedimentary rocks were deposited. Shackleton (1969 and 1975) interpreted the gneisses as being the highly metamorphosed parts of the Bedded Succession. He followed Greenly in his grouping of the sedimentary rocks, but inverted the

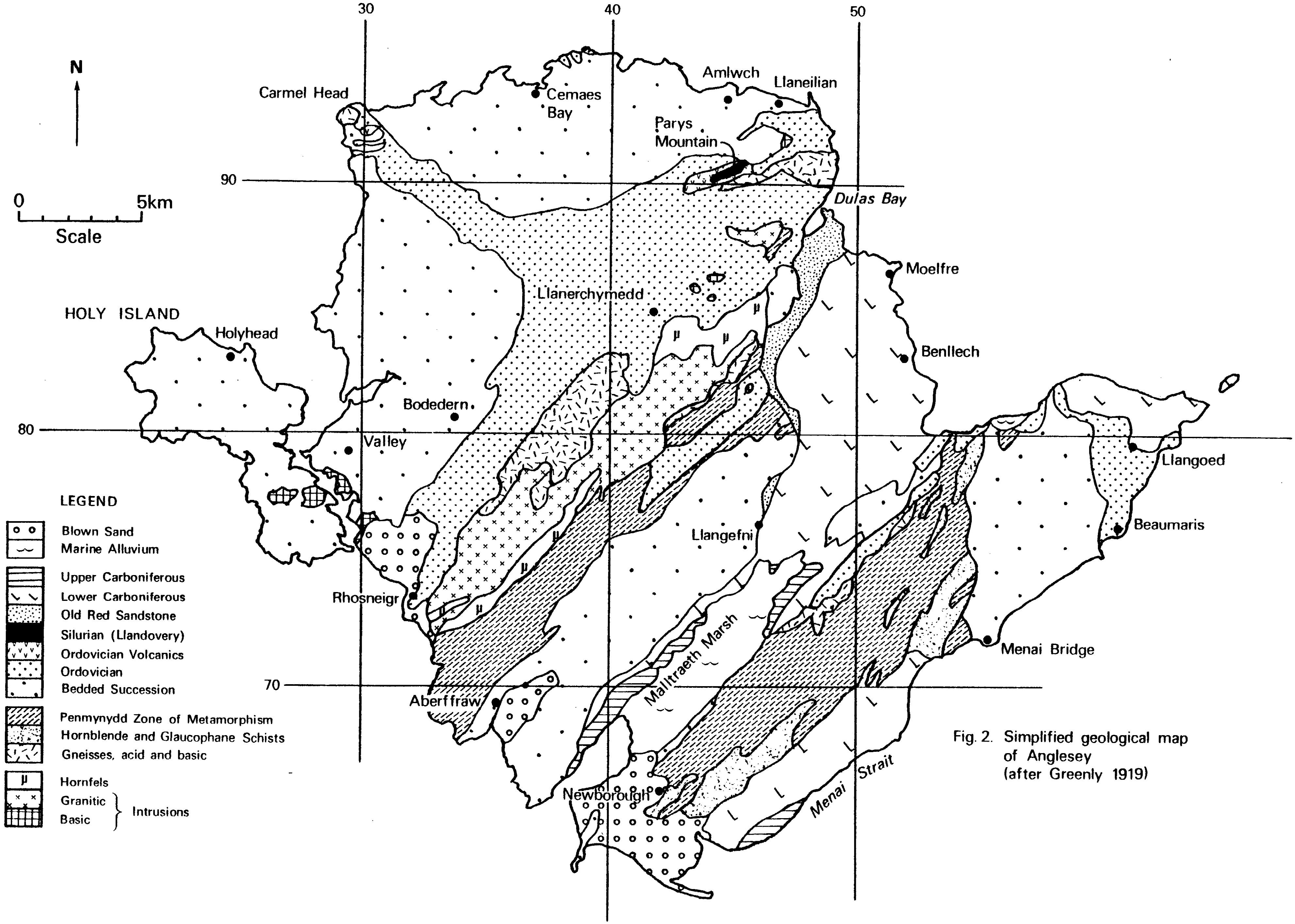


Fig. 2. Simplified geological map of Anglesey (after Greenly 1919)

Table 1 Proposed stratigraphical sequences in the Mona Complex

	Shackleton (1975)	Barber and Max (1979)
Ordovician/ Silurian	Arenig to Llandovery	Arenig to Llandovery
	~Unconformity~	~Unconformity~
Bedded Succession (Monian Supergroup)	Fydlyn Felsitic Formation	Gwna Mélange (2)
	Gwna Group	Skerries Grits and Shales
	Skerries Group including	Gwna Mélange (1)
	Church Bay Tuffs	Church Bay Tuffs
		~ Unconformity ~
	New Harbour Group	New Harbour Group
		— Thrust —
	Rhoscolyn Formation	Rhoscolyn Formation
	Holyhead Quartzite Formation	Holyhead Quartzite Formation
	South Stack Formation	South Stack Formation
		— Fault —
		Gneisses

sequence to give the succession shown in Table 1. Although Barber and Max (1979) agree broadly with this succession they would place the Fydlyn Felsitic Formation in the Ordovician and would separate the older Church Bay Tuffs from the Skerries Grits by a horizon of Gwna Mélange with a further horizon of Gwna Mélange at the top of the Bedded Succession (Table 1). The number of mélange horizons is at present uncertain (see Wood in discussion to Barber and Max, 1979), but there is stratigraphic and fossiliferous evidence to show that mélanges mapped by Greenly as Gwna Mélange also occur within sedimentary sequences in the Ordovician (Nutt and Smith 1981b).

The Penmynydd Zone of metamorphism (Figure 2) includes hornblende and glaucophane schists and was described by Greenly (1919) and Shackleton (1969) as being a zone composed of various stratigraphic units in a highly deformed state as a result of metamorphism and tectonic events.

Within the context of this report the tectonic history of the Mona Complex need only be considered briefly. Greenly (1919) believed that the Monian was folded and metamorphosed by large recumbent folds, a hypothesis rejected by Shackleton (1969 and 1975) and by Barber and Max (1979). Shackleton (1969) believed that there was an overall steady dip across Anglesey to the south-east which results in the oldest rocks occurring in the north-west on Holy Island, and the youngest in the south-east by the Menai Strait. Barber and Max (1979) divided the Monian into three tectonic units, the uppermost including lower Ordovician rocks. The uppermost unit was considered to be affected only by the Caledonian orogeny whilst the lower units were also deformed and metamorphosed by a pre-Ordovician orogeny.

Following Greenly (1919) the age of the Mona Complex was previously considered to be entirely Precambrian, but recent finds of stromatolites and microfossils from within blocks and matrix of mélanges in the Gwna Group (see Muir and others, 1979) have indicated that the upper part of the Bedded Succession must be early Cambrian in age, or even younger (see above).

Ordovician rocks occur in widely scattered outcrops throughout Anglesey whilst the only Silurian rocks present are restricted to a synclinal infold on Parys Mountain in north-east Anglesey (Figure 2). Greenly's (1919) account of these rocks was extended by Bates with particular regard to stratigraphy (1972) and structure (1974). Over most of Anglesey the Ordovician rocks rest unconformably on the Mona Complex, or are in tectonic contact with it. Argillaceous rocks (shales and mudstones) predominate, though coarser horizons (conglomerates, breccias and sandstones) and oolitic ironstones are variably developed locally. On Parys Mountain there is an important development of extrusive acid volcanic rocks (tuffs and lavas) whilst to the south-south-east of Carmel Head there is a further development of acid tuffs (Figure 2). The Silurian is represented almost entirely by graptolitic shales of middle to upper Llandovery age, but they contain a number of thin tuff bands (Nutt and others, 1979). Tectonic movements during the Caledonian orogeny produced fold trends ranging from NE-SW through E-W to ESE-WNW, with asymmetrical, southerly inclined, folds. Faulting, thrusting and cleavage developed, converting some of the argillaceous rocks into slates.

The Caledonian movements gave rise to an intermontane valley floodplain in eastern central Anglesey. On this floodplain was deposited the Old Red Sandstone, a dominantly arenaceous facies of conglomerate, sandstones and siltstones with a number of calcareous horizons and limestones (Allen, 1965). These deposits, resting unconformably on Mona Complex and Ordovician rocks (Figure 2) were gently folded and faulted by later movements of the Caledonian orogeny, before the Carboniferous was deposited.

Carboniferous rocks occur in the south-eastern half of Anglesey in three major areas (Figure 2). Deposition of these rocks took place in long narrow gulfs whose NE-SW alignments were controlled by the underlying Caledonian structures, especially major fault lines. The Lower Carboniferous rests unconformably on Mona Complex, Ordovician and Old Red Sandstone and is essentially a limestone lithology. Conglomerates and sandstones are developed at the base in some areas, but occur also at higher levels elsewhere. Unconformable Upper Carboniferous deposits of sandstone passing up into Coal Measures are to be found beneath the marine alluvium of the Malltraeth. These Coal Measures are overlain unconformably by Red Measures of assumed Upper Carboniferous age. A further area of Red Measures, of assumed Upper Carboniferous age, occurs overlying the Lower Carboniferous rocks at the south-west end of the Menai Strait. The overall structure of the Carboniferous rocks is very simple with a stready low dip towards the south-east. It is transected by a number of north-east trending major faults downthrowing to the north-west.

Igneous intrusions are confined almost entirely to the Mona Complex and Lower Palaeozoic rocks. Granitic intrusions form by far the largest bodies. The Coedana Granite is the largest, occurring across central Anglesey (Figure 2). It is contained within schists and gneisses of the Mona Complex and possesses clear magmatic contacts with its associated hornfels (Shackleton, 1969). Major basic intrusions within the Mona Complex occur on Holy Island and the adjacent part of mainland Anglesey (Figure 2). Composed dominantly of serpentinite with associated gabbro, dolerite, etc. the intrusions have been interpreted as tectonic slices by Dewey (1969) and Thorpe (1978). However, Maltmann (1975, 1977) has demonstrated chilled margins and a thermal aureole which indicates that they may have been intruded *in situ* as plutonic bodies. Other basic intrusions occur in the Lower Palaeozoic rocks as small plutonic bodies or sills. Dykes of acid or basic intrusives occur throughout the Mona Complex and Lower Palaeozoic rocks. They are generally aligned NW-SE. This alignment is also taken up by a few basic dykes of Tertiary age cutting both the Carboniferous and older rocks.

MINERALISATION

Research into the non-ferrous mineralisation of Anglesey has concentrated almost entirely on the area of Parys Mountain. Greenly (1919) gave a detailed account of the Parys Mountain mineralisation and mining (pp. 823–43) and metasomatism (pp. 561–68), and provided a bibliography of previous research into these topics (pp. 21–2). Since the mid-1950s there have been numerous exploration programmes by various mining companies at Parys Mountain. This work has resulted in a wealth of publications and confidential company reports.

Initially exploration was done by examining some of the old workings (Manning, 1959). This was followed by a programme of inclined boreholes to see if mineral deposits persisted in depth beneath the old flooded workings. A lithological account of these boreholes was given by Hawkins (1966), but details of the mineralisation encountered were not published.

The exploration of Parys Mountain by inclined boreholes continues today. So far some 130 boreholes have been drilled producing core in excess of 38,000 m from depths extending to over 600 m. This core has been examined by the mining companies concerned and by the IGS. Selected cores have also been made available for academic research.

From the borehole programmes two conflicting views (syngenetic and epigenetic) have emerged for the mineralisation of Parys Mountain. The syngenetic view is that mineralisation resulted from volcanic exhalations in the Ordovician whilst the epigenetic model is that mineralisation resulted from hydrothermal fluids during or after the Caledonian orogeny.

Conclusions agreeing with one or the other viewpoint are to be found within the unpublished company reports and Ph.D. theses or within published academic research. Thanasuthipitak (1974) produced a syngenetic model of Ordovician mineralisation which was later remobilised during the Caledonian orogeny to account for the mineralisation of the Silurian rocks. Ixer and Gaskarth (1975) proposed a syngenetic Kuroko-style model based on comparisons with the classical Tertiary volcanic Kuroko deposits of Japan (Ishihara, 1974). The syngenetic proposals of Pointon and Ixer (1980) continued the volcanic exhalations from the Ordovician into the Silurian to account for all the mineralisation. In their view mineralisation was later remobilised during the Caledonian orogeny. Manning (1959) showed, however, that mineralisation was epigenetic, being controlled by structures, particularly shear zones, and a similar view was expressed by Marengwa (1973). Wheatley (1971) argued that mineralisation resulted from hydrothermal fluids becoming active after the formation of the Silurian rocks with mineral deposition taking place prior to and during Caledonian tectonic deformation. On completing a structural study of the Ordovician rocks of Anglesey Bates (1974) concluded that mineralisation had taken place during the later phases of the Caledonian orogeny, after the main folding and cleavage formation, a conclusion corresponding with the earlier views of Greenly (1919).

In an attempt to resolve the syngenetic-epigenetic controversy by a less subjective method Nutt and others (1979) conducted K-Ar isotopic age determinations on core samples from Parys Mountain. From this work two isotopic events emerged with ages of 394 ± 9 Ma and 353 ± 7 Ma. It was concluded that the younger date represented a period of mineralisation after the major events of the Caledonian orogeny while the older date may represent a period of mineralisation or cleavage formation. In any event the geochronological evidence could not support a syngenetic hypothesis for all of the mineralisation at Parys Mountain. Likewise, though no isotopic dates relating to syngenetic mineralisation were obtained the syngenetic hypothesis could not be eliminated entirely, for the older date might possibly represent syngenetic mineralisation remobilised during the Caledonian orogeny.

Evidence which at present indicates that the syngenetic hypotheses are untenable is provided by clasts derived from Parys Mountain and occurring in younger rocks (see Nutt and others, 1979, p. 624). These clasts suggest that the mineralisation of Parys Mountain post-dated the Old Red Sandstone, but pre-dated the basal Carboniferous conglomerate of Anglesey, a suggestion consistent with the isotopic age dating.

There is very little published work on mineralisation throughout the rest of Anglesey. Greenly (1919) listed a number of mines (pp. 844—48), but the list is far from complete and he failed to record the existence of numerous mines, trials and mineralised localities on his field slips (housed in the IGS, Leeds Office). Foster-Smith (1977) recorded a number of mines on Anglesey, but, like Greenly, his list is far from complete. Greenly's description of Palaeozoic metasomatism in areas other than Parys Mountain (1919, pp. 568—77) is the only account of these processes throughout the rest of Anglesey. The metasomatism of Greenly (1919) occurs in association with metalliferous mineralisation at most of the places he lists, and, though he comments little on their mutual relationships, he does consider that they are all part of the same mineralising episode (p. 577). Bates (1974) in his structural study of the Ordovician noted a number of mineralised localities.

The paucity of information regarding mineral deposits on Anglesey necessitated a rapid reconnaissance field survey of the island to establish further evidence of mineralisation and its controls. Fundamental to this objective and for the elimination of mine contamination from the drainage survey, was the location of old mines and trials.

Establishing the presence of old workings was done initially by a page to page scan of the non-indexed Mining Journal, Railway and Commercial Gazette, together with other sources (see Appendix 1). These were followed up in the field, where other, unnamed, workings were also established. A list of named mines and trials is given in Appendix 1, with unnamed mining locations in Appendix 2; the named and unnamed locations being shown on Figure 3. Both lists of mining activities are incomplete, as it proved impossible to examine all the records, or to cover the whole of Anglesey during the field survey. Two mines (Rhoscolyn and Caeronneg) have been referred to actual mine sites which may not be the correct one for the name, while a third mine (Porth yr hŵch) may be referred to one, or both, of two sites. Evidence of unworked mineralisation is given in Appendix 3, and the sites are shown on Figure 3.

For the purposes of this report the reconnaissance field survey of Anglesey indicated that the non-ferrous mineralisation of the island may be divided into three groups based on parameters which include the metals present, the orientation and apparent age of the mineralisation, and the age, lithological and structural control of the country rock. The three groups may be referred to as (a) copper, (b) copper (lead, zinc) and (c) baryte (lead). In the location of future economic deposits only group (b) appears to be of significant importance. A brief account of the individual groups is as follows:-

(a) Copper. This group appears to be that of the oldest mineralisation on Anglesey, being confined entirely to the Mona Complex. It consists of thin veins of quartz, pyrite and chalcopyrite occupying fractures striking north-west in low-grade metamorphosed turbidite sequences in the South Stack Formation and New Harbour Group of Holy Island (locations shown in Figure 3). Similar mineralisation occurs in a metamorphosed turbidite sequence in the New Harbour Group on the coast (SH 470 932) north-east of Llaneilian (Figure 3).

The mines which worked the copper deposits in this group are small and insignificant. Much of Holy Island is free of drift deposits and the island will have been well prospected by the early miners. It is unlikely, therefore, that this group will yield further orebodies of economic significance near to the surface.

(b) Copper (lead, zinc). Exemplified by the ore deposits of Parys Mountain, this group is nearly always associated with Lower Palaeozoic rocks, mainly sediments, but including extrusive acid volcanic rocks and intrusive basic rocks. The Lower Palaeozoic rocks may form the hanging wall (e.g. Gadair Mine), the footwall (e.g. Caeronneg Mine) or both walls (e.g. Parys Mountain) to the

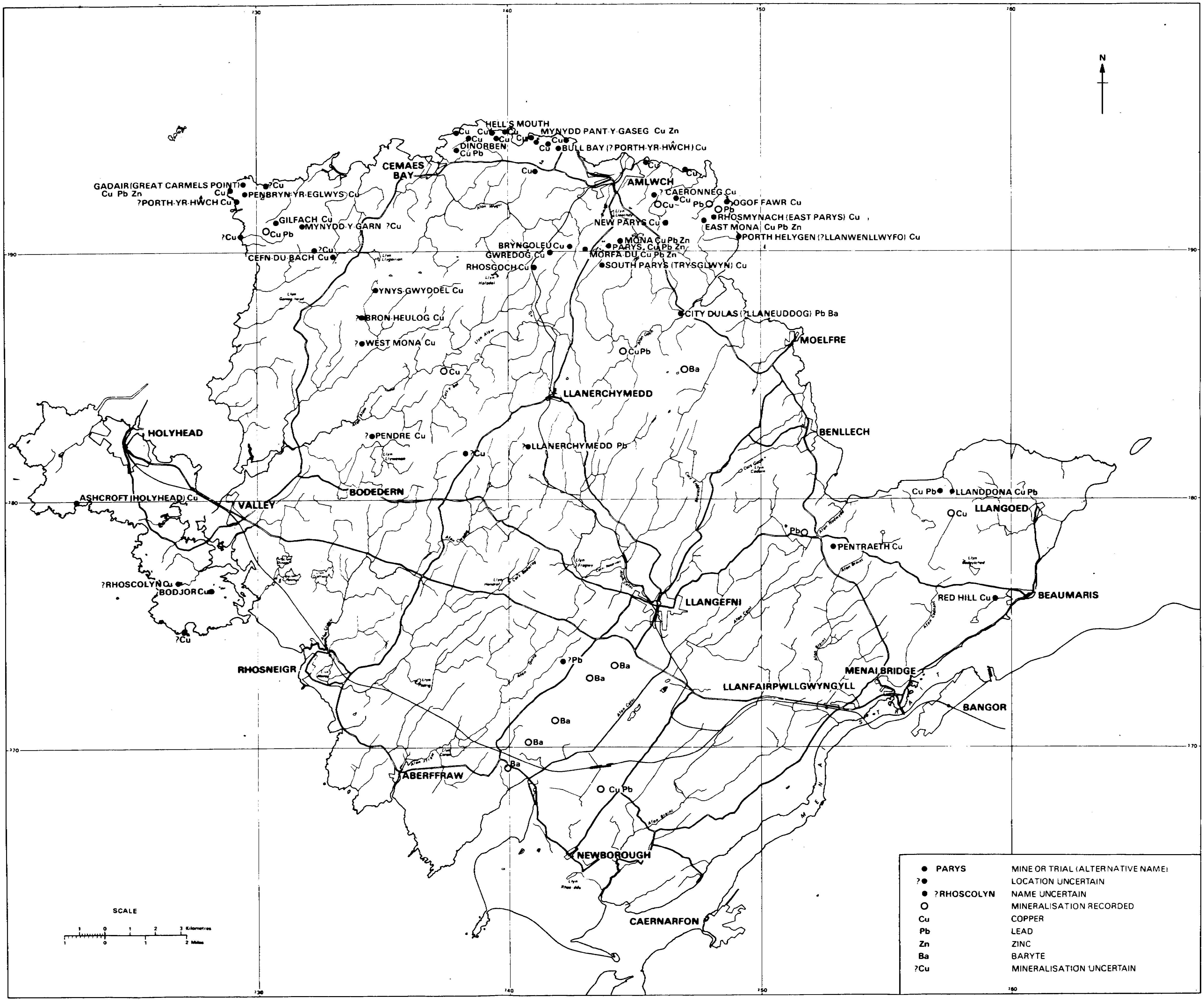


Fig 3 Location of non-ferrous mines and mineralisation.

mineralisation. Rare occurrences of this group are contained entirely within the Mona Complex, for example, a small mine at Llam Carw (SH 455 936) north-east of Port Amlwch.

The mineralisation always consists of quartz, pyrite and chalcopyrite. Lead, zinc or lead and zinc may be present and are probably more often present than the surface examination of old workings has indicated. While quartz is the ubiquitous gangue, a carbonate, usually dolomite, may also be present. Occurring as lodes or as mineral impregnations, forming lens-like bodies, the strike of the mineral deposits ranges from east-north-east through east to east-south-east, whilst the Parys Mountain (e.g. Morfa-du Mine) north-striking lodes are also present. Dip is usually to the north at moderate to steep angles, but occassionally, for example at Dinorben Mine (SH 379 948), the dip is to the south at a steep angle. The orientation of mineralisation was controlled by the local Lower Palaeozoic folding, shear zones and cleavage in the area concerned. In many instances mineral deposition clearly post-dates the formation of cleavage in the Lower Palaeozoic rocks, a view previously expressed by Bates (1974).

Mineralisation is preferentially developed in black pyritic mudstone, shale, or slate of Lower Palaeozoic age. The mineral deposits are usually present, at, or adjacent to, the junction of these black pelites with a competent rock originally rich in SiO_2 (lavas or ash-flow tuffs, granite gneisses, conglomerates or sandstones), or mélange rich in SiO_2, particularly sandstone or tuff mélanges. Even mines which at first sight appeared to be entirely within the Mona Complex were found to contain outliers of Ordovician black mudstone associated with the mineralisation, for example Llanddona Mine (SH 577 804). Similarly at Porth Helygen Mine there appears to be a tectonic outlier of Ordovician black shale (Greenly field slip), now unexposed, beneath the drift to the north of the mine. However, some workings appear to be entirely within the Mona Complex and no black mudstone has been located, for example Llam Carw.

The majority of the mines and trials, on Anglesey (Figure 3) worked mineral deposits in this group. These occur mainly in the northern half of mainland Anglesey along belts of mineralisation and metasomatism, which may be traced roughly east-west across the island. The group occurs over a larger area than either of the other two groups; it also contains the largest worked deposits, notably Parys Mountain. In any mineral exploration programme further deposits of this group must represent a prime target.

(c) Baryte (lead). This, the youngest of the three groups, is dominated by baryte mineralisation. Thin veins of baryte or lead are recorded from the Lower Carboniferous rocks, or from the Mona Complex near to the base of the Lower Carboniferous (Figure 3 and Appendix 3). Only in the case of City Dulas Mine has lead been noted to occur with baryte. It is reported (Lligwy Papers, in University College Library, Bangor) that in this mine there are three east-west lodes of lead associated with a north-south lode of baryte, but their relationships are unknown. Of the lead deposits the middle and southerly lodes are reported as dipping south. Mineral deposits in this group are unworked, except for City Dulas and possibly the unnamed mine (SH 422 736) near Cerrigceinwen. It is believed that any future finds will be of little or no economic significance.

No evidence was found during the reconnaissance survey to suggest that any of the mineralisation was syngenetic in origin. Indeed the evidence suggests that most of the mineralisation on Anglesey is epigenetic in origin, with group (a) being pre-Ordovician, group (b) pre-Lower Carboniferous and group (c) probably pre-Upper Carboniferous.

Syngenetic mineralisation has been suggested for Parys Mountain (see above). This mineralisation, if true, is dependent on the presence of associated Ordovician and or Silurian extrusive volcanic deposits. Such volcanic deposits are known only at Parys Mountain and in a very restricted area south-east of Carmel Head. The possibility of syngenetic stratabound mineral deposits of similar age, is, therefore, very restricted. In contrast to this the epigenetic deposits of group (b) are wide ranging and more likely to yield potential mineral target areas to a geochemical stream sediment survey.

SAMPLING AND ANALYSIS

DRAINAGE SAMPLES

The drainage sampling pattern was constructed to avoid major known centres of contamination and to yield a coverage of about 1 sample/km^2 in areas where stream density was sufficient. The exact position of sites was chosen on the ground to avoid contamination wherever possible, and to optimise the heavy mineral content of the sample by choosing sediment traps as sites. The central part of the stream was sampled to minimise the amount of locally derived bank material in the sample. At each site three sample types were collected (water, sediment and panned concentrate) in order to provide the maximum information on the likely cause and source of any anomalous results. Site parameters, such as background geology, stream conditions and observed contamination were noted on computer-compatible cards.

In total 440 sites were sampled. The larger areas not effectively covered by drainage samples are outlined in Figure 4 and amount to approximately 260 km^2 or about 35% of the survey area. In practice the effective cover is even less than shown in Figure 4 because several sites had effective sediment catchments which were less than the theoretical areas covered.

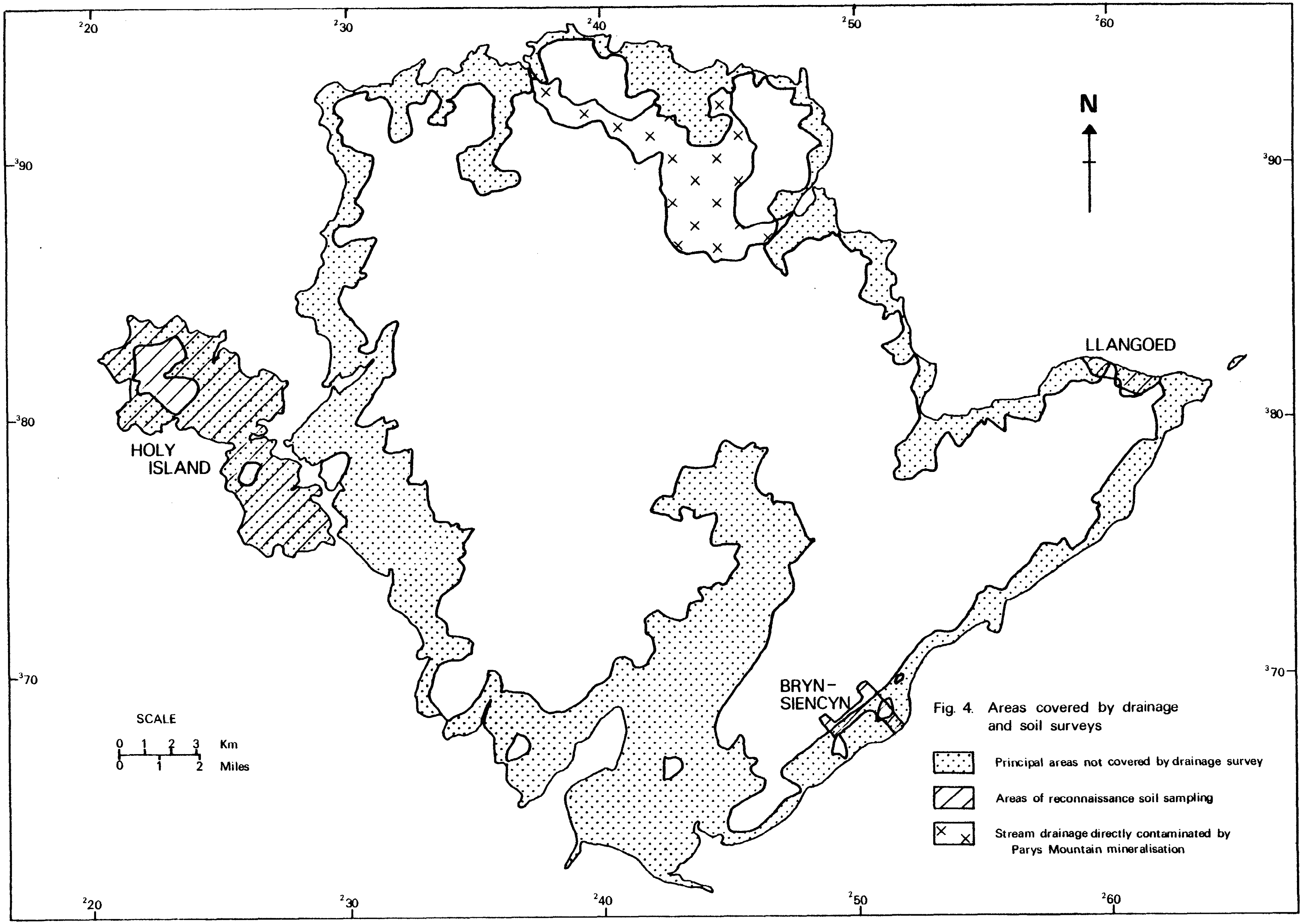


Fig. 4. Areas covered by drainage and soil surveys

The stream samples were collected using methods described in detail by Plant (1971), Leake and Aucott (1972), and Leake and Smith (1975). Briefly, water samples were collected in 30 ml polyethylene bottles, acidified in the field with 0.3 ml perchloric acid to prevent sorption of metals onto the container walls, and analysed for copper, lead and zinc by Atomic Absorption Spectrophotometry (AAS) without further sample preparation. Detection limits are approximately Cu and Zn 0.01 ppm, Pb 0.05 ppm. Stream sediments were wet-sieved at site to pass –8 mesh BSS (2 mm nominal aperture). In the laboratory the –8 mesh BSS sample was dried and sieved, and the –100 mesh BSS (0.15 mm nominal aperture) fraction finely ground prior to analysis. Copper, lead and zinc were determined by AAS following digestion of a subsample in boiling concentrated nitric acid for one hour. Other elements were determined by Optical Emission Spectrography (OES). Detection limits were approximately Cu 3 ppm, Pb 5 ppm, Zn 5 ppm, Fe_2O_3 1%, Mn 50 ppm, Ba 100 ppm, Zr 56 ppm, Co 2 ppm, Ni 4 ppm, and Mo 1 ppm. Panned concentrate samples (approx. 40 g) were made at site from 3-4 kg of the –8 mesh BSS fraction of the stream sediment. These were dried and split, and a 12 g subsample was ground in a tema mill for 15 mins with 3 g of 'elvacite' (Du Pont and Co's Polymethyl n-butyl methacrylate), before pelletising and analysis by X-ray Fluorescence Spectrometry (XRF) for the following elements (detection limits, in ppm given in brackets): Cu(6), Pb(13), Zn(3), Ba(27), Mn(6), Ni(5), Sn(9), Sb(11), Ce(21), Fe, Ca and Ti.

Elements determined in the drainage samples were chosen to include (a) those known to be associated with mineralisation in the area, (b) those which might be used as indicators of contamination, (c) those indicative of hydrous oxide precipitates, and (d) those which form concentrations in basic rocks. Where possible, elements indicative of the first three objectives were determined in both sediments and concentrates to aid interpretation of the results. Studies were made on all three drainage sample types to establish sampling and analytical variation by (a) duplicate sampling, (b) replicate analysis and (c) replicate sampling of the same site on a number of occasions. Appendix 4 contains details of the replicate sampling of a mildly contaminated background site from which an indication of the expected combined sampling and analytical variation can be obtained for all variables. Further information on the results of these studies will be presented elsewhere.

SOIL SAMPLES

Soil sampling, as a reconnaissance tool to supplement drainage coverage, was carried out on an experimental basis. On Holy Island 129 samples were collected on a north-orientated square grid at a spacing of 500 m. The whole island was covered except for two gaps caused by Holyhead town and the aluminium smelter at Penrhos. A few sites were displaced by up to 150 m because of buildings or the absence of soil. Near Bryn-Siencyn 46 samples were collected at 100 m intervals along three traverses and at Llangoed samples were collected on a rough north-orientated square grid at a spacing of 200 m (Figure 4). All the soil samples were collected from as great a depth as possible, using a 120 cm long hand auger. Each sample consisted of material from at least three holes made at the site within a radius no greater than one tenth of the distance between sites. Samples were dried and sieved, and a portion of the –85 mesh BSS (0.18 mm) fraction was taken for analysis. Analysis for Cu, Pb, and Zn was carried out by AAS following digestion in boiling concentrated nitric acid for at least one hour. Detection limits were approximately Cu 3 ppm, Pb and Zn 5 ppm.

INTERPRETATION OF DRAINAGE SAMPLE RESULTS

INTRODUCTION

Analytical results were screened by hand prior to computer processing. Results for Mo in stream sediment, Cu and Pb in water and Sb in panned concentrates were removed from the data matrix because most of results were below the detection limit of the analytical method. Results for Co and Ni in sediment were also removed because of the small range of over 95% of the results and limitations on data file size. Results for all the elements removed were treated manually and it was not possible to examine the inter-element relationships of these variables on a statistical basis.

Preliminary examination and manual plotting of the results indicated that high Sn and Sb results were solely the product of contamination because (i) there was a strong correlation of high values with probable sources of contamination and with contamination noted on field notes, (ii) the high values were not associated with areas where they might be expected from geological considerations and (iii) examination of panned concentrates containing high values under the microscope and by X-ray diffraction showed the presence of no definite natural Sn or Sb phases but abundant material derived from artificial sources.

Streams showing high levels of Sn and Sb were resampled in an attempt to reduce the effects of contamination on the results. The resample results were compared with the originals, and if the resample results showed appreciably lower Sn and Sb values the resample data were substituted for the original in the data matrix. If a less contaminated sample could not be obtained from the same section of stream the original results were retained since the sample might contain evidence of mineralisation as well as contamination.

A complete list of results is not presented but may be obtained on application to the Metalliferous Minerals and Applied Geochemistry Unit of IGS. A summary of the results is given in Table 2. In all statistical manipulations results below the detection limits have been treated as the value reported. Regional variation trends with the aid of contoured greyscale maps (Figures 18—34) are described in Appendix 5.

DISTRIBUTION ANALYSIS

Element distributions were determined from histogram and cumulative frequency plots following the methods of Lepeltier (1969), Parslow (1974) and Sinclair (1974, 1976). In the first instance data from the whole island was treated as a single sample population, and the resulting logscale cumulative frequency plots are shown on the contoured greyscale maps (Figures 18—34). The following types of plot were distinguished:-

(i) Approximately straight-line plots, indicating a near lognormal distribution, are shown by Mn, Co and Zr in sediments and Mn, Ti, Ca and Sn in panned concentrates. When examined in detail most of these plots show deviations from the straight line which suggest a weakly sigmoidal or more complex form; this is most evident in Ti in panned concentrates.

(ii) Apparently binormal ('dog-leg') plots, indicating the presence of two truncated lognormal distributions with little overlap, are shown by Cu, Zn and Ni in sediments and Pb, Zn, Ba and Ni in panned concentrates. Several of these may represent sigmoidal plots where one tail of the curve is not evident because of analytical imprecision, "stepped" results, or truncation by the detection limits.

(iii) Sigmoidal plots, indicating the presence of two sample populations, are shown by Pb in sediments and Cu and Fe in panned concentrates. The Pb and Cu distributions tend toward binormal form because the upper tail of the sigmoid is poorly developed, and consequently the upper population is difficult to define precisely.

(iv) Complex forms. Fe in sediment shows a distribution which is apparently a combination of a normally distributed lower population and a lognormal higher population. The true form may be more complex because of the poor analytical precision of this variable and truncation of the plot. Ti in panned concentrates and perhaps some other variables also tend toward this form.

(v) Indeterminate forms resulting from bottom truncation by the detection limit. This severely affected the following variables, with the percentage of samples at or below the detection limit given in brackets: Mo (95%) in sediment, Cu (95%), Pb (98%) and Zn (80%) in water, and Sb (80%) in panned concentrates. Less severely influenced are Sn (60%) in panned concentrates and Zr (17%) in sediments. The visible part of all these distributions is lognormal with the exception of Zn in water which shows a binormal plot. The plots of Mn, Fe, Co and Ni in sediment suffer from the small range of over 95% of the results compared with the analytical precision.

It is surprising that the total sample population plots are not more complex when the background geology is taken into account. This is attributed to: (i) elements determined being chosen primarily to reflect mineralisation and not background geology, (ii) the dominance of detrital sediments of broadly similar chemical composition, although of differing ages and degree of metamorphism, (iii) the smoothing effects of the drift cover from which most of the samples are derived, (iv) several overlapping populations may give rise to an apparently simple distribution, (v) a smoothing effect which can be produced by poor analytical precision and (vi) a simplification of the distribution which can be produced by truncation.

In order to try to simplify the more complex distributions and identify sub-populations, an attempt was made to sub-divide sample sites on the basis of catchment geology. This proved difficult for, with the exception of the Carboniferous Limestone, no rock type of strongly contrasting chemical composition to the non-basic pre-Carboniferous rocks occupied a sufficiently large area for a representative number of samples (50) to be identified. Even over the Carboniferous Limestone, problems were encountered from sites with catchments which contained other rock types and exotic drift cover. However, 61 samples with a Lower Carboniferous Limestone catchment were identified and cumulative frequency curves plotted. It was found that removal of the limestone sub-population did not simplify the distribution of the remaining samples. In the Lower Carboniferous group the majority of variables show approximately lognormal distribution but some, such as Pb, Ba and Ni in panned concentrates, have more complex (binormal or sigmoidal) forms. Therefore it was apparent that a limestone population was not a primary cause of the more complex total sample populations and, as this was the only readily separable sub-group, it was decided to treat all the data as a single group during statistical analysis.

Further examination of the element distributions indicated that binormal or sigmoidal plots are produced by elements (Cu, Pb, Zn and Ba) known to be associated with mineralisation on Anglesey. Assuming that the higher population of each variable is related to mineralisation it may be deduced that significant Pb and Ba but not Cu or Zn mineralisation is located within the Lower Carboniferous or its margins. The high Ni in panned concentrate population within the Lower Carboniferous sub-group is related to basic rocks near the margins east of Llangefni and pyritiferous

Table 2 Summary of analytical results on 439 stream sediments, waters and panned concentrates in ppm.

	Median	Mean	Standard deviation	Maximum	Minimum	Geo. mean	Geo. mean + geo. dev.	Geo. mean + 2 geo. dev.
Stream sediments								
Cu	15	42	194	3140	< 3	15	43	117
Pb	20	30	37	440	< 5	21	50	120
Zn	70	112	203	2000	< 5	69	169	416
Ba	320	356	250	4200	< 100	288	676	1580
Mo	<1	<1	-	2	<1	-	-	-
Co*	13	14	8.4	75	2	12	23	43
Ni*	24	23	20	320	4	20	33	55
Mn	750	1380	1760	22700	130	933	2090	4680
Zr	100	112	108	1000	<56	49	316	2040
Fe_2O_3%	5.6	4.9	2.83	42.0	1.0	4.0	6.6	10.8
Stream waters								
Cu	<0.01	-	-	16.6	<0.01	-	-	-
Pb	<0.05	-	-	0.07	<0.05	-	-	-
Zn	<0.01	-	-	>30	<0.01	-	-	-
Panned concentrates								
Cu	10	69	295	4500	<6	12	62	323
Pb	25	166	685	9100	<13	33	144	630
Zn	80	145	428	6800	15	85	177	371
Ba	220	446	1460	19700	40	234	512	1120
Fe	37400	46100	34200	267700	2900	38000	70700	131000
Mn	540	648	49	4200	55	524	977	1820
Ni	55	62	51	740	9	51	91	162
Ti	2600	3380	3140	33700	210	2690	5250	10200
Sn	<9	47	138	1300	<9	<9	47	309
Sb	<11	-	-	310	<11	-	-	-
Ca	8500	13800	18600	147800	1100	8700	23200	52500

* Results on 386 samples

basal sediments along the Afon Lligwy.

The two elements whose visible distributions are considered to be the products of contamination show lognormal form (Sn and Sb). The majority of elements concentrated in basic rocks (Ti, Co, Mn and Ca) show approximately lognormal forms which are more complex in detail; this is attributed to a small contribution to the sample population from a basic and ultrabasic rock population. The complex distribution of iron in sediment is related to a combination of all these factors and hydrous oxide precipitates.

ELEMENT ASSOCIATIONS

Inter-element relationships were examined by means of correlation, cluster and factor analysis of the complete data-set (Davis, 1973). The data-set was log-transformed prior to analysis, but because of the imperfect lognormal form of many variables, the data formed a theoretically unsound basis for parametric statistics and therefore, even allowing for a certain robustness in the methods, the greatest caution had to be exercised in interpreting the results.

The Pearson-product moment correlation matrix is shown in Table 3. With such a large sample population, theoretical significance levels are low (99% = 0.11) but for the reasons outlined above spurious results could be expected and only very high significance levels were considered to be useful. The correlation matrix was used as a basis for cluster analysis (Figure 5) and consequently only high level clusters were relied upon. Factor analysis, as might be expected, showed similar inter-element relationships to the other methods; trial and error indicated that a six-factor model (Table 4) accounting for 73% of total variation provided the best expression of the likely sources of variation.

Regional variation maps (Appendix 5, Figures 18—34), mineralogical work (see below) and inter-element relationships indicated that the major sources of variation in the data-set were related to:

(i) Base-metal mineralisation. Expressed by the association of Cu, Pb and Zn in sediment and Cu, Zn and Fe in panned concentrates. This is the dominant source of variation in the data-set and much of it is related to the Parys Mountain mineralisation. It shows clearly as factor one (Table 4) where it is associated with Fe and Mn in sediments, the result of hydrous oxide precipitates in streams draining Parys Mountain. The absence of Pb in panned concentrate from factor one and the lack of a tie between Pb in sediment and the other 'mineralisation elements' on the dendrogram (Figure 5) is a result of distortion and the large amount of Pb associated with contamination.

(ii) Basic and ultrabasic rocks. Expressed by the association of Mn, Ti, Fe, Ca and Ni in panned concentrates and Mn and Fe in sediments. This does not show very clearly on the dendrogram because some of the elements are also associated with mineralisation but it is clearly defined by factor two of the six factor model.

(iii) Detrital sedimentary rocks. Expressed by variation in Zr. In this data-set it represents a relatively minor source of variation because other elements concentrated in these rocks (Rosler and Lange, 1972) were not determined.

(iv) Contamination. Expressed by Pb, Sn and Sb in panned concentrates, it shows up as a clear grouping on the dendrogram and as factor four of the six-factor model, where the additional presence of Cu, Zn and Fe in panned concentrates suggests that some of their variation is caused by contamination. High values of Sb in panned concentrates coincide with high Pb and Sn contents.

(v) Baryte and potash feldspar. Expressed by Ba in sediments and panned concentrates, which do not show strong associations with any other variables. Small baryte veins are recorded in the basal Carboniferous and nearby Mona complex rocks between Dulas and Trefdreath (Figure 3) and the association reflects these and possibly other unknown occurrences. Ba shows its most significant correlation with Fe and this may be an expression of pyritiferous rocks in the basal Carboniferous or basic rocks in the Mona complex. High Mo results may also be related to the basal Carboniferous, but results above the detection limit are too few to be certain. Moderately high Ba values are related to potash feldspar bearing rocks such as the Coedana granite and hornfels. The negative association of Ca with Ba is not regarded as significant in this context, as most other elements are also negatively correlated with Ca (Table 3).

(vi) Limestone. A clear grouping of elements outlining the limestone outcrops by high values is not found because no suitable variables were determined; calcium in panned concentrate emphasises the presence of lithologies containing heavier calcium bearing minerals, such as garnet and hornblende, rather than calcite. However, the limestone area is clearly delineated as a negative feature by factor three and a wide range of variables.

(vii) Aqueous systems. Zinc in water shows no close relationships with other elements, this may be because it was the only element determined in water included in the data-matrix, or because of the truncated distribution. The factor analysis shows an association with nickel in panned concentrates, which is not readily explained in geological terms, and a negative relationship with manganese which may be a reflection of hydrous oxide precipitation from groundwater.

DEFINITION OF ANOMALIES

Threshold levels were obtained and the anomalous samples subdivided into classes by a combination of cumulative frequency curve analysis and percentile division (Table 5).

For elements showing an approximately log-

Table 3 Correlation matrix of log-transformed drainage data.

		Sediments							Panned concentrates									
		Cu	Pb	Zn	Ba	Fe	Mn	Zr	Cu	Pb	Zn	Ba	Fe	Mn	Ni	Ti	Sn	Ca
Panned concentrates	Ca	-0.20	-0.07	-0.25	-0.29	-0.11	-0.08	-0.11	0.01	0.06	-0.09	-0.11	0.21	0.22	0.29	0.21	-0.02	1.00
	Sn	0.16	0.30	0.19	-0.04	0.05	-0.02	0.06	0.33	0.51	0.31	0.05	0.23	0.02	0.03	0.06	1.00	
	Ti	0.14	0.06	0.23	0.18	0.33	0.20	-0.03	0.17	0.17	0.26	0.34	0.56	0.51	0.27	1.00		
	Ni	0.26	0.24	0.19	-0.06	0.26	0.02	-0.17	0.28	0.22	0.41	0.19	0.49	0.30	1.00			
	Mn	0.37	0.28	0.43	0.19	0.43	0.68	0.03	0.36	0.20	0.45	0.37	0.65	1.00				
	Fe	0.50	0.31	0.46	0.12	0.47	0.33	0.04	0.59	0.39	0.64	0.45	1.00					
	Ba	0.31	0.26	0.28	0.41	0.28	0.28	0.08	0.35	0.19	0.34	1.00						
	Zn	0.73	0.54	0.76	0.17	0.51	0.27	0.04	0.65	0.44	1.00							
	Pb	0.25	0.37	0.26	0.02	0.11	0.03	0.08	0.42	1.00								
	Cu	0.63	0.43	0.51	0.16	0.41	0.19	0.09	1.00									
Sediments	Zr	0.03	0.10	0.59	0.19	0.20	0.11	1.00										
	Mn	0.32	0.28	0.47	0.31	0.40	1.00											
	Fe	0.59	0.35	0.61	0.45	1.00												
	Ba	0.25	0.09	0.28	1.00													
	Zn	0.78	0.57	1.00														
	Pb	0.55	1.00															
	Cu	1.00																

$n = 440$

$r_{99.95\%} = 0.15$

Table 4 R-mode, six-factor loading graph for log-transformed drainage data.

Loading \ Factor	1	2	3	4	5	6
+0.9	Cu_s Zn_s					Zr_s
+0.8				Sn_p	Zn_w	
	Zn_p		Ba_s	Pb_p		
+0.7	Pb_s		Ba_p			
	Fe_s					
+0.6	Cu_p					
+0.5						
	Mn_s				Ni_p	
+0.4	Fe_p Mn_p			Cu_p		
			Fe_s Ti_p	Zn_p		
+0.3	Ni_p			Fe_p		Mn_s
	Pb_p			Pb_s		Fe_s
+0.2			Fe_p	Ba_p		Ba_s
	Ba_s Ba_p		Cu_s Zn_s Cu_p			
+0.1					Ca_p	
-0.1						
		Pb_p			Zn_s	
-0.2		Cu_p Zn_p			Mn_p	
	Ca_p	Fe_s		Mn_s		
-0.3		Ba_p				Ni_p
-0.4		Mn_s				
		Ni_p	Ca_p		Mn_s	
-0.5						
-0.6		Ca_p				
		Fe_p				
-0.7						
		Ti_p				
-0.8		Mn_p				
-0.9						
Σ% total var.	33	44	54	61	67	73

Clustering truncated at 99.9% confidence level for r

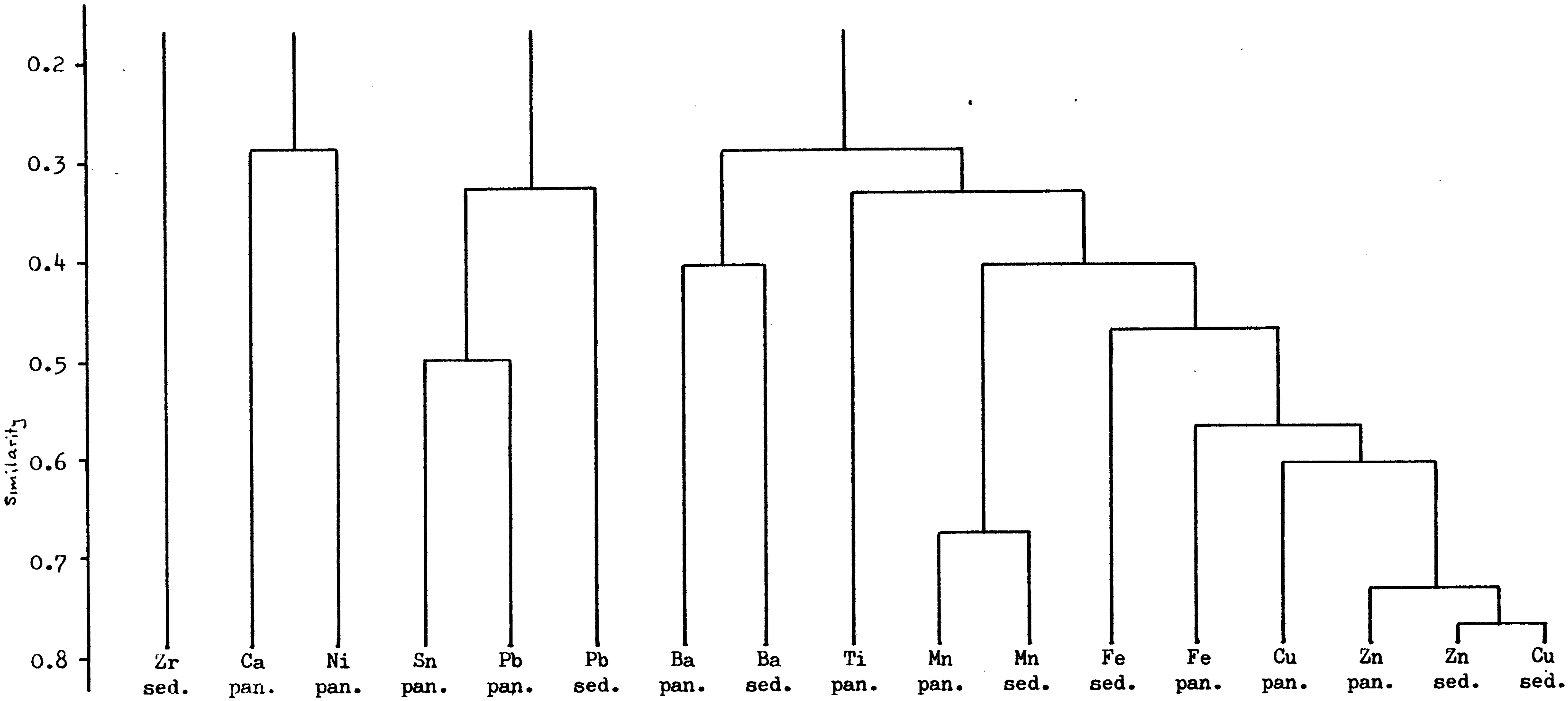


Fig.5. R-mode cluster analysis: dendrogram based on correlation coefficients.

normal distribution (Ba, Mn, Zr and Co in sediment, and Ca, Mn and Ti in panned concentrates), and hence no clearly defined separate population of high values, the threshold was set at the 97½ percentile level, equivalent to the mean plus two standard deviations for a perfect lognormal distribution. The threshold for elements showing a binormal distribution (Cu, Zn and Ni in sediment, Zn in water, Pb, Zn, Ba and Ni in panned concentrates) was set at the break point on the 'dog-leg' plot (Lepeltier, 1969; Parslow, 1974); these values are printed bold in Table 5. For the three variables showing sigmoidal distributions (Pb in sediment, Cu and Fe in panned concentrates), the threshold was set where the curve starts to deflect markedly from the well-defined lower (background) population because two of the plots (Pb in sediment, Cu in panned concentrate) were near binormal and the upper population could not be clearly defined. These values are printed in italics in Table 5. A consequence of this definition is that the lower anomaly classes contain a mixture of two populations with a significant proportion of background samples. For example, the threshold for Fe in panned concentrate is set at 7.5% Fe which is about the 90% level of the lower population and 20% level of the upper. However, at 16% Fe virtually all samples belong to the upper population as this is approximately the 99.99% level for the lower population. For Fe_2O_3 in sediment, the most complex sample population, the threshold was arbitrarily set at the 97.5 percentile level.

The visible parts of both the Sb and Sn in panned concentrate distributions were lognormal but their thresholds were set lower than the 97.5% levels because of their role as indicators of contamination. It was considered that naturally occurring background amounts of both elements would be close to or below the 3σ detection limits (Sn 13 ppm, Sb 16 ppm) and so all values above these levels were considered anomalous and likely to indicate contamination.

Other elements with a very high proportion of results below the detection limits (Mo in sediment, Cu and Pb in water) had indeterminate distributions and it was arbitrarily decided to treat all values greater than the detection limits (Mo 1 ppm, Cu 0.01 ppm, Pb 0.05 ppm) as anomalous.

Above the threshold level, anomalies were subdivided into classes based on the 90, 95, 97.5 and 99 percentile levels (Table 5) which were used in plotting anomaly maps (Figures 6–13).

THE CONTAMINATION PROBLEM AND DEFINITION OF ANOMALOUS AREAS

Four methods were used to distinguish anomalies caused by contamination from those related to mineralisation.

(i) Field observation. All anomalous results were plotted on 1:25 000 maps, and anomalies clearly derived from the old workings at Parys Mountain were removed from further consideration. Field notes were examined and all sites were plotted at which (a) sulphides were seen in panned concentrate, (b) some other indication of mineralisation was noted, or (c) appreciable contamination was reported. All the larger (>95% level) and many of the smaller anomalies were briefly examined in the field and in several cases the streams resampled.

This approach, if used in isolation, proved ineffective, except for distinguishing anomalies related to old mine workings or infill derived from them. This was because an obvious source of contamination near the sample site was often not sufficiently corroded to contribute significantly to the sediment sample, whereas decomposed material may be present in an apparently clear stream.

(ii) Mineralogical examination of panned concentrates. When, after field examination, there was some doubt as to whether an anomaly was the product of contamination or bedrock mineralisation, the panned concentrate from the site was submitted for mineralogical examination. A brief outline of the methods used is given in Appendix 6.

Samples from 56 sites were investigated mineralogically. The ore minerals found were sphalerite, smithsonite, galena, chalcopyrite and baryte. A wide range of contaminants were found, including lead glass, basic lead carbonate ('white lead'), solder, lead metal, lead-antimony alloys, tin oxide (from tinplate or glazes), bronze or brass, copper wire and galvanised iron. Two important general conclusions were drawn from this work: (a) that the presence of appreciable Sb in the analysis was a reliable indication of lead contamination, and (b) the contaminants occurred at similar grain sizes to the natural phases in the sample and therefore could not be reduced or eliminated by screening.

Mineralogical examination was the most sensitive and reliable method of identifying the source of anomalies but suffered from some disadvantages, namely the difficulty of distinguishing minerals derived from an old mine from those of an unknown deposit, the time-consuming nature of the investigation, and subsampling problems.

(iii) Factor analysis. Factor scores from factor 1 (base metal mineralisation), factor 3 (barium mineralisation) and factor 4 (contamination) of the six-factor model (Table 4) were plotted and contoured manually in an endeavour to delineate areas where variation due to mineralisation or contamination were dominant (Figures 14–16). Factor 2 scores were not plotted because although they reflect basic rocks the low loadings on Co and Ni make it unlikely that high scores would indicate any concentrations of economic value. It may also be implied that such concentrations are unlikely to exist in areas covered by the drainage survey. Similarly factors 5 and 6 were not considered to be of direct economic significance.

Table 5 Threshold levels and class intervals for anomalous results. See text for explanation. Values are in ppm except where otherwise stated.

Variable	Percentile level (approx.)				
	<90%	90%	95%	97.5%	99%
Sediments					
Cu			45	251	891
Pb	*41*	51	71	131	201
Zn		191	301	551	1401
Ba				651	901
Fe_2O_3%				8.5	12
Mn				5501	7501
Co				31	35
Ni				41	71
Zr				351	501
Panned concentrates					
Cu	*61*	81	201	901	1301
Pb	41	221	601	1501	3651
Zn	121	181	301	951	1501
Ba		451	731	2101	9501
Fe		*7.5*	11.6	16.1	20.3
Mn				1901	3001
Ni				141	251
Ti				9501	15001
Sn	13	91	251	471	751
Sb			16	36	91
Ca%				6.5	12.0
Water					
Zn				0.06	10.1

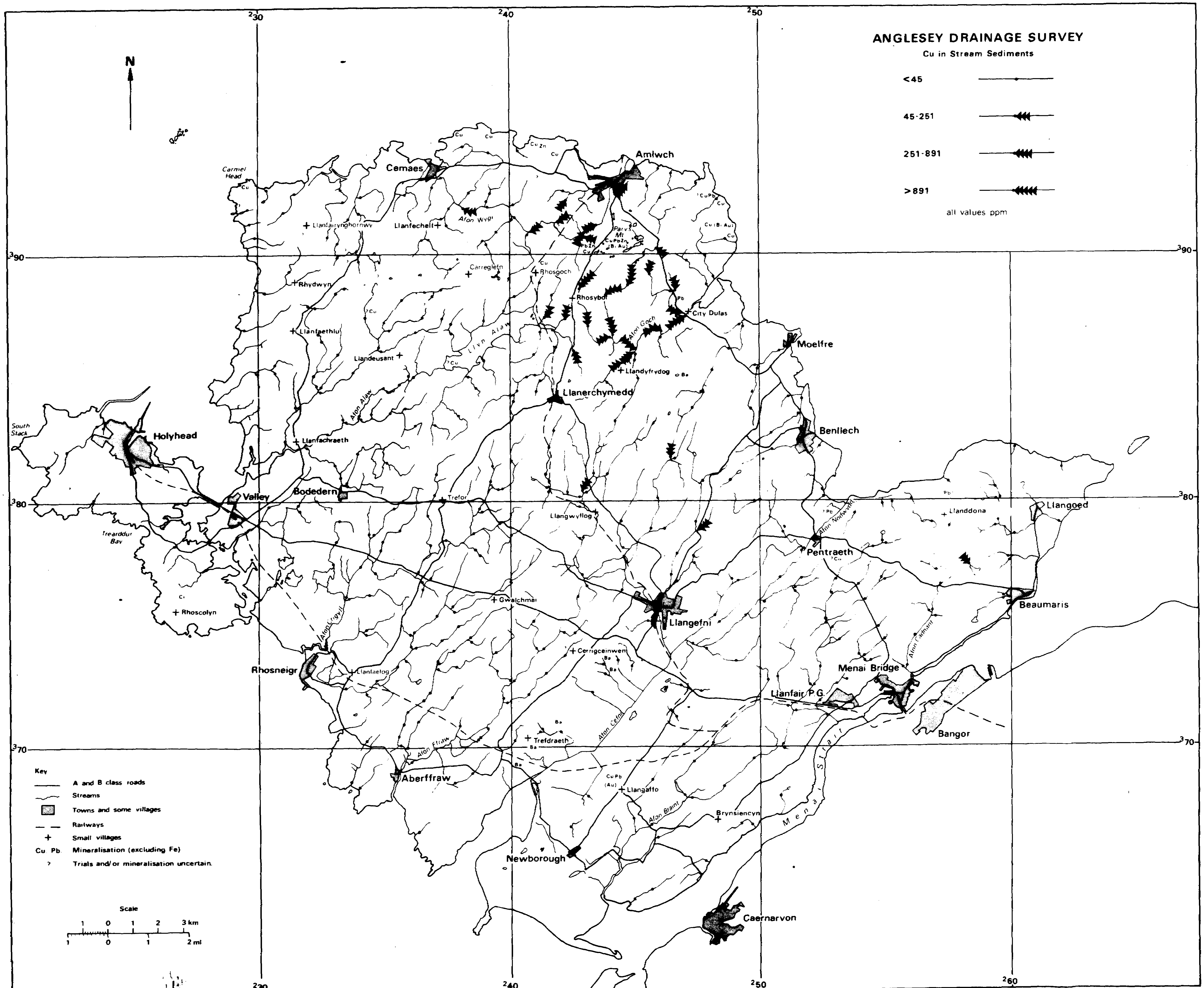


Fig.6 Distribution of anomalous levels of copper in stream sediments

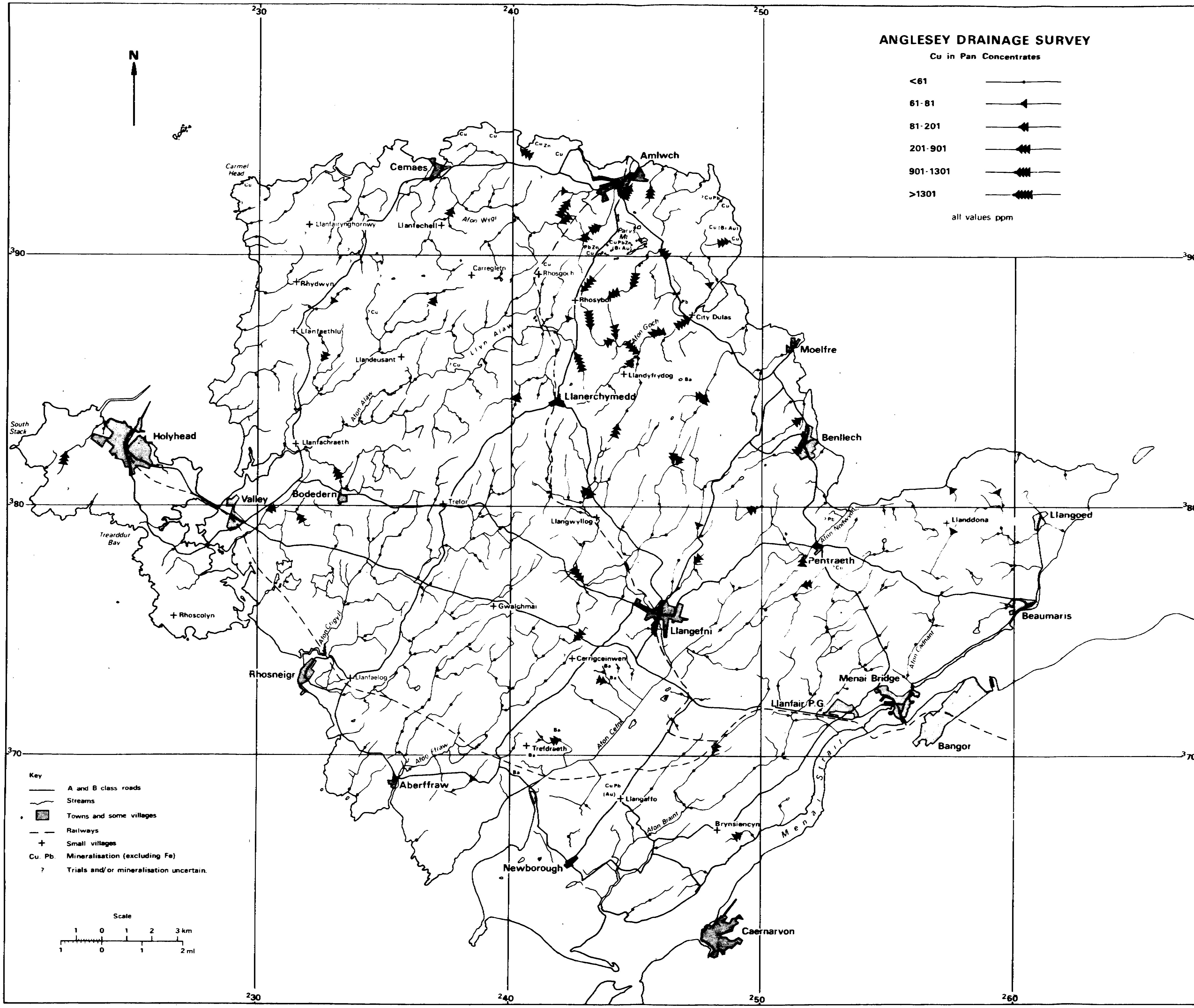


Fig. 7 Distribution of anomalous levels of copper in pan concentrates

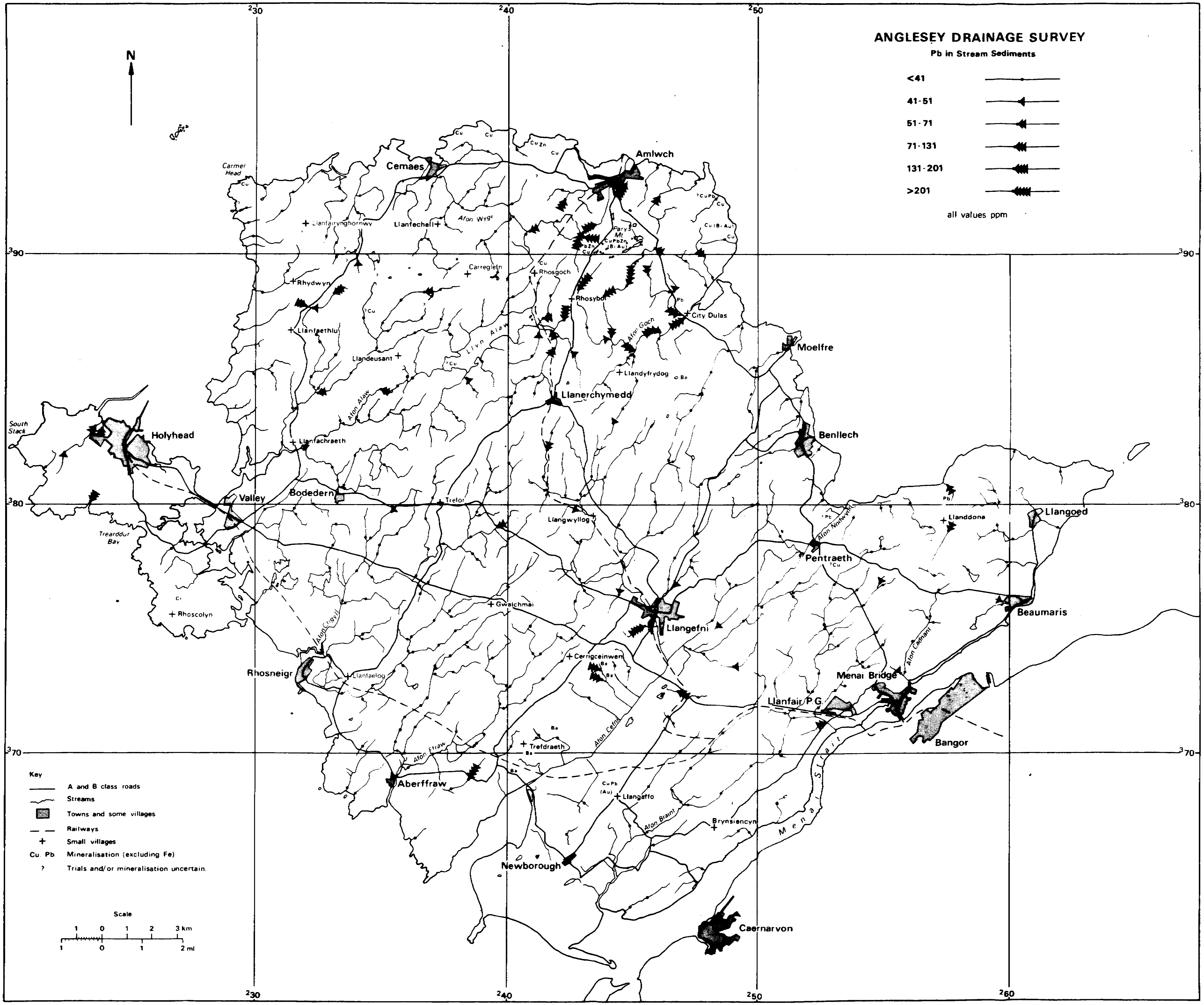


Fig. 8 Distribution of anomalous levels of lead in stream sediments

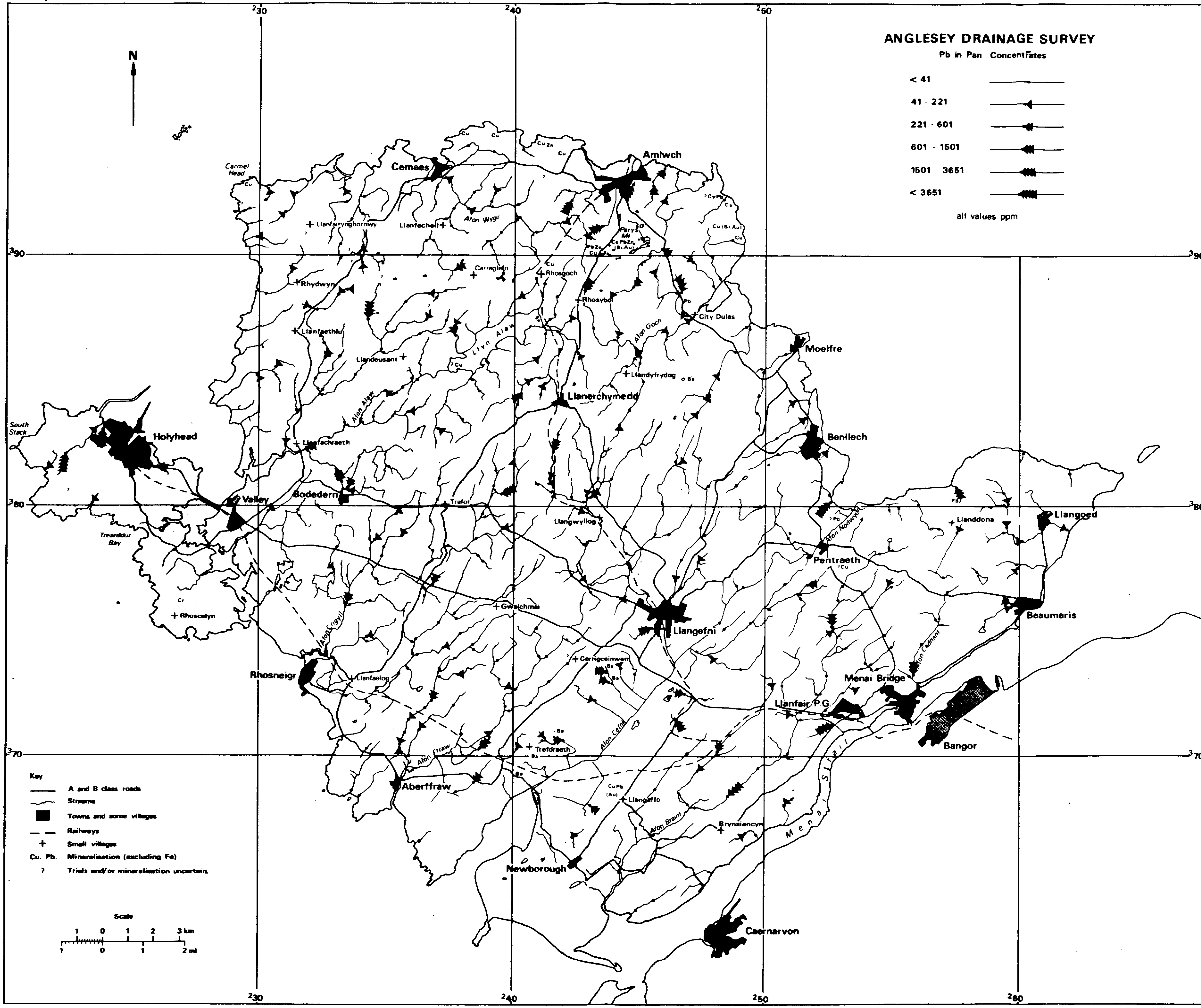


Fig. 9 Distribution of anomalous levels of lead in pan concentrates

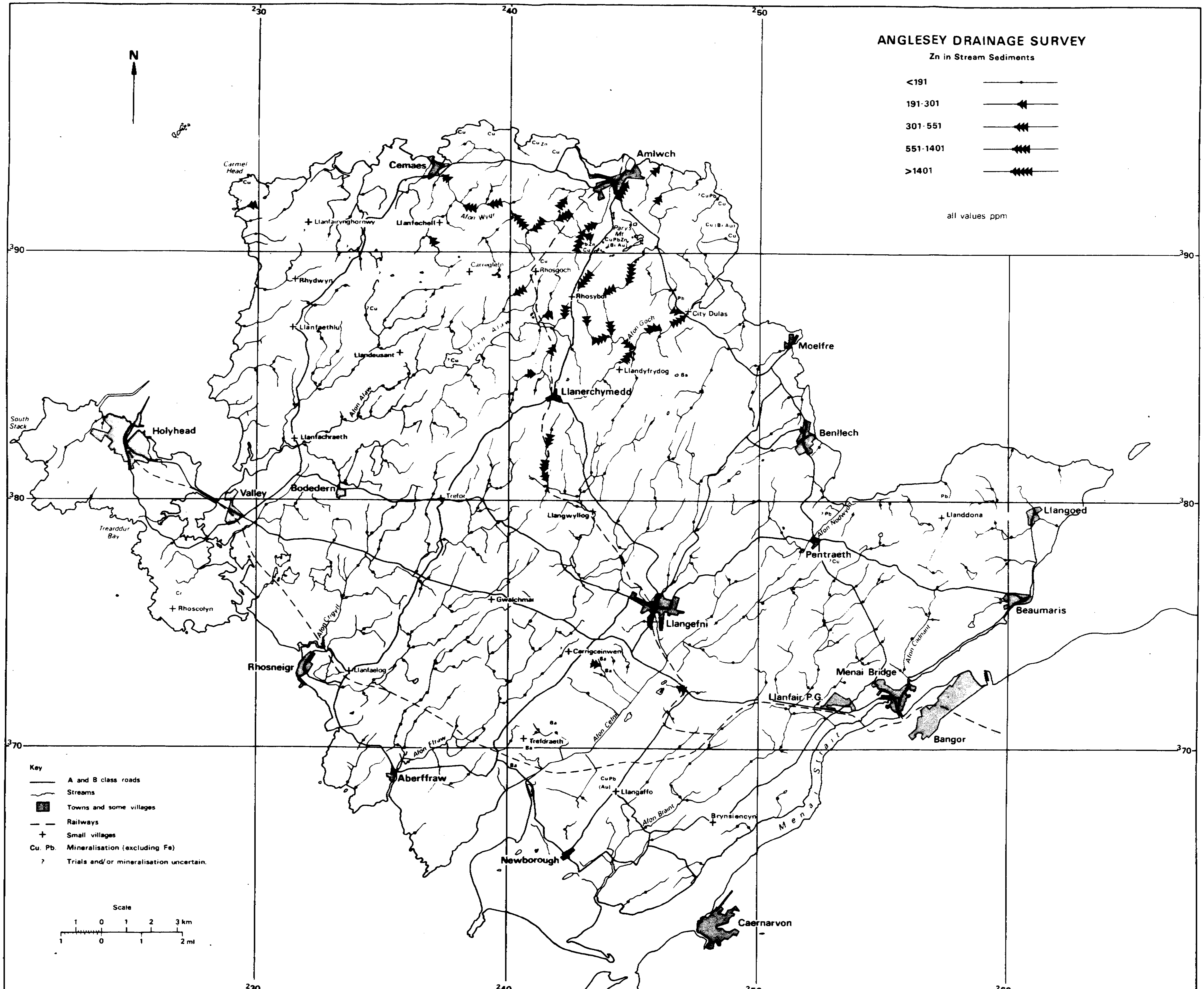


Fig. 10 Distribution of anomalous levels of zinc in stream sediments

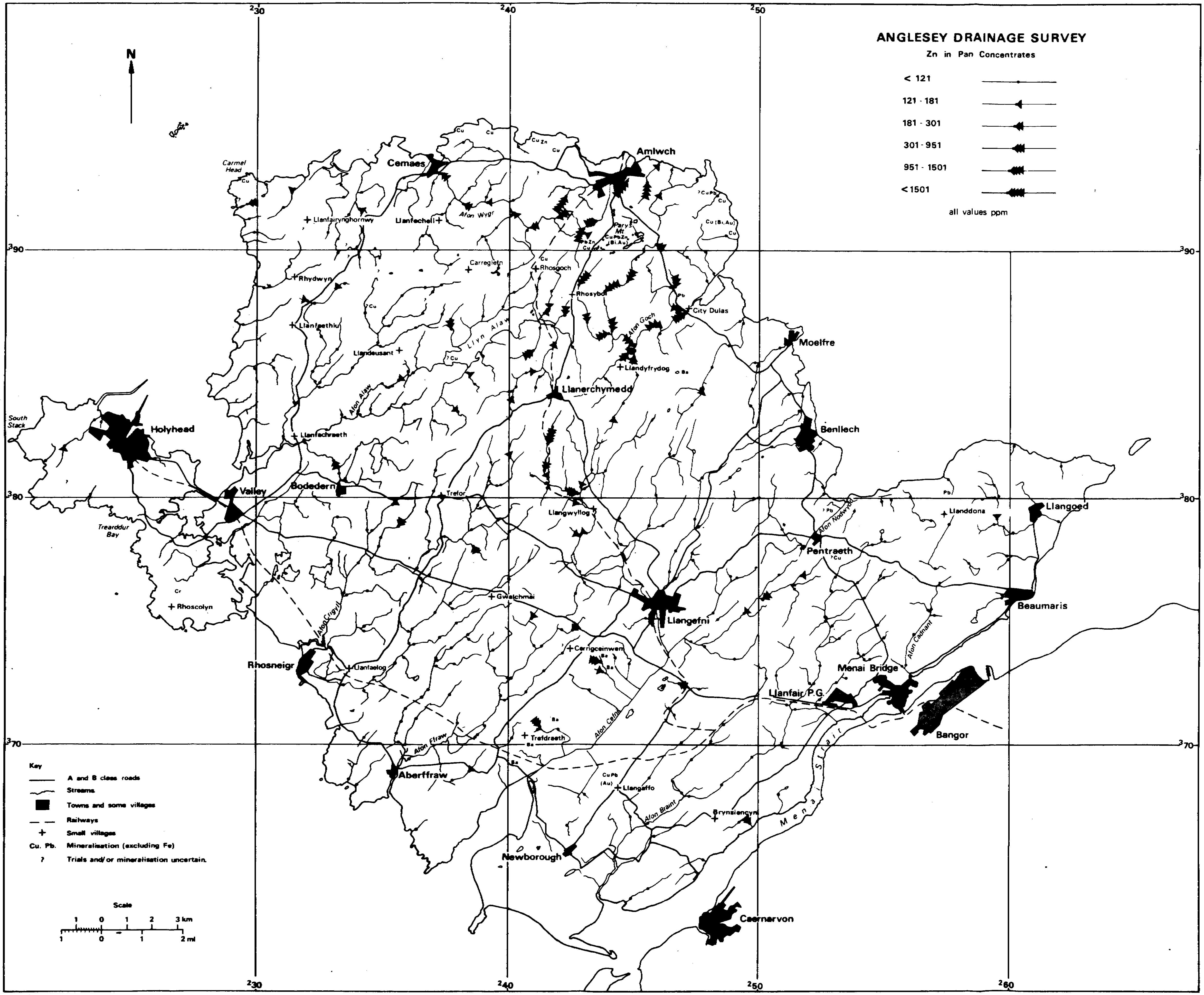


Fig. 11 Distribution of anomalous levels of zinc in pan concentrates

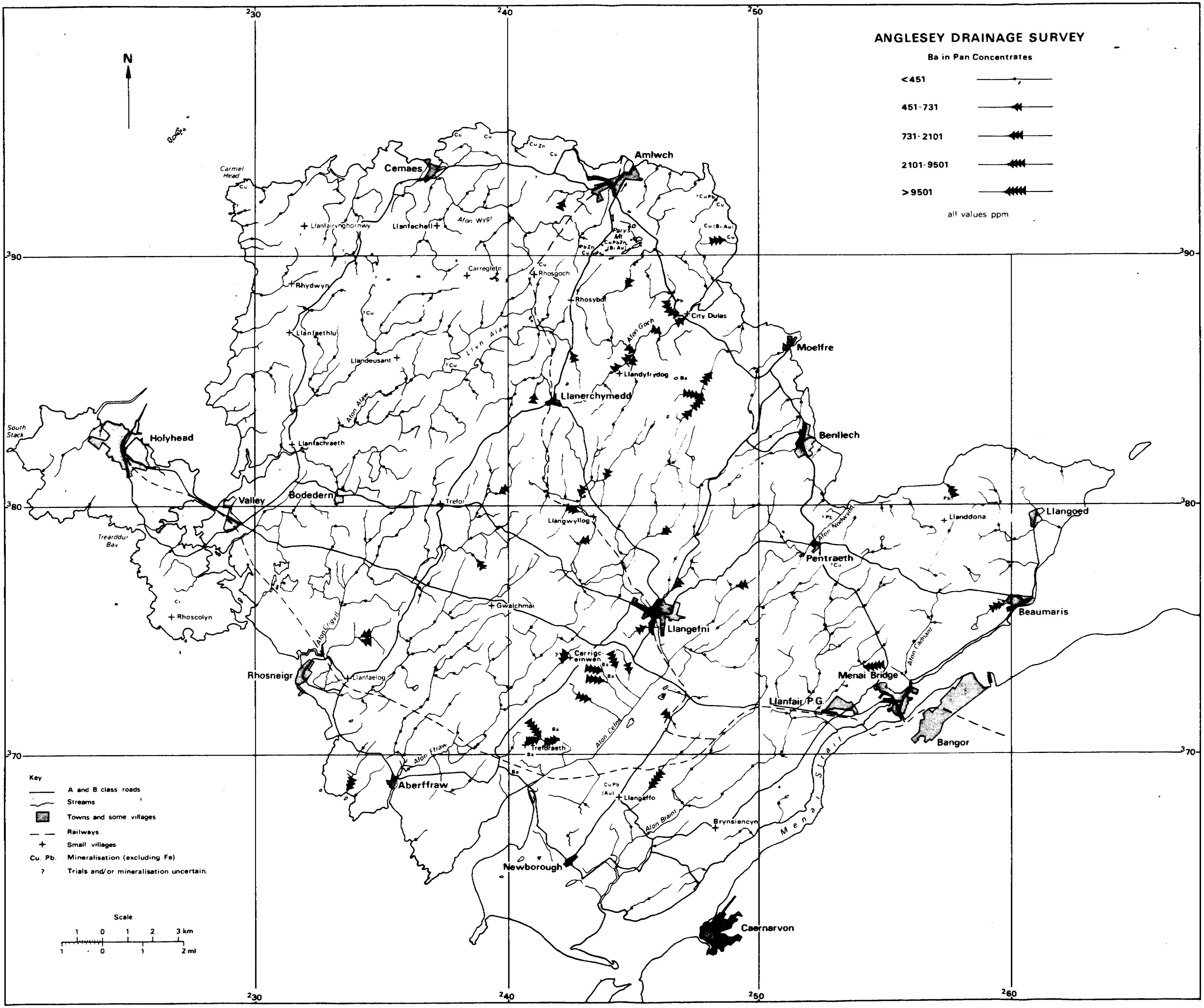


Fig. 12 Distribution of anomalous levels of barium in pan concentrates

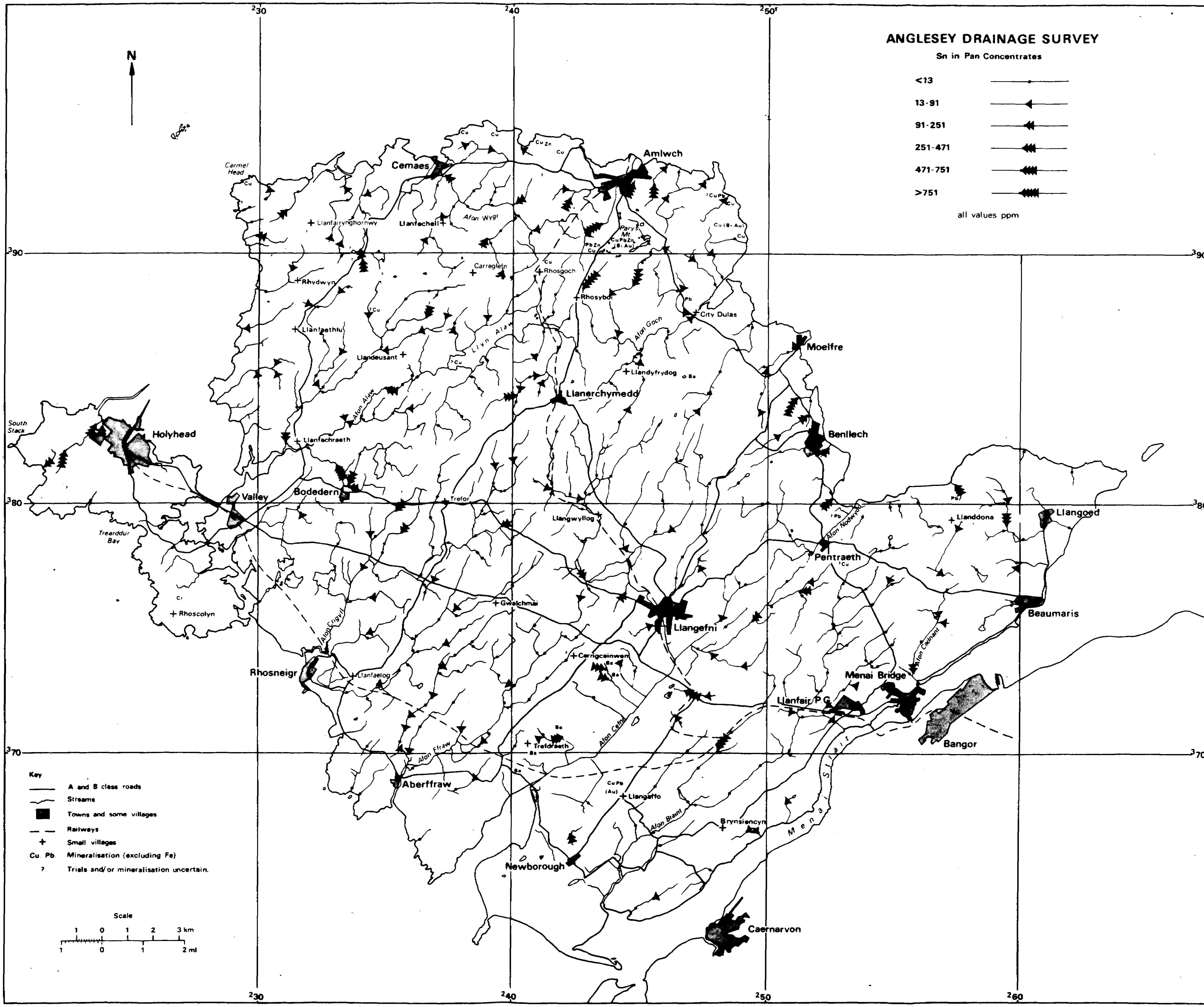


Fig. 13 Distribution of tin in pan concentrates

Factor 1 element loadings and plots (Figure 14) show that high factor scores are related principally to base metal mineralisation at Parys Mountain, and therefore high values in other areas of Anglesey suggest the presence of similar mineralisation. However, in the streams draining Parys Mountain heavy iron and, to a lesser extent, manganese precipitates are found which gives iron in sediment a heavy loading in factor one; this results in anomalies caused by secondary iron and manganese precipitates unrelated to mineralisation also giving relatively high factor one scores. Hence high factor one values may be (a) related directly to base metal mineralisation, (b) indirectly related to mineralisation via secondary precipitates from acid stream and groundwater derived from mineralisation, or (c) unrelated to mineralisation, the precipitates being generated from a background source. The lack of acid, peaty environments means that the latter possibility can be discounted in most areas.

Factor 3 (Figure 15) is dominated by barium, and comparison with mineralogical results (Table 6) indicates that factor scores above about 0.6 strongly suggest the presence of baryte. Lower levels are related to potash-feldspar bearing rocks. The low loadings on Ti, Fe, Cu and Zn variables express the weak association of baryte with basic rocks and sulphides. High factor 3 scores suggest the presence of a mineralisation which is different from that found at Parys Mountain and characterised by the presence of baryte. This conclusion agrees with the work of Thanasuthipitak (1974) on the Parys Mountain deposit who suggested that the main base metal mineralisation was followed by a later hydrothermal remobilisation characterised by the more volatile elements such as Hg but including Ba and Cu.

Factor 4 is dominated by Sn and Pb in panned concentrates. Regional variation plots (Figure 16) and mineralogical results show that it is principally produced by variation caused by contamination. The significant loadings on Cu, Zn and Fe in panned concentrates in this factor indicate that these elements are also involved in contamination, a conclusion which is supported by field observations and mineralogical work (Table 6). However, although the widespread occurrence of lead as a contaminant in solder, lead glass, batteries and white lead dominates its variation in streams on Anglesey, it also occurs naturally and hence old mines containing galena also show up in this factor. This effect is enhanced by the dumping of rubbish in old mines, which results in the production of Sn anomalies as well.

The results of this method were compared with those obtained from mineralogical examination (Table 6; samples in which high values were related to basic rocks by both factor analysis and mineralogy have been omitted for clarity). The agreement between factor analysis and mineralogy was good, both methods managing to identify mixed anomalies. Therefore, bearing in mind the likely causes of factor loadings, superimposed contoured plots of factors 1, 3 and 4 were used to indicate the origins of anomalies.

Using computers, factor analysis is a rapid method and proved able to provide information on samples where the results of mineralogical examination were unhelpful because firstly, either no sample or only an unrepresentative panned concentrate subsample remained after analysis or, secondly, the anomalous metal was not readily attributable to a definitive mineral. Because of the role of Sn and Pb old mines tended to show as areas of contamination but in one sense this was correct. In areas where mineralisation and contamination are not so prominent, a clear factor analysis model is unlikely, and the technique could not be applied in areas containing Sn and Sb mineralisation. Even in the Anglesey data the split of variance was imperfect and a few anomalies which mineralogy indicated as entirely due to contamination produced weak factor 1 highs. Also areas not directly related to mineralisation but to iron precipitates showed prominently on factor 1 plots.

(iv) Simple statistical methods. Linear regression and manual plots proved unreliable, as did plots of regional trends eliminating samples with high Sn and/or Pb contents. This was because contamination was often present in the absence of Sn, and a linear model proved ineffective at distinguishing mixed anomalies.

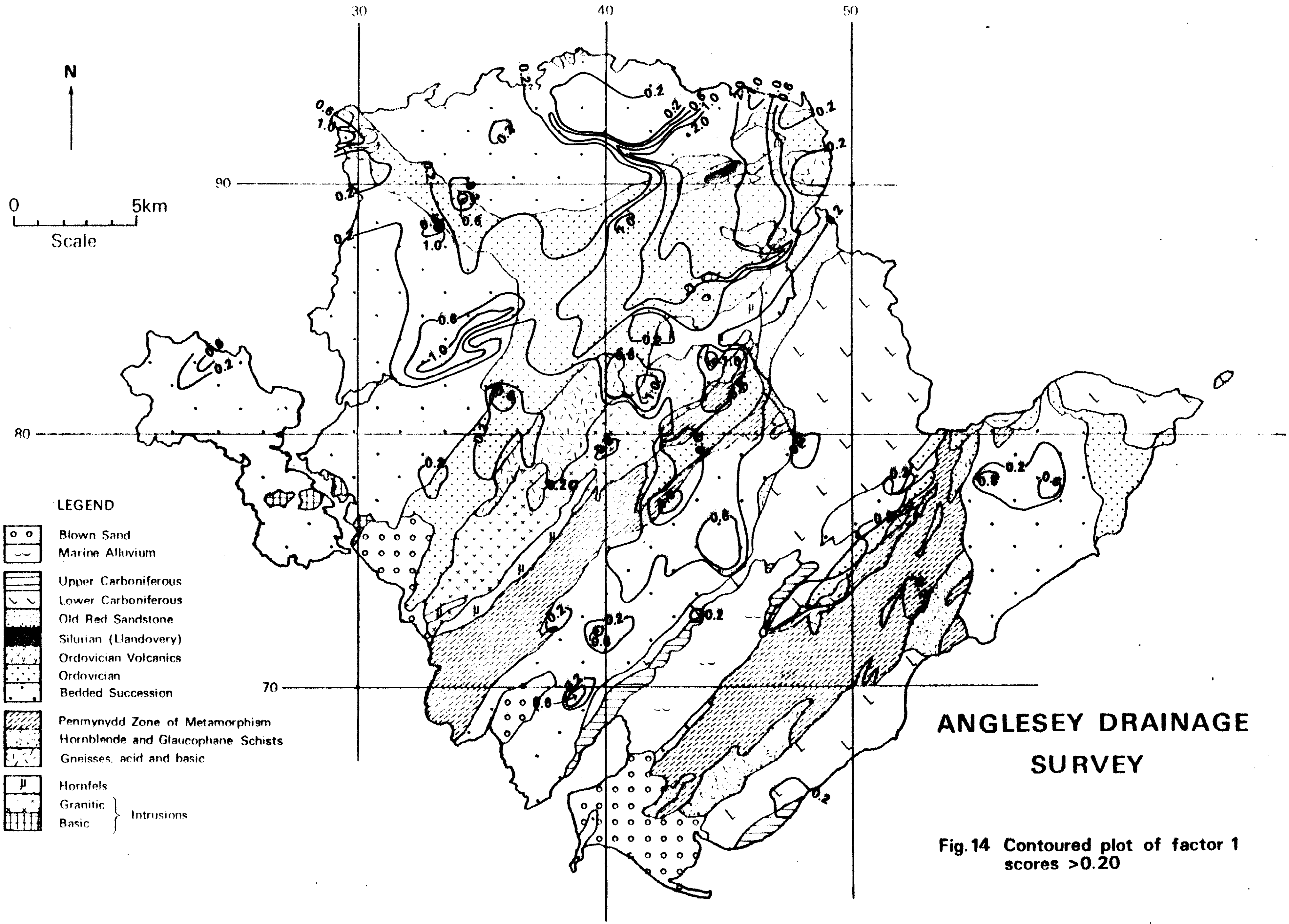
It was concluded that the best approach to the contaminated drainage problem in terms of time and effort was to combine factor score plots with the mineralogical examination of selected samples. Quarfort (1977) describes an alternative method of overcoming stream contamination, involving the drilling of boreholes parallel to the flow in the banks of the stream, but it is suggested that the methods used on Anglesey are no more time consuming and likely to yield more information on any target area than the bank sampling approach.

SOIL SAMPLING RESULTS

The areas from which soil samples were collected are shown in Figure 4. Histograms were plotted and summary statistics calculated for the results from all three areas (Table 7).

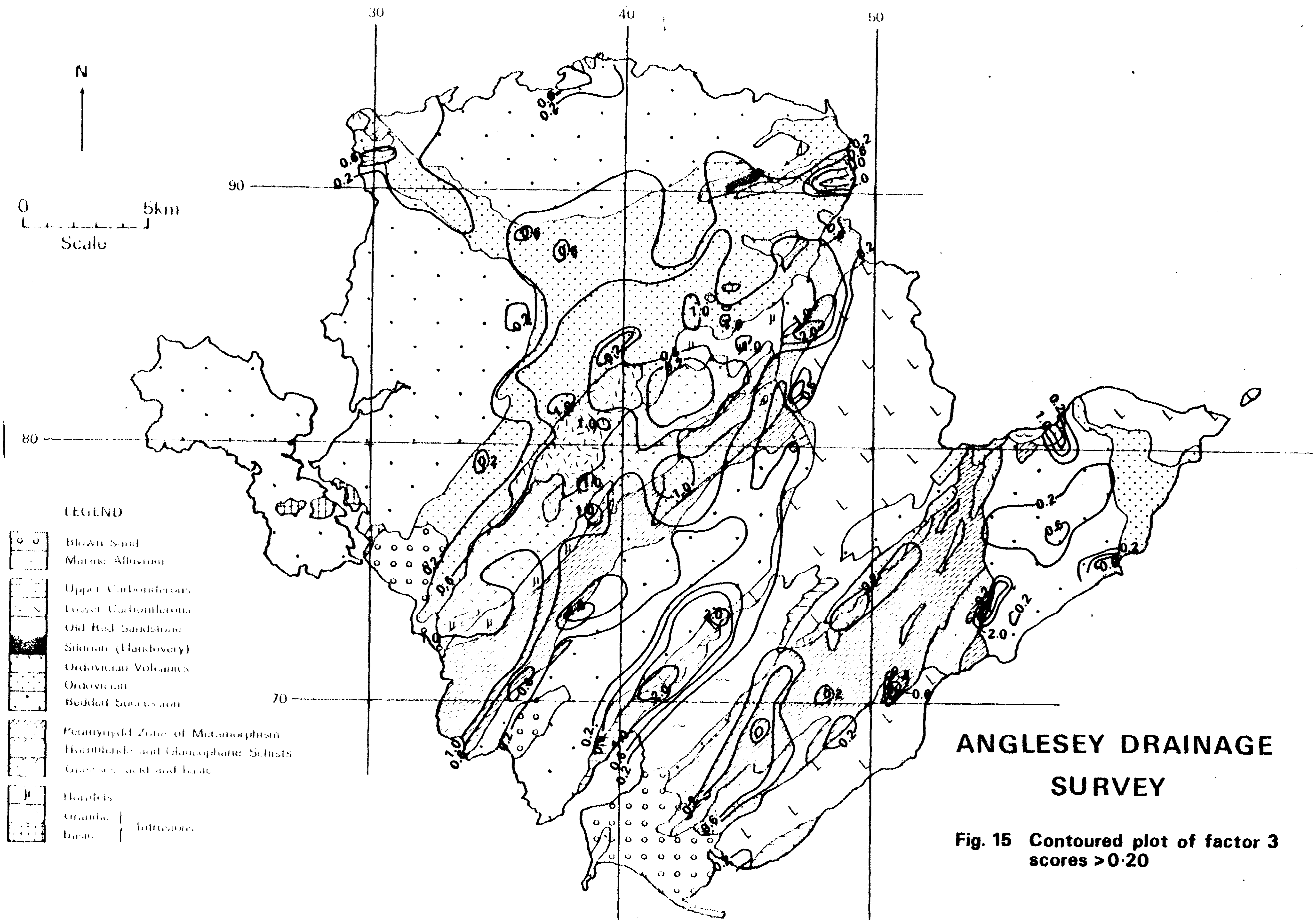
LLANGOED

The small number of samples and the limited range of the results prevented determination of the element distributions. It was clear, however, from the maximum values and absence of "outliers" in the Pb and Zn distributions that none of the results were distinctly anomalous. The maximum Cu value of 40 ppm, collected from SH 6082 8140,



ANGLESEY DRAINAGE SURVEY

Fig. 14 Contoured plot of factor 1 scores >0.20



ANGLESEY DRAINAGE SURVEY

Fig. 15 Contoured plot of factor 3 scores >0·20

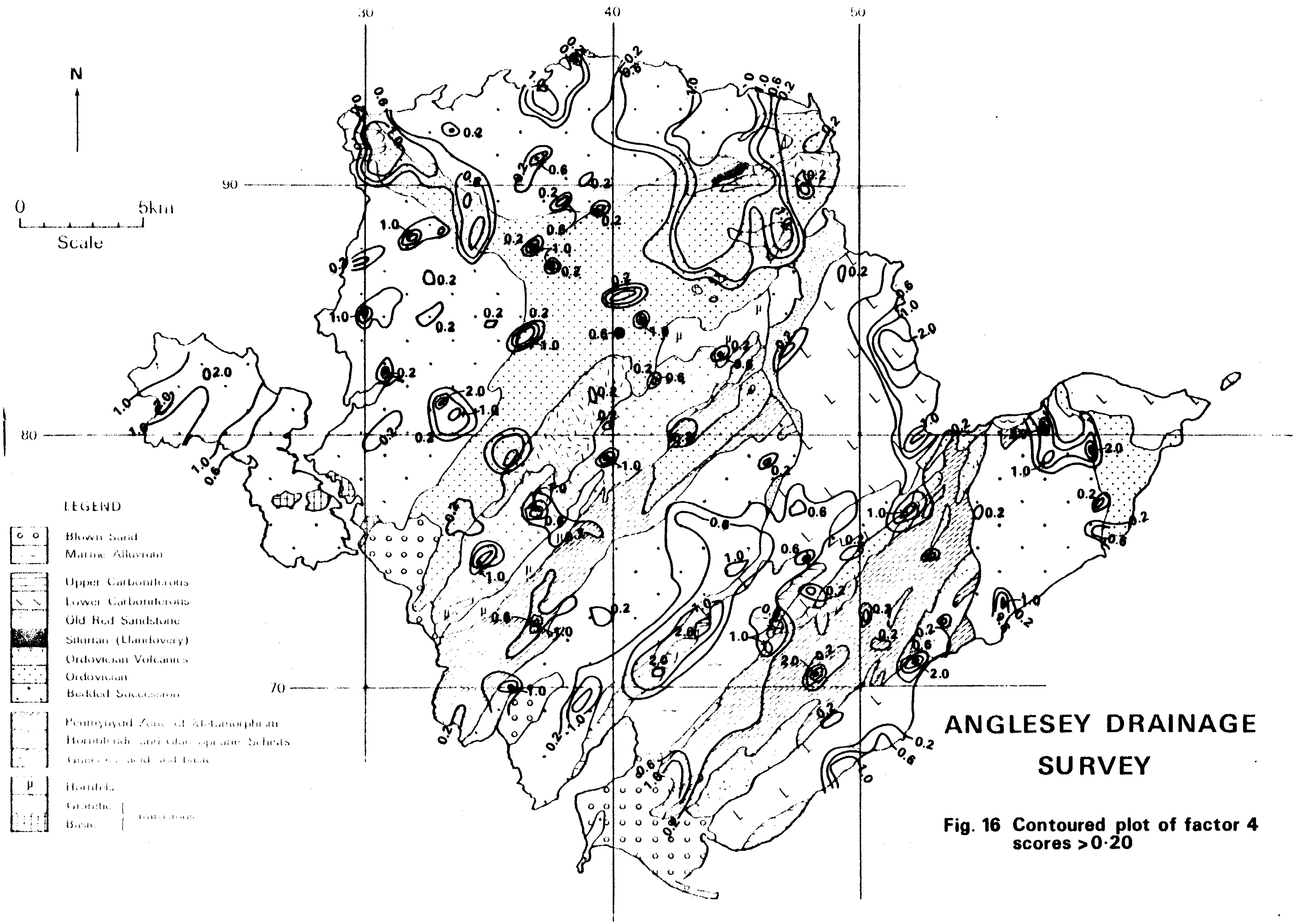


Fig. 16 Contoured plot of factor 4 scores >0·20

Table 6 Comparison of mineralogical and statistical methods of discrimination between contamination and mineralisation

Sample	Mineralogy			Factor Scores			Agreement
	Sulphides	*Other ore minerals*	*Contaminants*	1 *Base metals*	3 *Barium*	4 *Contaminants*	
46	chalcopyrite	–	Abundant (Cu, Pb, Zn, Sn, Sb)	0.147	-0.384	3.706	good
47	v. rare chalcopyrite	–	Abundant (Cu, Pb, Sn)	-0.216	0.119	1.877	moderate
87	pyrite, sphalerite, minor galena	–	rare (Pb)	0.730	0.638	1.235	moderate
98	chalcopyrite	baryte	rare (Pb)	0.152	2.044	-0.299	moderate
102	–	baryte	present (Pb)	-2.069	1.391	0.382	excellent
106	–	–	rare (Cu, Pb)	0.006	-0.493	0.482	excellent
108	Entire sample used in analysis			-0.231	-1.063	0.151	–
112	Source of anomalous Pb, Zn, Ni not found		present (Cu, ?Sn)	-0.087	0.091	2.911	? excellent
149	No discrete Pb - bearing phases could be isolated			-0.327	0.505	0.462	–
170	chalcopyrite	–	–	-0.044	-0.394	-0.343	moderate
186	chalcopyrite	–	–	-0.577	-0.153	0.989	poor
216	–	magnetite	?Zn dispersed in Fe-oxides	0.675	0.574	0.369	poor
218	–	baryte	–	0.733	1.495	-0.535	moderate
249	abundant sphalerite, galena	magnetite smithsonite	present (Pb, Sn)	1.779	-0.061	1.691	excellent
259	chalcopyrite	–	present (Cu, Pb, Sn)	-1.244	-0.849	2.623	moderate
266	Galena, pyrite, ?chalcopyrite	baryte	present (Pb, Sn, Sb)	-0.398	1.199	2.625	moderate
272	–	–	present (Cu, Pb, Zn, Sn)	-0.551	0.354	2.013	excellent
288	Source of Pb (3700 ppm) not found			-1.130	0.451	0.582	–
291	–	baryte (abundant)	–	-1.529	4.350	0.250	good
296	–	–	abundant (Cu, Pb, Sn)	-0.118	-0.729	2.375	excellent
308	sphalerite, chalcopyrite	baryte	–	0.840	2.564	1.104	moderate
315	–	baryte	–	-0.155	1.474	-0.265	excellent

Table 6 continued

Sample	Mineralogy			Factor Scores			Agreement
	Sulphides	*Other ore minerals*	*Contaminants*	1 *Base metals*	3 *Barium*	4 *Contaminants*	
316	chalcopyrite	baryte (abundant)	present (Cu)	-0.147	3.355	-0.082	poor
317	sphalerite, chalcopyrite	baryte	–	-0.097	2.555	0.361	poor
319	pyrite, chalcopyrite	–	–	0.496	-0.508	-0.596	excellent
320	chalcopyrite, pyrite	–	–	-0.491	1.096	-0.351	poor
339	pyrite, rare chalcopyrite, sphalerite marcasite	–	–	0.243	-0.384	0.233	moderate
361	chalcopyrite, pyrite	baryte	–	-0.161	-0.630	0.291	very poor
375	–	magnetite	?trace (Sn)	0.179	-0.837	0.597	good
376	–	magnetite	–	0.562	-0.251	-0.887	moderate
378			present (Pb)	-0.423	-0.245	1.671	? excellent
385	Source of Pb (1100 ppm) not found		–	-0.726	-0.528	0.710	–
407	chalcopyrite v. rare galena	baryte	present (Cu, Pb, Zn)	1.294	-0.541	0.082	moderate
408	–	baryte	abundant (Pb)	0.964	0.252	1.545	moderate
421	–	baryte (abundant)	–	-0.274	3.138	-0.517	excellent
427	–	baryte	–	-0.679	1.031	0.154	excellent
428	–	–	rare (Pb)	0.147	-0.091	0.613	excellent
451	rare galena	magnetite	abundant (Cu, Pb, Sn, Sb)	0.688	-0.913	1.878	excellent
454	chalcopyrite	baryte magnetite	abundant (Cu, Pb, ?Zn, Sn)	-0.068	1.127	2.355	moderate
455	–	baryte magnetite	abundant (Cu, Pb, Zn, Sn, Sb)	0.208	1.773	2.190	good
462	–	magnetite	present (Pb, Sn)	0.154	-0.856	1.032	excellent
463	–	–	present (Cu, Pb)	-0.572	-1.989	1.610	excellent
508	rare chalcopyrite	baryte	present (Pb)	-0.414	0.480	1.451	moderate
522	rare sphalerite	magnetite	abundant (Cu, Pb, Zn, Sn)	1.021	-0.916	0.954	good

does represent an apparent 'outlier' but additional evidence of mineralisation in the area would be required to merit further investigation of this isolated result.

BRYN-SIENCYN
Distributions of all three elements appeared to be lognormal but the number of samples collected was too small for this to be certain. Element levels, particularly for Cu, were distinctly higher than in the Llangoed area although the samples were collected from over similar bedrock. It is suspected that here a higher background is caused by the sampled drift containing basic material derived from the Penmyndd and Gwna rocks. The clearest 'outlier' in the results is 120 ppm Pb from SH 5108 6822; this sample also contains 110 ppm Zn. Three of the highest Cu values (50, 55, 60 ppm) come from consecutive samples collected in an area containing several springs near the margin of the Carboniferous around SH 506 696, but the highest Cu result comes from further south at SH 5094 6894. The sample with the highest Zn content also shows the second highest Pb result and comes from SH 5056 6878. There is no obvious cause of any of these high values except for the proximity of the basement in the case of the high copper results. Therefore, as all the high values occur within one part of the sampled area, this area might be considered anomalous although it is impossible to be definite without more information on regional trends and levels in soils across the whole area.

HOLY ISLAND
Element distributions were lognormal but skewed by an excess of low values produced by samples collected over the Holyhead Quartzite in the north of the island. Samples collected over the South Stack Series in the north-west of the island were also characterised by low Cu and Pb results. Contrasting lithologies did not stand out in the south of the island. In the case of the ultrabasic rocks this was attributed to sampling marine alluvium (and at one site blown sand) filling in depressions between ultrabasic rock outcrops which carried no soil. A similar situation was encountered elsewhere and therefore the soil sampling, as well as the drainage sampling, of Holy Island were ineffective, and mineralisation may easily have escaped detection.

No anomalous populations could be defined but both the Pb and Zn distributions showed distinct 'outliers' (Table 7). 120 ppm Pb was recorded in the sample from SH 2350 8050 and is supported by weak Pb anomalies in both the sediment and concentrate samples taken at the drainage site (SH 2346 8004) which covers this catchment. The source of lead is uncertain, but there is a record of copper mineralisation in this area (Figure 3). The highest Zn value is a clear 'outlier' and comes from by Holyhead Dockyard (SH 2550 8250). The second highest Zn result may also be considered anomalous and comes from the same area, close to the A5 (SH 2592 8152). Both these samples may be contaminated for they come from ground which is close to industry and shows indications of past disturbance. No distinct high values which might represent anomalies were identified in the areas of low background and no high values of Cu were recorded.

ANOMALOUS AREAS

It is not intended to detail every drainage anomaly. Anomalous areas which may be related to mineralisation were defined by the methods described in a previous section and are shown in Figure 17. They are divided into four groups and discussed below on a rough north-east to south-west basis, and not in any particular order of significance. Further investigations were carried out in some areas, and it is intended that the results will be described in subsequent reports.

ANOMALIES RELATED TO PARYS MOUNTAIN MINERALISATION

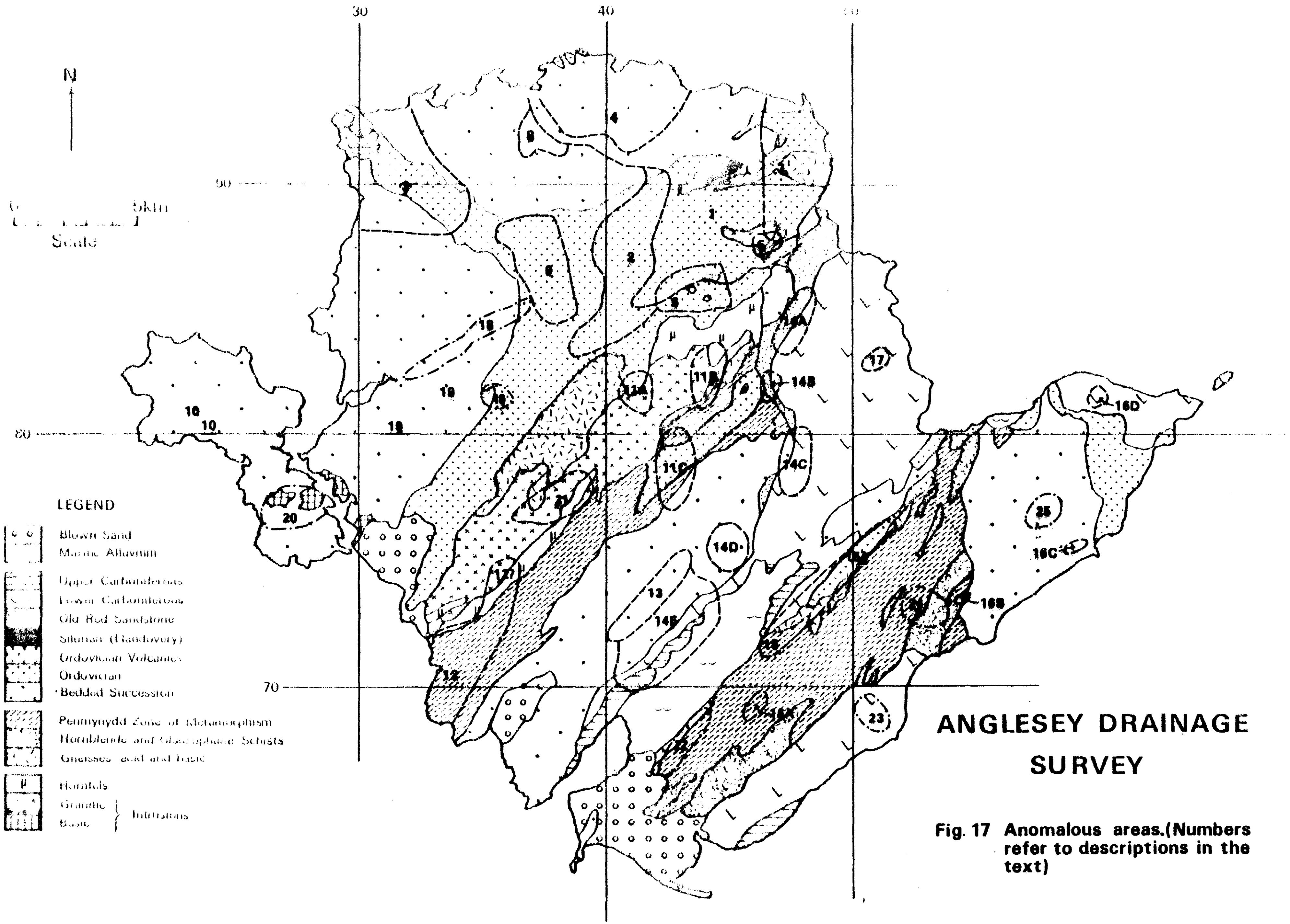
1. Parys Mountain

Anomalies derived from the Parys Mountain mines cover an exceptionally large area. This is because (a) the workings were large, (b) they were worked over a long period of time, (c) smelting and other processes to extract copper were carried out in the area, (d) the mineralisation occupies a prominent watershed, (e) a boulder train of mineralised rocks was developed to the south-west of Parys Mountain during glaciation, (f) mineralised waste has been used for roadstone, (g) the mineralisation has generated acid groundwater by the dissolution of sulphides thereby increasing the mobility of elements such as copper (Sato, 1960).

The contaminated zone around the mountain, as indicated by drift fragments and blocks in stone walls, covers a large area elongated in a south-westerly direction by the glaciation at least as far as Caergeiliog (SH 311 785) (Greenly, 1919, p. 734) and extending northward to the coast at Amlwch as a result of human activities. Drainage anomalies persist over greater distances. Anomalies along the Afon Wygyr as far as Cemaes Bay are attributed to the Parys workings as the headwaters of this river receive material directly from the Morfa-du Mine. This river displays a classic dispersion pattern with the anomaly train of Zn>Cu>Pb and sediment>panned concentrate>water. In the Afon Goch large Cu, Pb, Zn and Fe anomalies in sediments and panned concentrates persist to the coast at Dulas in the west, whilst streams draining the mountain to the north and reaching the sea around Amlwch are similarly anomalous.

Table 7 Summary statistics and highest results for reconnaissance soil samples collected near Llangoed, Bryn-Siencyn and on Holy Island

Variable	Median	Mean	Standard deviation	Geometric mean	Minimum	Three highest results 3	2	1
Langoed (32 samples)								
Cu	15	17.6	6.21	16.7	10	25	25	40
Pb	20	21.7	5.47	21.0	10	30	30	30
Zn	40	42.2	8.32	41.3	20	50	50	60
Bryn-Siencyn (46 samples)								
Cu	30	31.6	11.54	29.3	5	55	60	65
Pb	30	37.4	17.31	34.6	10	60	80	120
Zn	50	54.6	21.10	50.1	20	100	110	120
Holy Island (129 samples)								
Cu	15	16.0	9.08	12.4	< 3	40	40	40
Pb	20	21.5	13.37	18.1	< 5	50	60	120
Zn	50	45.3	19.84	41.1	10	80	100	180



ANGLESEY DRAINAGE SURVEY

Fig. 17 Anomalous areas.(Numbers refer to descriptions in the text)

The result of this contamination is that over the wide area (1 on Figure 17) in the north-east of the island where drainage catchments are contaminated by Parys mineralisation it is most unlikely that any other mineralisation of similar type would be detected. For example, several sites on the eastern side of Llyn Alaw forming the margin of the highly anomalous area and containing distinct Cu, Pb and Zn anomalies in sediments and concentrates were examined. The presence of material derived from Parys in the drift or walls suggested that the anomalies are Parys derived, and the railway from Amlwch forms an additional source of contamination at some sites. However, a site (Table 6, No. 87) south of Gwredog (SH 409 858) contains unworn sphalerite, pyrite, and occasional altered and rounded grains of galena, suggesting two sources. It is therefore uncertain whether the worn and fresh sulphides represent derivation from drift and blocks of Parys material transported by human agencies respectively, or if there is an unknown source of mineralisation in the area. Therefore because of these interpretational difficulties, the whole area must be added to the parts of Anglesey not effectively covered by the drainage survey (Figure 4).

The absence of strong Ba anomalies and high factor 3 scores suggest that baryte is virtually absent from the Parys mineralisation. This agrees with the work of Wheatley (1971) and Thanasuthipitak (1974), although Greenly (1919, p. 837) recorded baryte in the Great Lode. Moderate Ba levels are associated with the area (Appendix 4) but it is uncertain whether these are solely the product of relatively high background levels in the shale and volcanics or represent a halo of the type reported to be associated with some volcanic exhalative mineral deposits (Shiikawa and others, 1974; Thurlow and others, 1975).

2. NNE of Llyn Alaw

It is uncertain whether Cu and Zn anomalies recorded in two samples here reflect underlying mineralisation in the vicinity or transported material from Parys. Mineralogical examination of one of the panned concentrates (SH 401 882) detected sphalerite, some of which is intergrown with smithsonite, and pyrite. The fresh, unworn grains suggest either a local derivation or transportation by human agencies, but no sulphide-bearing blocks or other source of the sulphides could be found at surface near the anomalous sites. Contoured factor 1 scores separate this anomaly from those of Parys Mountain and there is an old trial for Cu in the area, at Rhosgoch (Figure 3).

ANOMALOUS AREAS COVERED BY FOLLOW-UP INVESTIGATIONS

3. Carmel Head

Factor analysis defines a weak zone of potential mineralisation extending in a south-easterly direction from Carmel Head. Baryte was detected in a panned concentrate at SH 317 926 and sphalerite in a sample taken near Llanrhyddlad (SH 331 884). Several trials and an old copper working (Figure 3) indicate the presence of mineralisation in the area but they are not directly responsible for any of the stream anomalies. The clearest drainage anomaly related to mineralisation is in water (Cu 0.02 ppm, Pb 0.08 ppm, Zn 0.12 ppm) at SH 299 244, fed from springs on Mynydd y Garn. Other more prominent anomalies such as at SH 331 884 (Table 6, No. 522) are partly the result of contamination.

Subsequent soil sampling and drilling showed the presence of greater metalliferous concentrations in the north-west part of this area than are indicated by the feeble drainage anomalies. Efforts were made in this area to achieve a reasonable sample density in spite of the inadequate drainage, and the results highlight the problems of drainage sampling in Anglesey. The poor response is attributed to (i) stream sediment derived from alluvial infill and not from the erosion of bedrock, (ii) local derivation of sediment, unrepresentative of the theoretical catchment, and (iii) interference from contamination.

4. Llanbadrig—Bull Bay

In this coastal area of poor surface drainage and known mineralisation one of the three sample sites (SH 404 942) shows a distinct Cu in panned concentrate anomaly and another (SH 384 944) an elevated Cu in sediment (40 ppm) result. Both values are confused by contamination, but in view of the geology and poor surface drainage some reconnaissance soil traverses were sampled which confirmed the presence of metal anomalies not directly related to the known mineralisation.

5. City Dulas

A site at City Dulas in a tributary to the Afon Goch at SH 469 876 is on the edge of the highly contaminated area draining Parys Mountain, but it is quite distinct from other sites in the area because of high Ba (1%) in panned concentrate and consequently shows prominently in plots of factor 3 scores. Two samples taken upstream (SH 465 885 and SH 467 886) also contain anomalous Cu, Pb, or Zn but only background amounts of Ba. The anomaly may be related to old workings for lead and baryte at City Dulas (Figure 3; Appendix 1) or unknown mineralisation in the vicinity. Reconnaissance soil traverses in the area located base-metal anomalies but some at least were related to contamination from Parys Mountain.

6. Llandyfrydog

A group of Cu, Pb, Zn and Ba anomalies in three pyrite-rich panned concentrates (SH 450 860, SH 449 859, SH 446 855) appeared to be related to the outcrop of ultrabasic intrusions. Other sites in the area, all in the Afon Goch, were heavily contaminated by material from Parys Mountain and provided no useful information except for the presence of weak Ba in panned concentrate anomalies. Inspection of the stream catchments revealed the presence of pyritisation in baked shales adjacent to the intrusion and minor vein mineralisation carrying galena and chalcopyrite in a quarry below Bodneithior Farm (SH 446 859). Reconnaissance soil sampling indicated that weak vein mineralisation coupled with a high background derived from the ultrabasic intrusions were the probable sources of the drainage anomalies.

OTHER AREAS WHERE SULPHIDES OR BARYTE WERE IDENTIFIED IN DRAINAGE SAMPLES

7. East of Parys

The sample collected near Porth Helygen at SH 488 905 contains chalcopyrite and baryte. There is an old trial for copper nearby (Figure 3) from which chalcopyrite has been obtained but there is no record of baryte here or from the more extensive workings to the north at Rhosmynach. The geology of this area has made it a target for base-metal mineralisation similar to that exploited on Parys Mountain, but the presence of baryte at Porth Helygen suggests that the mineralisation detected here is slightly different. Only two other samples (from SH 484 922 and SH 476 928) cover this area and neither were anomalous, but this limited cover suggests that mineralisation could easily be missed and indeed the Rhosmynach workings did not register. Therefore, the area should not be discarded on the evidence of this survey and the mineralisation may be more extensive than is indicated by the single anomaly.

8. Llanfechell

This is a weak anomaly which did not show on the factor score plots and is based on the presence of chalcopyrite in the panned concentrate (Table 6, No. 170) taken at SH 377 919. Samples taken 0.5 km upstream were not anomalous. A water sample taken at SH 370 926 contained anomalous Cu (0.03 ppm). Several other Cu and Zn anomalies recorded in the area appear to be related to the spread of Parys detritus down the Afon Wygyr, but this could mask a contribution from underlying mineralisation.

9. Llanbabo

A weak anomaly for Cu in panned concentrate north of Llanbabo is caused by weak quartz-sulphide vein mineralisation within Ordovician grits and siltstones found in a quarry (SH 368 880) upstream of the sample site. During the construction of the Llyn Alaw dam (SH 374 854) thin veins containing pyrite and chalcopyrite were recorded in a pipe trench (Hawkins, 1964, unpublished IGS report). In the same area elevated Ba results generate relatively high factor 3 scores but they may be caused by the Ordovician shale bedrock rather than mineralisation. In a highly contaminated panned concentrate taken at SH 377 868 chalcopyrite was tentatively identified; this probably has a source similar to those described above. Immediately south of Llyn Alaw (SH 383 850) a weak Zn in panned concentrate anomaly and high background levels of Cu and Zn in sediment generate a high factor 3 score which may indicate the presence of further minor mineralisation, although ground examination of the stream showed contamination from a rubbish dump to be the only visible source of metal anomalies. The presence of oolitic ironstone in this area might produce weak zinc anomalies.

10. Holyhead area

Three of the four drainage samples taken from the highly contaminated streams of this area contained large metal anomalies which mineralogy and factor analysis attributed largely to contamination. However, mineralogical examination of the sample (Table 6, No. 47) from SH 216 815 identified rare chalcopyrite amongst the rubbish, the soil sample taken at SH 235 805 contained anomalous Pb and the panned concentrate taken nearby showed an anomalous Pb content which was not obviously caused by contamination. There is some evidence of copper mineralisation in this area (Figure 3), but the source of the lead is unknown.

11. Coedana

Three clusters of anomalies occur west, north-west and south of Coedana near the margins of the granite.

a. The sample taken at SH 416 821 (Table 6, No. 249), immediately upstream of the railway, contained abundant angular sphalerite, and lesser amounts of galena and smithsonite. It proved impossible to decide whether the anomaly was caused by dumping from the railway or mineralisation. The angular nature of the sphalerite and lack of outcrop in the area suggested derivation from the railway but no mineralised fragments were found on the embankment or in the track ballast.

b. The sample (Table 6, No. 407) taken near Cwyrt (SH 444 834) contains chalcopyrite and baryte derived from the extensive drift cover. No cause of this anomaly was found but it may be related to the same source as anomalies to the south.

c. A series of anomalies and high values for Ba and Zn in both sediment and concentrate are recorded in the Afon Cefni at sites between Bodffordd (SH 429 769) and north of Llangwyllog (SH 429 803). Anomalous levels of Cu and Mn in sediment, and Cu, Pb, Fe and Ti in panned concentrate were also found at some sites. Many of these anomalies are caused by contamination or secondary precipitates, and some may be related to Ordovician ironstones, but base-metal mineralisation may also be present. The only sample (Table 6, No. 218) examined mineralogically, from SH 428 797, showed the presence of baryte. Except for the southernmost site there is no bedrock exposure upstream and all the sediment is derived from the extensive superficial deposits. The origin of the mineralisation is therefore related to the provenance of the superficial deposits and may not be in the immediate vicinity of the drainage anomalies.

12. Aberffraw

An ill-defined zone of high Ba values is recorded in a zone stretching inland along the regional strike from just north of Aberffraw. The only clearly anomalous result is in a sample (Table 6, No. 102) taken near Aberffraw (SH 338 688) where baryte was identified in the panned concentrate. No source of baryte is known in the area and the anomaly has not been investigated. The zone defined by factor 3 scores is peculiar for it does not entirely coincide with the hornfels and granite, the only rocks bearing appreciable potash-feldspar in the area, but partly overlies Penmynydd mica schists. Scrutiny of the raw data indicates that it is a product of high Ba values in sediment generated from the granite, and some high background values for elements normally concentrated in basic rocks, derived from the Penmynydd Zone. Base-metal anomalies in this area appear without exception to be the result of contamination.

13. Cerrigceinwen

Three samples taken in a stream flowing along the strike between SH 427 747 and SH 407 721 are characterised by high and anomalous amounts of Fe, Ti, Ni, Zn and Cu in panned concentrates. These appear on the regional variation trends to be related to outcrops of spilitic lavas but the presence of trials in carbonate lenses within the spilites near one site (SH 422 737) suggests that mineralisation has been sought here. No sulphides could be found around these trials though local inhabitants reported that they had been for lead. The most promising drainage anomaly occurs to the north at SH 427 747 where the panned concentrate contains pyrite, marcasite, sphalerite and rare chalcopyrite. Only water samples could be collected upstream and these contain anomalous amounts of Cu (0.04 - 0.05 ppm). Some soil samples collected in the fields upstream of the anomalous site failed to show any high Cu, Pb or Zn results, which is surprising as most of the stream sediment appears to be derived from the local drift. Groundwater samples were collected across the area and several anomalies recorded, but the source of these and the surface anomalies is unresolved. Greenly (1919, p. 114) records 'a remarkable schist at Gwalchmai rich in contemporaneous, granoblastic, pyrite' which may be connected with any mineralisation in the area and this, with the drainage anomalies, requires further investigation.

14. Dulas–Llangefni–Malltreath

A prominent line of anomalies, all characterised by the presence of baryte, follows the base of the Carboniferous. Drainage anomalies are typically of Ba with Cu, Pb, Zn and Ni at some sites in both sediments and panned concentrates. The Ba anomalies are related to veins of baryte recorded at several localities in this zone (Appendix 3). The main anomalies are clearly delineated by factor 3 scores (Figure 15).

a. Of the four samples which form this sub-anomaly baryte has been identified in three, chalcopyrite in two and sphalerite in one. The streams drain Lower Carboniferous and Old Red Sandstone (ORS) rocks. Upstream of the sphalerite-bearing site (SH 478 843) excavations for irrigation channels exposed blocks of Carboniferous rocks consisting of pyritised conglomerate, sandstone, and shales which are the probable source of Fe, Zn, Ni and possibly the Cu anomalies. Cu also occurs in veins with baryte, for in the drift near the site at SH 471 835 a block was found containing a vein of pink baryte with minor chalcopyrite. Greenly (1919) records pebbles of pyritised material from Parys Mountain in the basal Carboniferous, and this may be a partial cause of the anomalies in this area.

b. The two samples which form this anomaly are close to the junction of the ORS and Carboniferous with basement rocks and both show Cu and Ni but no Ba anomalies. There are no exposures of bedrock in the area and the drift from which the samples are derived contains fragments of the metamorphosed basement, ORS and Lower Carboniferous shales and sandstones.

c. This sub-anomaly is based on the sample (Table 6, No. 361) from SH 474 777 containing pyrite, chalcopyrite and baryte, supported by a groundwater anomaly for Cu, Pb and Zn at SH 479 783. Four other drainage samples taken in the area are not strongly anomalous; weak Cu anomalies in the sediment from SH 475 787 and panned concentrate from SH 475 790 may be related to basic material in the sediment rather than mineralisation.

d. A highly contaminated sample from SH 455 751 contains baryte from an unknown source; the catchment is entirely within the Gwna rocks.

e. In this zone of poor surface drainage the majority of samples collected were heavily contaminated and a large proportion of the sediment derived from the underlying Gwna rocks. Mineralogy (Table 6, Nos. 454 and 455) indicated that these two sources accounted for the majority of the large metal anomalies, but baryte and chalcopyrite were also identified. Again the baryte veins recorded by Greenly (1919, p. 846) are the obvious source of these minerals, but they must be more extensive than the small occurrences described.

The problem surrounding the Ba and base-metal anomalies in this zone is whether the known mineralisation, derived pebbles from Parys Mountain and the high background of some Gwna lithologies is sufficient to account for this prominent belt of anomalies, or whether there is some additional metalliferous concentration. Such a concentration may be present in the basal Carboniferous and in the northern part of the zone the possibility of a placer deposit related to the Parys mineralisation cannot be ruled out.

15. Pentre Berw

A highly anomalous, contaminated sample (Table

6, No. 451) with Ti, Cu, Ni and Pb anomalies in panned concentrate from a stream draining Carboniferous and basement rocks at Pentre Berw (SH 468 725) contains a small amount of galena. Another sample (Table 6, No. 508) taken along the strike to the south-west (SH 466 715) with high levels of Ba, Ni and Pb contains baryte and rare chalcopyrite. To the north-east of Pentre Berw in a zone stretching nearly to Pentreath several other sites show anomalous Ni, and occasionally Zn, in panned concentrate. The high Ni results, culminating in the value of 740 ppm at SH 501 759 are attributed to basic lithologies (spilitic) in the Gwna rocks with the Ni held in magnetite (Morgan, 1974). As well as a high Ni content (390 ppm) the panned concentrate (Table 6, No. 375) from SH 494 753 contains baryte, which, in conjunction with the baryte and sulphide found near Pentre Berw suggests some minor mineralisation associated either with the Bern Fault or with the margins of the Carboniferous.

16. Isolated barium anomalies in the south-east of Anglesey.

Four isolated but prominent Ba in panned concentrate anomalies were found in the south of the island. Three of the sites are characterised by an absence of any other metal anomalies and a derivation of the sediment from drift deposits.

a. A sample (291) from near Llangaffo (SH 454 683) contained nearly 2% barium, present as baryte. The sediment is derived from drift deposits containing blocks of the metamorphic basement and Carboniferous rocks. One block of brecciated greenschist contained a thin vein of baryte.

b. A sample from near Menai Bridge (SH 542 735) contained more than 1% Ba in panned concentrate. There is no rock exposure in the catchment and the sediment is derived from drift deposits which appear to consist entirely of metamorphic basement fragments. Samples taken less than 0.5 km upstream are not anomalous, suggesting a local source.

c. A sample from near Beaumaris (SH 596 760) with a catchment occupied by Gwna mica-schists and spilitic rocks covered in part by drift deposits also contains pink and white baryte. An old working for copper is located in the upstream catchment (Figure 3) but baryte is not recorded from the working and copper was not anomalous in the sample, suggesting that the sediment may be derived from the local drift deposits and not the mineral working.

d. This occurrence, near Llanddona (SH 575 808), differs from the other three because it is contaminated and contains galena and pyrite as well as baryte. The immediate source of the anomalies is the lead workings in this valley. The workings have not been examined in detail and there is no record of baryte associated with the galena (Greenly, 1919, p. 364, 846); the baryte was probably not seen or considered to be gangue, but it may be derived from another source.

These occurrences suggest that at least thin veins of baryte are fairly widespread in the metamorphic rocks of the southern part of the island. With two of the occurrences near the boundary with Ordovician sediments, and a third coming from drift containing Carboniferous rock fragments, the distribution suggests a spatial association with the base of these younger deposits, similar to that seen in the Dulas-Malltreath zone.

17. Marianglas

Field examination and factor analysis both suggested that the metal anomalies in the Moelfre-Benllech-Pentreath area were entirely caused by contamination, but a sample (Table 6, No. 259) from SH 516 835 with a Cu in panned concentrate anomaly contained chalcopyrite amongst the contaminants responsible for Pb and Sn anomalies. The catchment of this site is relatively small (<1 km^2) and no indications of mineralisation were found near the stream. It is possible that, as the site is close to the main road, even the chalcopyrite is the result of dumping; if not it represents the only indication within the Carboniferous of chalcopyrite-bearing mineralisation without baryte.

OTHER ANOMALOUS AREAS

18. Afon Alaw

Strong Fe and Mn anomalies in sediment are found in all samples taken from Afon Alaw; the anomalies tend to increase in magnitude downstream and generate high factor 1 scores. They are accompanied by high background or weakly anomalous values of Pb and Zn in sediment. Panned concentrate anomalies for Cu and Sn are also found at SH 350 845, but these are most probably caused by contamination. The high levels of Fe and Mn in sediment but not panned concentrate suggested the presence of hydrous oxides. Examination of the most anomalous sites showed the sediment to be derived from drift deposits containing layers cemented by hydrous oxide precipitates, which are the immediate cause of the anomalies. The origin of these hydrous oxide precipitates and the source of the metals is uncertain.

19. Bodedern

A site at SH 351 815 contains high background levels of Pb and Zn and anomalous amounts of Fe and Mn in sediment, which show clearly in contoured factor 1 plots. The site is in low ground by a lake and the anomaly is attributed to hydrous oxide precipitates. Several other weak isolated anomalies for a range of elements in sluggish streams cutting drift deposits between here and Valley are attributed to a combination of contamination, basic rocks in the New Harbour Group and material from Parys Mountain in the drift.

20. Rhoscolyn

A panned concentrate collected from an irrigation ditch within the outcrop of ultrabasic rocks at SH 276 768 contained 660 ppm Ni but was not included in the data matrix because no corresponding sediment sample was obtained. The Ni level in panned concentrate is not high for a background of ultrabasic rocks but it is not possible to discount this area completely because (i) drainage sample coverage is so poor, (ii) soil samples collected in the vicinity gave misleading results as they were not representative of the bedrock, and (iii) Greenly (1919, p. 277) recorded chromite-bearing rocks in the area.

21. Gwalchmai

North of Gwalchmai (SH 385 781) a panned concentrate with a catchment in the Coedana Granite was found to contain 20% Ti, 27% Fe and anomalous Ni, Zn and Mn. Mineralogy showed the anomalous elements to be present in pyroxene and magnetite which could be related in the field to rounded blocks of ultrabasic rock in the drift. The source of the blocks, one of which contained sulphides, was not traced but according to Greenly (1919, p. 709) the boulder train comes from either the intrusions at Llandyfrydog or Mynydd Eilian. Smaller Ti anomalies to the south-west (SH 365 767 and SH 368 768) may have a similar origin, but at the latter site interpretation is confused by basic gneisses in the bedrock and contamination from the A5 trunk road. It is not clear why the boulder train should only cause anomalies in this particular area, and why no large Ti anomalies are found in the supposed source rock areas. There may be another source of Ti, Greenly (1919, p. 130) noting that sphene is a remarkably abundant accessory in the hornblende gneisses.

22. Llangaffo

Two weak Pb anomalies in panned concentrates accompanied by high background values of Ni, attributable to basic rocks within the Penmynydd zone, occur in streams at SH 432 678 and SH 424 668 along strike from recorded mineralisation and silicified rocks (Greenly, 1919, p. 568 and 846).

23. Bryn-Siencyn

A few of the soil samples collected to the north-east of here, around SH 510 682, SH 506 696 and SH 506 688 contained relatively high Cu, Pb and Zn. The metal contents (Table 7) were not very high compared with areas of known mineralisation, and those in the north of the area in particular may be caused by basic material in the drift.

24. Llanfair P.G.

A Pb anomaly in panned concentrate occurs at SH 535 727 in a small stream on the edge of a low-lying area. The bedrock consists of glaucophane schists and there is no obvious reason for the anomaly. To the west of here, centred on SH 524 732, is located an area characterised by weak increases in factor 1 scores (Figure 14). There are no anomalous base-metal levels recorded and the feature is attributed to weakly elevated levels of Fe and Mn in both sediment and concentrate.

25. Llanddona

At SH 583 774 a weak Cu anomaly in stream sediment in an uncontaminated sample draining a marshy area forms the high point of an ill-defined area of high factor 1 scores. There are three other sites showing Cu, Pb or Zn anomalies (SH 595 791, SH 576 789 and SH 597 776) in the general area. Mineralogical examination of the panned concentrate from the latter site and factor analysis suggests that all the anomalies are caused by contamination. Site SH 576 789, though contaminated (field observation), is downstream of a record of chalcopyrite mineralisation in a temporary exposure and the old Llanddona Mine lies about 1 km further north (Figure 3), so the anomalies may have a dual source.

CONCLUSIONS

1. A reconnaissance field survey of known non-ferrous mineralisation suggested the presence of three types of deposit on Anglesey: (a) copper, (b) copper (lead-zinc) and (c) baryte (lead). Group (b), exemplified by the ore deposits of Parys Mountain and nearly always associated with Lower Palaeozoic rocks, is considered by far the most important from the economic viewpoint.

The drainage survey indicated the presence of two chemically distinct types of mineralisation, a base-metal type and a baryte type. These correspond to groups (a + b) and (c) of those defined by the study of known mineralisation.

2. Critical examination of drainage catchments and sampling points indicate that about 35% of Anglesey was not covered by the drainage survey, and that within the area theoretically covered there are tracts not effectively sampled. There are two main reasons for the ineffective coverage, firstly poor surface drainage and secondly contamination from Parys Mountain mineralisation. In these areas any mineralisation will have escaped detection. In three of the poorly drained areas, reconnaissance soil sampling was carried out on an experimental basis to supplement the drainage survey. On Holy Island this was not entirely successful because of too wide a sample spacing and the sampling of superficial material unrepresentative of the bedrock. In the other two areas the number of samples collected and the area covered were insufficient to provide a regional picture.

3. The complex background geology did not prove as great a problem to data interpretation as was envisaged. This was, firstly, because of the presence of clearly defined mineralisation and, secondly, because for the elements determined many of the rocks of contrasting age and metamorphism were of broadly similar chemical composition. Minor mineralisation is widespread on Anglesey and the most difficult problem proved to be distinguishing drainage anomalies caused by minor mineralisation from those of greater significance. This was hampered by the extensive and variable drift deposits which hindered attempts to trace the source of metal anomalies and masked

bedrock mineralisation by spreading materials from Parys Mountain over a wide area. Profile sampling to bedrock is the only satisfactory solution to this problem.

4. The survey showed the drawbacks of drainage sampling in contaminated terrains but also indicated some methods by which the problems can be overcome. It proved essential to obtain a panned concentrate as well as a sediment at every site, and a high density must be maintained wherever possible because of limited dispersion trains caused by dilution of the sample from locally derived drift. Factor analysis proved a most effective statistical method for distinguishing anomalies caused by contamination from those related to mineralisation. More time-consuming, but more sensitive, was the mineralogical examination of panned concentrates. The joint application of factor analysis and mineralogical examination was found to be the most effective means of evaluating anomalies. Neither method may work as well in other areas where, perhaps, there are problems such as less clearly defined anomalies and Sn or Sb mineralisation. Simpler techniques, such as manual plots of Sn content and site examination proved to be unreliable indicators of contamination.

5. The drainage survey outlined a large number of areas containing sulphide or baryte mineralisation. Except for high values related to the Parys mineralisation none of the anomalies was of outstanding magnitude. This was partly attributable to the poor drainage and partly to the widespread minor mineralisation found on the island.

Limited follow-up sampling has been carried out in four of the anomalous areas and the detailed results of this work will be contained in a later report. A fifth anomalous area, at Carmel Head, was investigated in detail and drilling was carried out. Of the anomalous areas not investigated in detail by IGS, those with some mineral potential appear to be (i) the area east of Parys Mountain, (ii) the basal Carboniferous between Dulas and Malltreath, and (iii) the spilitic Gwna rocks in the vicinity of Cerrigceinwen. The area east of Parys Mountain was investigated by two companies (Intermine and Amax) in the early 1970s. Extensive soil sampling, pitting and trenching were carried out, along with geophysical surveys, but there was no follow-up to this work. Two other areas where information is very limited because of ineffective coverage may also be worthy of investigation: the ultrabasic rocks of Rhoscolyn and the area south of Parys Mountain.

6. From the data available the mineral potential of Anglesey appears to centre principally upon locating base-metal ore deposits of copper, lead and zinc (groub b). These may show features of both vein-type and stratabound deposits. The scattered vein mineralisation dominated by baryte (group c) and copper (group a) is unlikely to be substantial enough to be of any economic importance, but the possibility of metalliferous concentrations associated with basic igneous rocks cannot at present be ruled out.

Mineral deposits which have escaped detection are almost certainly concealed in some way and may be very difficult to locate. However, the incomplete coverage of this survey and the indications found suggest that further work in the form of ground geophysical surveys and soil sampling is warranted in the more promising areas.

ACKNOWLEDGEMENTS

The Institute would like to thank farmers and landowners on Anglesey for their co-operation in granting access to their land for sampling purposes. The assistance of Mr G.W. Hall was greatly appreciated during the literature search for old mines.

The following members of the Institute have contributed substantially to work contained in this report: Mr N. Bell, who assisted at all stages of the survey, Mr P. Green, who helped with computer processing, Dr T.K. Ball, who helped with the field survey, members of Analytical Chemistry Unit, too numerous to mention individually, who undertook all the sample preparation and analysis, and members of the Applied Mineralogy Unit who assisted in the mineralogical studies.

REFERENCES

Allen, J. R. L. 1965. The sedimentation and palaeogeography of the Old Red Sandstone of Anglesey, North Wales. *Proc. Yorks. Geol. Soc.*, Vol. 35, 139–85.

Baker, J. W. 1973. A marginal Upper Proterozoic ocean basin in the Welsh region. *Geol. Mag.*, Vol. 110, 447–55.

Barber, A. J. and Max, M. D. 1979. A new look at the Mona Complex (Anglesey, North Wales). *J. Geol. Soc. London*, Vol. 136, 407–32.

Bates, D. E. B. 1968. The Lower Palaeozoic Brachiopod and Trilobite Faunas of Anglesey. *Bull. Brit. Mus. (Nat. Hist.) Geol.*, Vol. 16, 127–99.

— 1972. The Stratigraphy of the Ordovician rocks of Anglesey. *Geol. J.* Vol. 8, 29–58.

— 1974. The structure of the Lower Palaeozoic rocks of Anglesey, with special reference to faulting. *Geol. J.* Vol. 9, 39–60.

Davis, J. C. 1973. *Statistics and data analysis in geology.* (New York: John Wiley & Sons Inc.), 550 p.

Dewey, J. F. 1969. Evolution of the Appalachian/Caledonian Orogen. *Nature, London*, Vol. 222, 124–29.

Foster-Smith, J. R. 1977. The mines of Anglesey and Caernarvonshire. British Mining No. 4. *Monogr. Northern Mines Res. Soc. Skipton.*

Greenly, E. 1919. The geology of Anglesey. *Mem. Geol. Surv. G.B.* 2 vols.

Hawkins, T. R. W. 1966. Boreholes at Parys Mountain, near Amlwch, Anglesey. *Bull. Geol. Surv. G.B.* Vol. 24, 7–18.

Institute of Geological Sciences. 1964. Aeromagnetic map of part of Great Britain and Northern Ireland. 1:250 000 Series, Sheet 4. Institute of Geological Sciences, London.

Ishihara, S. (editor) 1974. Geology of Kuroko deposits. Tokyo: Society of Mining Geologists of Japan. *Min. Geol. Tokyo, Spec. Issue 6*
Ixer, R. A. and **Gaskarth, J. W.** 1975. Parys Mountain – a possible Kuroko-style deposit. Paper presented to Mineral Deposits Study Group, *Geol. Soc. London*, Session 6: Stratiform mineral deposits, Leicester, Dec. 1975.
Jeffery, K. G., Gill, E. M., Henley, S. and **Cubitt, J. M.** 1976. G-exec system users manual. *Inst. Geol. Sci./ N.E.R.C.*
Leake, R. C. and **Aucott, J. W.** 1972. Geochemical mapping and prospecting by use of rapid automatic X-ray fluorescence analysis of panned concentrates. *In* **Jones, M. J.** (editor) *Geochemical Exploration 1972*, (London: Inst. Mining Metall.) 389–400.
— and **Smith, R. T.** 1975. A comparison of stream sediment sampling methods in parts of Great Britain. *In* **Elliott, I. L.** and **Fletcher, W. K.** (editors), *Geochemical Exploration 1974*, (Amsterdam: Elsevier), 79–94.
Lepeltier, C. 1969. A simplified statistical treatment of geochemical data by graphical representation. *Econ. Geol.* Vol. 64, 538–550.
Lewis, W. J. 1967. *Lead Mining in Wales.* (Cardiff: Univ. of Wales Press).
Maltman, A. J. 1975. Ultramafic rocks in Anglesey – their non-tectonic emplacement. *J. Geol. Soc. London*, Vol. 131, 593–606.
— 1977. Serpentinites and related rocks of Anglesey. *Geol. J.* Vol. 12, 113–28.
Manning, W. 1959. The Parys and Mona Mines in Anglesey. *In* The future of non-ferrous mining in Great Britain and Ireland – a symposium. 313–28. (London: Instn. Min. Metall).
Marengwa, B. S. I. 1973. *The mineralization of the Llanrwst area and its relation to mineral zoning in North Wales with reference to the Halkyn-Minera area and Parys Mountain.* Ph.D thesis, Univ. Leeds (unpubl.).
Muir, M. D., Bliss, G. M., Grant, P. R. and **Fisher, M. J.** 1979. Palaeontological evidence for the age of some supposedly Precambrian rocks in Anglesey, North Wales. *J. Geol. Soc. London.* Vol. 136, 61–64.
Nutt, M. J. C., Ineson, P. R. and **Mitchell, J. G.** 1979. The age of mineralisation at Parys Mountain, Anglesey. *In* **Harris, A. L.** and others (editors) *The Caledonides of the British Isles – reviewed.* Spec. Publ. geol. Soc. London. 8, 619–27.
— and **Smith, E. G.** 1981a. Transcurrent faulting and the anomalous position of pre-Carboniferous Anglesey. *Nature, London.* Vol. 290, 492–95.
— — 1981b. Transcurrent faulting and pre-Carboniferous Anglesey. *Nature, London.* Vol. 293, 760–762.
Parslow, G. R. 1974. Determination of background and threshold in exploration geochemistry. *J. Geochem. Explor.* Vol. 3, 319–336.
Plant, J. 1971. Orientation studies on stream sediment sampling for a regional geochemical survey in Northern Scotland. *Trans. Instn. Min. Metall. (Sect. B: Appl. earth sci.)* Vol. 80, B324–345.
Pointon, C. R. and **Ixer, R. A.** 1980. Parys Mountain mineral deposit, Anglesey, Wales: geology and ore mineralogy. *Trans. Instn. Min. Metall.* Vol. 89, B143–55.
Power, G. and **Somerville, I. D.** 1975. A preliminary report on the occurrence of minor sedimentary cycles in the Middle White Limestone (D_1 Lower Carboniferous) of North Wales. *Proc. Yorks. Geol. Soc.* Vol. 40, 491–97.
Quarfort, U. 1977. An alternative stream sampling method useful in contaminated areas. *Geol. Foren. Stockh. Forh.* Vol. 99, 72–74.
Roberts, E. 1958. The County of Anglesey. *Mem. Soil Surv. G.B.* HMSO.
Rosler, H. H. and **Lange, H.** 1972. *Geochemical tables.* (Amsterdam: Elsevier)
Sato, M. 1960. Oxidation of sulphide ore bodies, 1: Geochemical environment in terms of Eh and pH. *Econ. Geol.* Vol. 55, 928–961.
Shackleton, R. M. 1969. The Pre-Cambrian of North Wales. *In* **Wood, A.** (editor) *The Pre-Cambrian and Lower Palaeozoic rocks of Wales.* 1–22 (Cardiff: Univ. of Wales Press.)
— 1975. Precambrian Rocks of Wales. *In* **Harris, A. L.** and others (editors) *A correlation of Precambrian rocks in the British Isles*, Geol. Soc. London Spec. Rep. No. 6, 76–82.
Sinclair, A. J. 1974. Selection of threshold values in geochemical data using probability graphs. *J. Geochem. Explor.*, Vol. 3. 129–149.
— 1976. Application of probability graphs in mineral exploration. *Ass. Explor. Geochemists* Spec. Vol. 4.
Shiikawa, M., Wakasa, K. and **Tono, N.** 1974. Geochemical exploration for Kuroko deposits in north-east Japan. *In* **Elliot, I. L.** and **Fletcher, W. K.** (editors), *Geochemical Exploration 1974*, (Amsterdam: Elsevier), 65–76.
Smith, I. F. 1979. Airborne geophysical survey of part of Anglesey, North Wales. *Miner. Reconnaissance Prog. Rep. Inst. Geol. Sci.* No. 27.
Thanasuthipitak, T. 1974. *The relationship of mineralisation to petrology at Parys Mountain, Anglesey.* Ph.D. thesis, Univ. Aston in Birmingham (unpubl.).
Thorpe, R. S. 1974. Aspects of magmatism and plate tectonics in the Precambrian of England and Wales. *Geol. J.* Vol. 8, 115–36.
— 1978. Tectonic emplacement of ophiolitic rocks in the Precambrian Mona Complex of Anglesey. *Nature, London.* Vol. 276, 57–8.
Thurlow, J. G., Swanson, E. A. and **Strong, D. F.** 1975. Geology and lithogeochemistry of the Buchans polymetallic sulphide deposits, Newfoundland. *Econ. Geol.* Vol. 70, 130–144.
Virdi, N. S. 1978. The Mona Complex of Anglesey, North Wales and Plate Tectonics – A Reappraisal. *Bull. Ind. Geol. Assoc.* Vol. 11, 11–23.
Wheatley, C. J. V. 1971. Aspects of metallogenesis within the Southern Caledonides of Great Britain and Ireland. *Trans. Instn. Min. Metall.* Vol. 80, B211–23.
Wood, D. S. 1974. Ophiolites, Melanges, Blueschists and Ignimbrites: Early Caledonian Subduction in Wales? *In* **Dott, R. H.** and **Shaver, R.A.** (editors) *Modern and Ancient Geosynclinal Sedimentation, Spec. Publ. Soc. Econ. Paleontol. Mineral, Tulsa.* Vol. 19, 334–44.

APPENDIX 1 *LIST OF NAMED MINES AND TRIALS*

Mine	*Alternative names*	*Grid reference*[1]	*Minerals*	*Workings*	*References*
Ashcroft	Holyhead	228 799	Cu;	Shafts	M.J. 1858–61, 1871.
Bodjor		282 763	Cu;	Shafts (filled in)	M.J. 1861.
Bron-heulog		? 342 877	Cu;	Unlocated	Greenly 1919.
Bryngoleu		425 902	Cu;	Shaft	M.L. 1906–7.
Bull Bay	Porth-yr-hŵch; Ty-gwyn	421 942) 424 946) 418 943)	Cu;	Shafts and adits	M.J. 1863, 1881–4; O.S.
Caeronneg		458 923	Cu;	Shaft (filled in)	M.J. 1853.
Cefn-du-bach		331 898	Cu;	? Adits	M.J. 1861–2, 1868, 1891; M.L. 1861–64
City Dulas	?Llaneuddog	469 875	Pb; Ba;	Adits	Greenly 1919; Lewis 1967; O.S.; U.C.B.
Dinorben		378 941) 379 948) 384 947)	Cu; Pb;	Shafts and adits	M.J. 1862, 1868, 1884; O.S.
East Mona		479 914	Cu; Pb; Zn;	Shafts	M.J. 1858, 1860, 1861; O.S.
Gadair	Great Carmels Point	295 928 290 927	Cu; Pb; Zn;	Shafts and adits	Greenly 1919; M.J. 1838, 1841, 1847, 1848, 1849, 1872, 1891; O.S.
Gilfach		308 914	Cu;	Adit (filled in)	M.J. 1860.
Gwredog		417 900	Cu;	Shaft (filled in)	M.J. 1853.
Hells Mouth		393 948) 394 946)	Cu;	Shafts and adit	Greenly 1919; O.S.
Llanddona		577 804) 573 804)	Cu; Pb;	Adits and shaft	Greenly 1919; M.J. 1869.
Llanerchymedd		? 408 814	Pb;	Not visited	M.J. 1862, 1868–9.
Mona		443 904	Cu; Pb; Zn;	Shafts, adits and opencast	Greenly 1919; Manning 1959 and numerous others; M.J. 1830–88, 1897, 1928.
Morfa-du		431 901	Cu; Pb; Zn;	Shafts and adits	Greenly 1919; M.J. 1877–82.
Mynydd y garn		318 913) 323 901)	?Cu	Shafts and adits	Greenly 1919.
Mynydd Pant-y-gaseg	Pant-y-gaseg	412 945	Cu; Zn;	Shafts and adit	Greenly 1919; M.J. 1863, 1871–2; M.L. 1892, 1906–7.
New Parys		463 912	Cu;	Shaft	M.J. 1872.
Ogof Fawr		487 921	Cu;	Shafts and adits	Greenly 1919.

[1] The area lies wholly within 100-km square SH.

APPENDIX 1 (continued)

Parys		440 902	Cu; Pb; Zn;	Shafts, adits and opencast	Greenly 1919; Manning 1959 and numerous others; M.J. 1830–88, 1897, 1928.
Penbryn-yr-eglwys		295 924) 289 925)	Cu;	Shafts and adits	See Gadair.
Pendre		? 345 828	Cu;	Not visited	M.J. 1860–1.
Pentraeth		529 783	Cu;	Shafts (filled in)	Greenly 1919.
Porth Helygen	?Llanwenllwyfo	491 906	Cu;	Adit and ?shaft	Greenly 1919; M.J. 1835; O.S.
Porth-yr-hŵch		292 921	Cu;	Adit	M.J. 1881–4.
Red Hill		597 760	Cu;	?Open cut	M.J. 1856–7.
Rhoscolyn		269 766	Cu;	Adit and open cut	M.J. 1859, 1861, 1871.
Rhosgoch		411 895	Cu;	?Adit (filled in)	Greenly 1919.
Rhosmynach	East Parys; Rhosmonarch	482 914	Cu;	Shafts and adit	Greenly 1919; M.J. 1858, 1861, 1870–1, 1882,
South Brada		Unlocated	Pb;		M.L. 1864–66.
South Parys	Trysglwyn; Plas Newydd	438 896	Cu; Zn;	Pits	M.J. 1859, 1861, 1863, 1890.
West Mona		? 340 862	Cu;	Not visited	M.L. 1878.
Ynys-gwyddel		347 885	Cu;	Adit (filled in)	M.L. 1914.

Mineral abbreviations

Cu - Copper
Pb - Lead
Zn - Zinc
Ba - Baryte

Reference abbreviations

M.J. Mining Journal, Railway and Commercial Gazette, London.
M.L. List of Mines, Geol. Surv. London.
O.S. Old Series Ordnance Survey Maps.
U.C.B. Lligwy Papers in University College Library, Bangor.

APPENDIX 2 *LIST OF UNNAMED MINES AND TRIALS*

Grid reference	*Minerals*	*Workings*
271 746	? Cu	Open Cut
294 906	? Cu	Adit
304 927	? Cu	Adit
383 819	? Cu	Shaft
400 949	? Cu	Adit
409 947	Cu	Open Cut
412 933	Cu	Shaft
422 736	? Pb	Shaft (filled in) and adit
455 936	Cu	Shafts (filled in) and adit
467 922	Cu	Shaft (filled in)
470 932	Cu	Adit and ?shaft (filled in)

APPENDIX 3 *MINERALISATION RECORDED (UNWORKED)*

Grid reference	*Minerals*	*References*
303 909	Cu; Pb;	This survey
374 852	Cu;	Hawkins 1964. IGS Record SH 38 NE/2 (unpublished)
399 692	Ba;	Greenly 1919
408 701	Ba;	Greenly 1919
418 710	Ba;	Greenly 1919
432 728	Ba;	Greenly 1919
436 683	Cu; Pb;	Greenly 1919
442 732	Ba;	Greenly 1919
446 859	Cu; Pb;	This survey
459 919	Cu;	This survey
470 852	Ba;	Greenly 1919
481 918	Pb;	O.S. 78 NW Geol. Surv.
484 918	Pb;	O.S. 78 NW Geol. Surv.
517 786	Pb;	Greenly 1919
576 792	Cu;	This survey

APPENDIX 4 *SAMPLING AND ANALYTICAL VARIATION*

Six waters, sediments and panned concentrates were collected from the same site (SH 466 777) at different times during the sample collection period by different personnel who were only given the grid reference of the site. The site was near a road and therefore subject to contamination but was known to show background levels of the variables determined. The results (Table 8) are considered to show the normal range of total (sampling and analytical) variation to be expected in a background sample collected during this survey.

The exercise formed part of a wider study of sampling variation carried out in North Wales and the results of this work will be presented in more detail elsewhere. Here it is sufficient to add that, firstly, higher coefficients of variation are found for comparable elements in panned concentrates than in sediments and, secondly, variables present in heavy detrital phases tend to show the greatest variation. Variables held in a small number of discrete particles in the sample, such as Au or sometimes Sn as a contaminant, are particularly susceptible to wild fluctuations. This is largely a product of natural sorting in the stream, and in this case additional operator variation introduced by using six different panners. Within the sediment samples Zr shows by far the highest coefficient of variation. This is due to natural sorting, to laboratory subsampling, and to poor analytical reproducibility as a result of the refractory nature of zircon.

Table 8 Results of replicate drainage sampling on Anglesey. All values in ppm

Sample No.	1	2	3	4	5	6	Mean	Std. dev.	Coeff. var.
Sediment									
Cu	10	15	15	15	15	15	14.2	2.04	0.14
Pb	20	30	20	20	30	20	23.3	5.16	0.22
Zn	50	50	40	40	50	40	45.4	5.47	0.12
Ba	320	180	240	180	180	320	236	68.6	0.29
Co	10	13	13	13	13	13	12	1.22	0.10
Ni	18	18	24	18	18	24	20	3.1	0.15
Mn	1000	1000	750	1000	750	560	843	185	0.22
Zr	56	<56	100	130	<56	130	79	47.7	0.60
Fe_2O_3%	4.2	3.2	4.2	4.2	4.2	5.6	4.3	0.76	0.18
Panned concentrates									
Cu *	<6	15	8	25	15	<6	11.5	8.5	0.74
Pb	<13	90	<13	25	15	<13	24.9	33	1.32
Zn	45	50	45	130	65	50	64	33	0.51
Ba	120	190	150	120	230	65	145	58	0.40
Fe	23800	38300	29800	31800	50300	30000	34000	9240	0.27
Mn	300	400	260	310	300	320	315	46	0.14
Ni	60	65	60	60	60	65	62	2.6	0.04
Ti	870	1100	1200	1000	1900	820	1148	394	0.34
Ca	1900	2200	2100	2700	2500	3000	2400	410	0.17

*Values < detection limit set at half detection limit for calculations. Cu, Pb and Zn in water, Mo in sediment and Sn and Sb in panned concentrate were also determined but all results were below the detection limits.

APPENDIX 5 *REGIONAL VARIATION*

Gross variations of the data across Anglesey were studied by hand contoured, computer generated 'greyscale' maps (Jeffrey and others, 1976). On these maps the results are averaged on a "moving window" basis and the result output on a line-printer as a symbol covering an area of 0.35 km^2. A series of symbols represent different classes which, in this case, were defined as elemental concentrations corresponding to the 10, 30, 50, 70 and 90 percentile levels of the element distribution. In a few cases, because of stepped results or truncated data, it was not possible to adhere exactly to the percentile values; the most affected variables are Zn in water and Sn in panned concentrates. The unequal distribution of sample sites (Figure 4) resulted in arbitrary and imprecise contouring in some areas and insufficient sites were sampled on Holy Island to include this area. The averaging within a given area by the greyscale program produces a smoothing effect which tends to eliminate isolated very high or very low values and the lineprinter method of output produces a spatial error which can be as large as the area of the symbol. However, bearing in mind these limitations, the maps (Figures 18–34) do fulfil the purpose of drawing attention to large areas characterised by particular levels of a given element. The main features of the areal distributions are summarised below. Detailed interpretations are inappropriate on this type of data. High levels of Cu, Pb, Zn, Ba and Sn are detailed on the anomaly maps (Figures 6–13).

The patterns of Cu and Zn in sediments and panned concentrates (Figures 18, 19, 22, 23) are dominated by high values emanating from Parys Mountain. High Cu values on the north coast are also within an area of known mineralisation but high values of both elements near the northern end of the Coedana Granite, along the outcrop of the basal Carboniferous between Dulas and Malltreath, and along the line of the Bern Fault, may be more significant and are discussed in more detail elsewhere in this report. Moderately high values are found over parts of the Gwna Group, whilst lows characterise the Carboniferous Limestone and blown sand areas. Several isolated high values such as those on the coast at Benllech are related to contamination. Groups of samples containing detectable amounts of Zn in stream water are confined to the northern part of the island and are dominated by the high levels emanating from Parys Mountain (Figure 24). There may be a more general relationship to the Carmel Head Thrust and two isolated highs in the south may be related to the basal Carboniferous on the north side of Malltreath Marsh. The areal distribution of Fe (Figures 27, 28) is broadly similar to that of Cu and Zn except for (i) some high values in sediments that are associated with high manganese and related to hydrous oxide precipitates and (ii) some high levels over the Penmynydd Zone related to the ferruginous hornblende and glaucophane schists.

The pattern shown by Pb in sediments and concentrates (Figures 20, 21) is also similar to that of Cu and Zn except for the absence of high values over the basic rocks of the Gwna Group and increased 'noise' produced by contamination. As a result of contamination the pattern of Pb in panned concentrate shows several similarities to that of Sn in panned concentrate. The Sn distribution, in which high values are believed to be entirely the product of contamination, shows a large high centred on the Parys-Amlwch mining area and smaller peaks centred on Benllech, Pentreath, Holyhead, the Llanddona lead mine, villages between Bodedern, Llanfachreath and Cemaes, and the Llangefni–Pentre Berw–Malltreath area. It should be noted that the map of Sn in panned concentrate (Figure 13) cannot be used as an indicator of the degree of contamination of various streams on Anglesey because sampling was biased against contaminated sites.

A distinctive pattern is shown by Ba in both sediment and panned concentrates (Figures 25, 26). This is dominated by a belt of high values between Dulas and Malltreath coincident with the Old Red Sandstone and Basal Carboniferous outcrop. Moderately high levels can be related to the Coedana Granite, the Ordovician shales, parts of the Gwna Group and Penmynydd Zones, and the old mines at Llandonna and Parys. The prominent peaks in the south-east of the island result from drift-derived samples containing baryte which are discussed above. Low values, particularly in concentrates, outline Carboniferous Limestone outcrops and, less clearly, the Bedded Succession of the Mona Complex. The more confused pattern of the sediment results is attributed to a combination of less precise analytical data and potash feldspar and mica distribution.

The highest Mn results (Figures 29, 30) are related to the Afon Alaw, Cors-y-bol and some other freshwater alluvium-filled depressions containing peaty layers (Greenly, 1919), and are the result of hydrous oxide precipitates in the streams and hydrous oxide cemented layers in the alluvium and drift. Moderately high values are recorded over basic rocks, particularly in panned concentrates over the Gwna and Penmynydd rocks; low values are again prominent over limestone and blown sand.

High levels of Ti in panned concentrates are located over basic rocks of the Gwna Group and Penmynydd Zone and low values over limestone (Figure 31). High values over the gneisses may be caused by a hornblende picrite boulder train rather than bedrock. The pattern shown by Ni is similar (Figure 32). Highs are also formed over basic rocks of the Gwna Group and Penmynydd Zone, with a series of peaks occurring close to the Bern Fault. High values, which may be explained by contamination or the presence of pyrite, are also located around Parys Mountain and in the Dulas–Malltreath belt. Low Ni levels are recorded over limestone, blown sand and the southern part of the Coedana Granite.

High Ca results are related to limestone outcrop, but they also roughly delineate the Bedded Succession (particularly the Amlwch Beds in the west of the island) and basic rocks within the Gwna Group and Penmynydd Zones, whilst low values characterise the Ordovician and Old Red Sandstone (Figure 33). The pattern of Zr results is very confused (Figure 34) and this is attributed in part to poor analytical precision. High values show some relationship to the Ordovician outcrop, the Carboniferous Limestone around Benllech and blown sand, whilst a consistent group of low values is found over the Penmynydd Zone and the Amlwch Beds in the west of the island.

Areal variation is therefore related to bedrock geology, old mining areas, contamination, drift deposits and hydrous oxide precipitates. The following features were clearly defined geochemically:

(i) Carboniferous Limestone Series. Characterised by low levels of all the variables determined except Ca in panned concentrate and Zr in sediment.

(ii) Parys Mountain mineralisation. Indicated by high values of Cu, Pb, Zn and Fe in both sediments and concentrates, with patchy enrichment in Ni and Ba.

(iii) Basal Carboniferous between Malltreath and Dulas. Shown by high levels of Ba and Cu in panned concentrates and some increases in Zn, Fe and Ni in panned concentrates, Fe and Mn in sediment, and possibly Zn in water. Pb in panned concentrate is also prominent, but highs may be generated by contamination.

(iv) Basic rocks in the Gwna Belt around Cerrigceinwen. Indicated by elements concentrated in basic rocks, notably Mn, Ni, Ti and Ca.

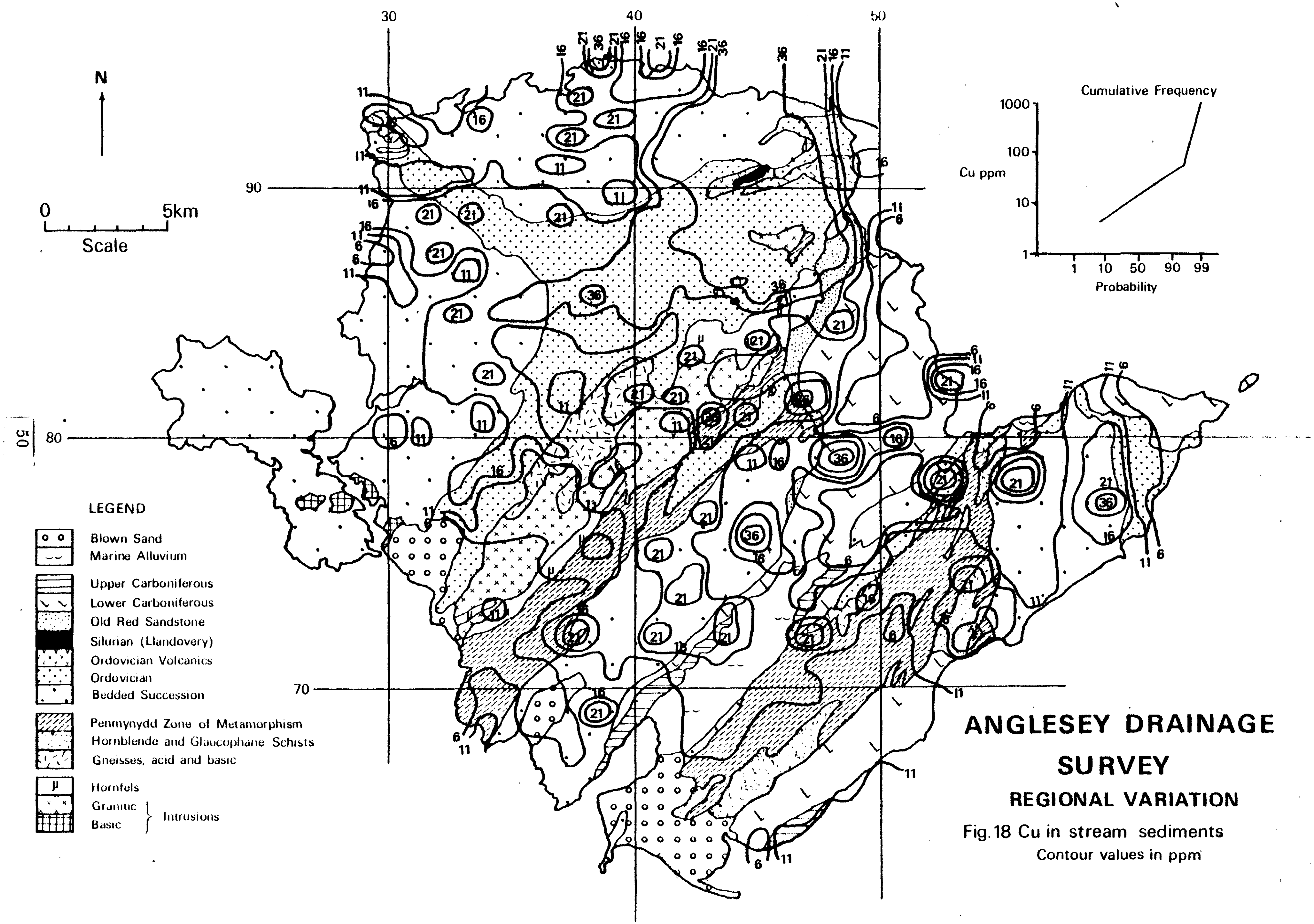
(v) Basic rocks within the Penmynydd Zone. High values of Ti, Ni and Mn in panned concentrates are recorded and the whole zone is characterised by low Cu and Pb in both sediments and concentrates.

(vi) Bern Fault, particularly near Pentre Berw. This feature is partly the result of contamination, but strong geochemical changes shown by Cu, Pb, Zn, Fe, Ni and Ti in panned concentrates, are related to the contrast across the fault between metabasic rocks in the Penmynydd Zone and the alluvium of the Malltreath Marsh or the Carboniferous Limestone Series.

(vii) Manganese-rich hydrous oxide deposits along the Afon Alaw. Shown by Mn in sediments and panned concentrates and Fe, Zn and possibly Ba and Pb in sediments.

(viii) Blown sand deposits. These show as lows for all variables except Zr in sediment.

Some further areas were distinguished by one or two variables; the Coedana Granite is outlined by high Ba, the Bedded Succession, especially the Amlwch Beds by high Ca and moderate levels of Ba in panned concentrates and low Zr in sediments, and the Ordovician sediments by high Ba and low Ca in panned concentrates. The gneisses are apparently defined by high Ti, Fe and Ni in panned concentrates but the feature may in part be produced by a boulder train.

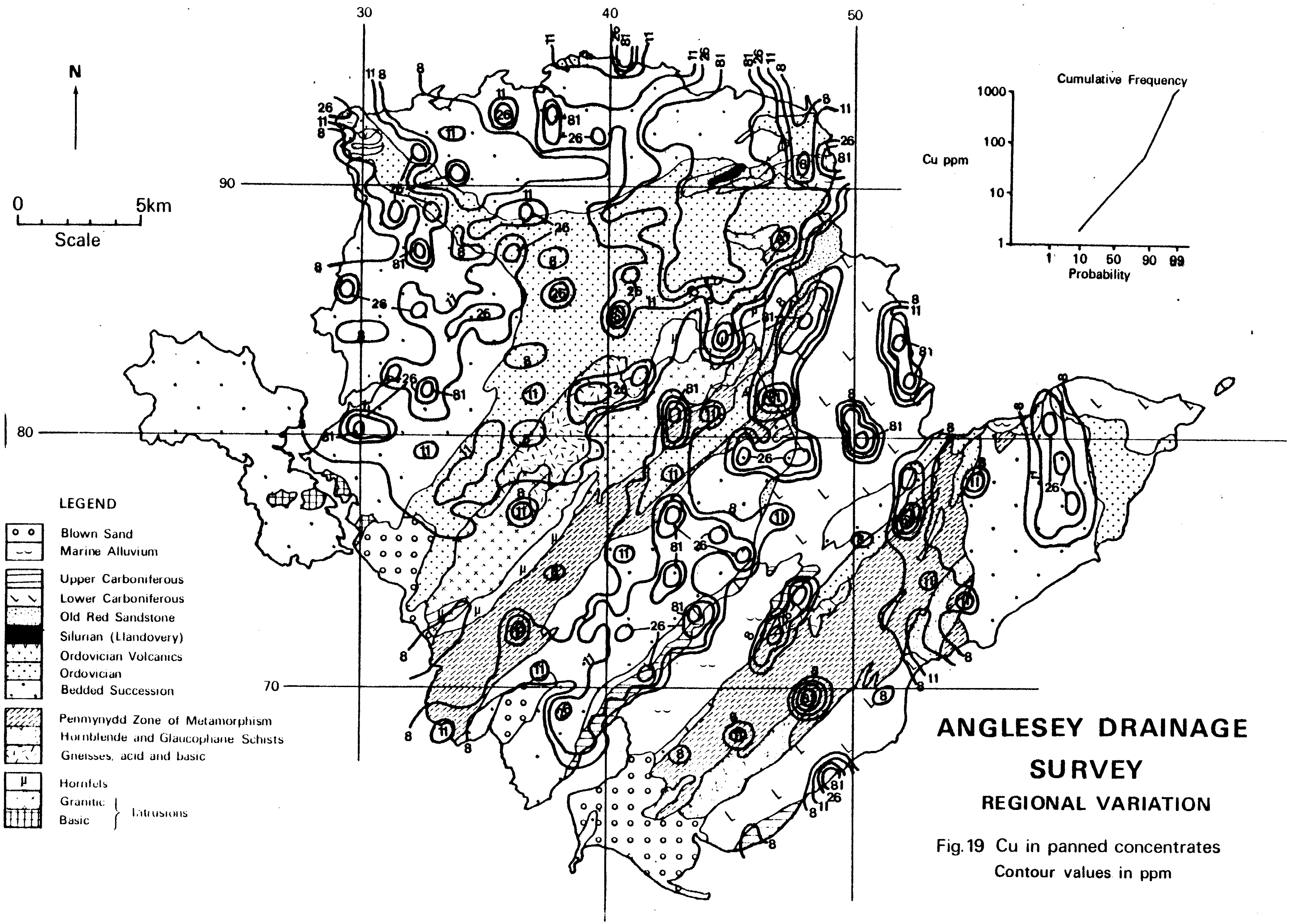


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 18 Cu in stream sediments

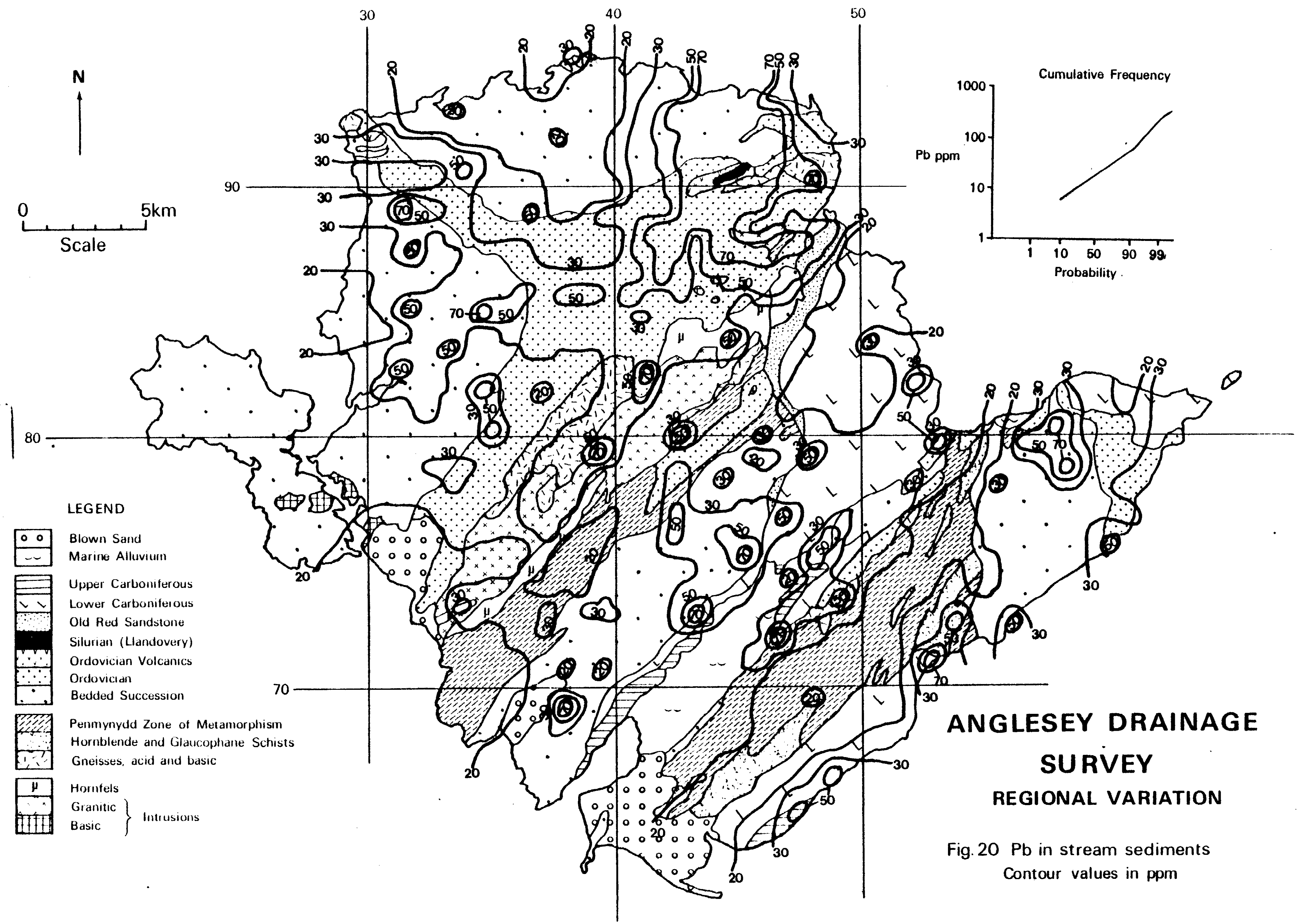
Contour values in ppm



ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

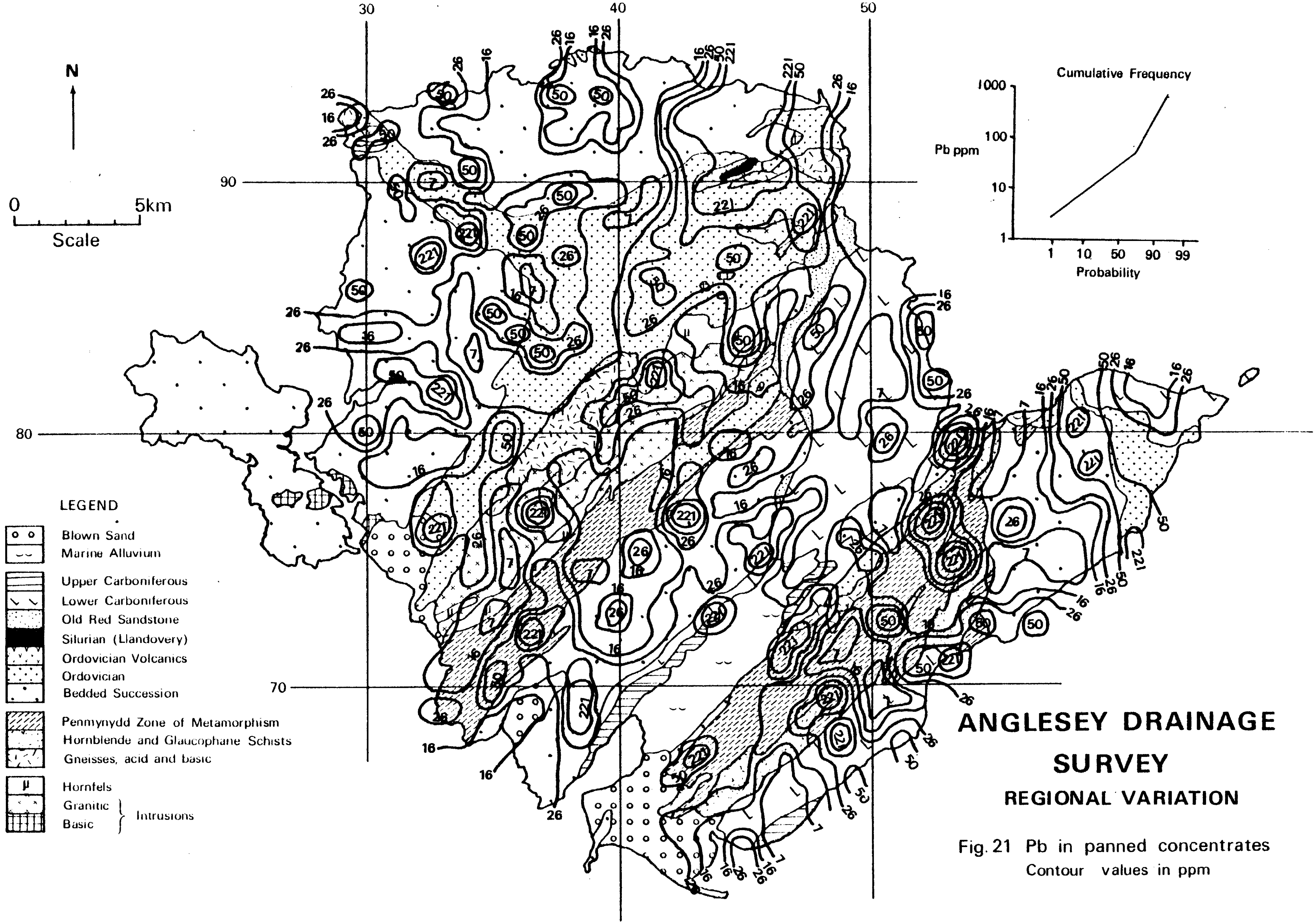
Fig. 19 Cu in panned concentrates
Contour values in ppm



ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

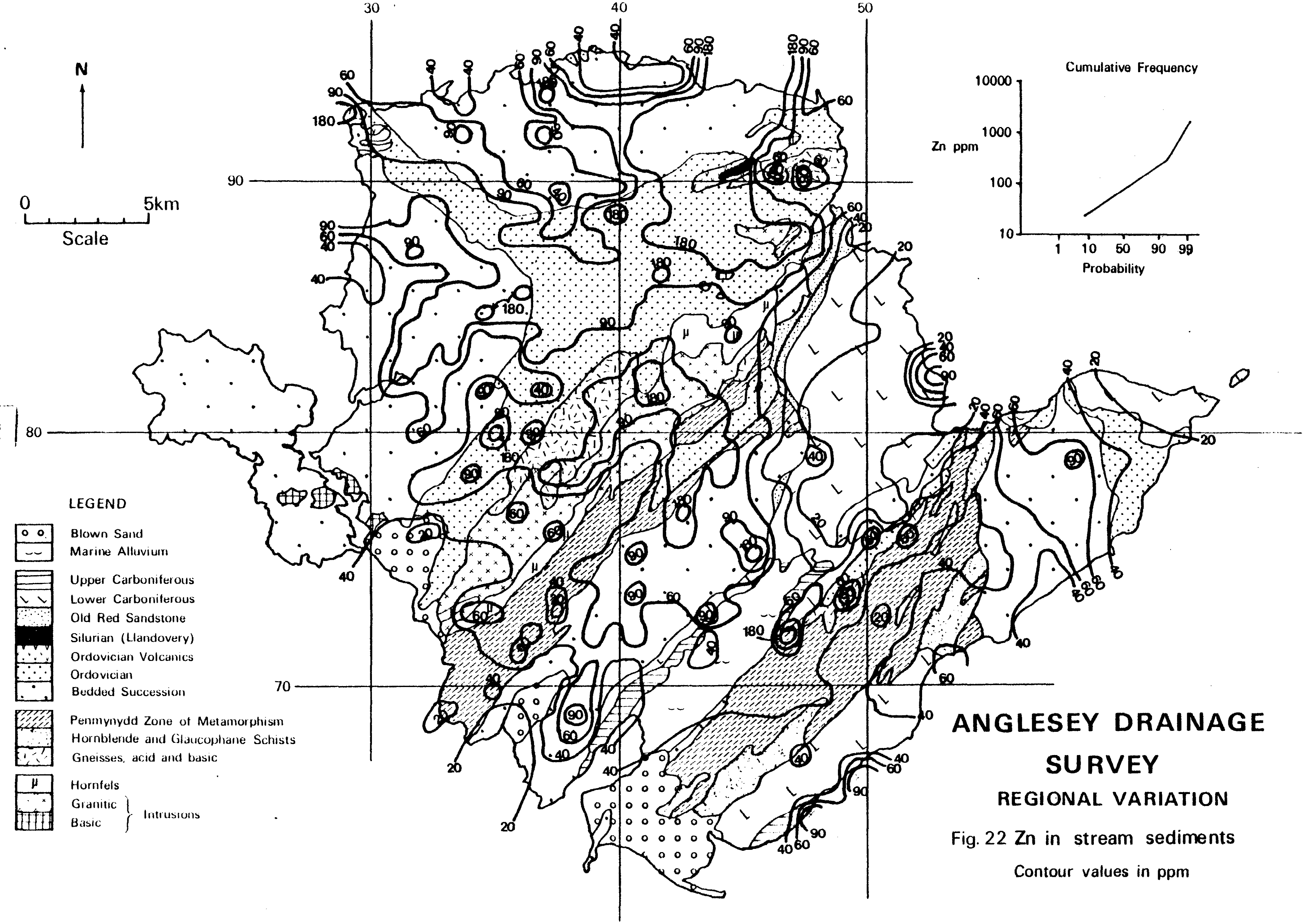
Fig. 20 Pb in stream sediments
Contour values in ppm



ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 21 Pb in panned concentrates
Contour values in ppm

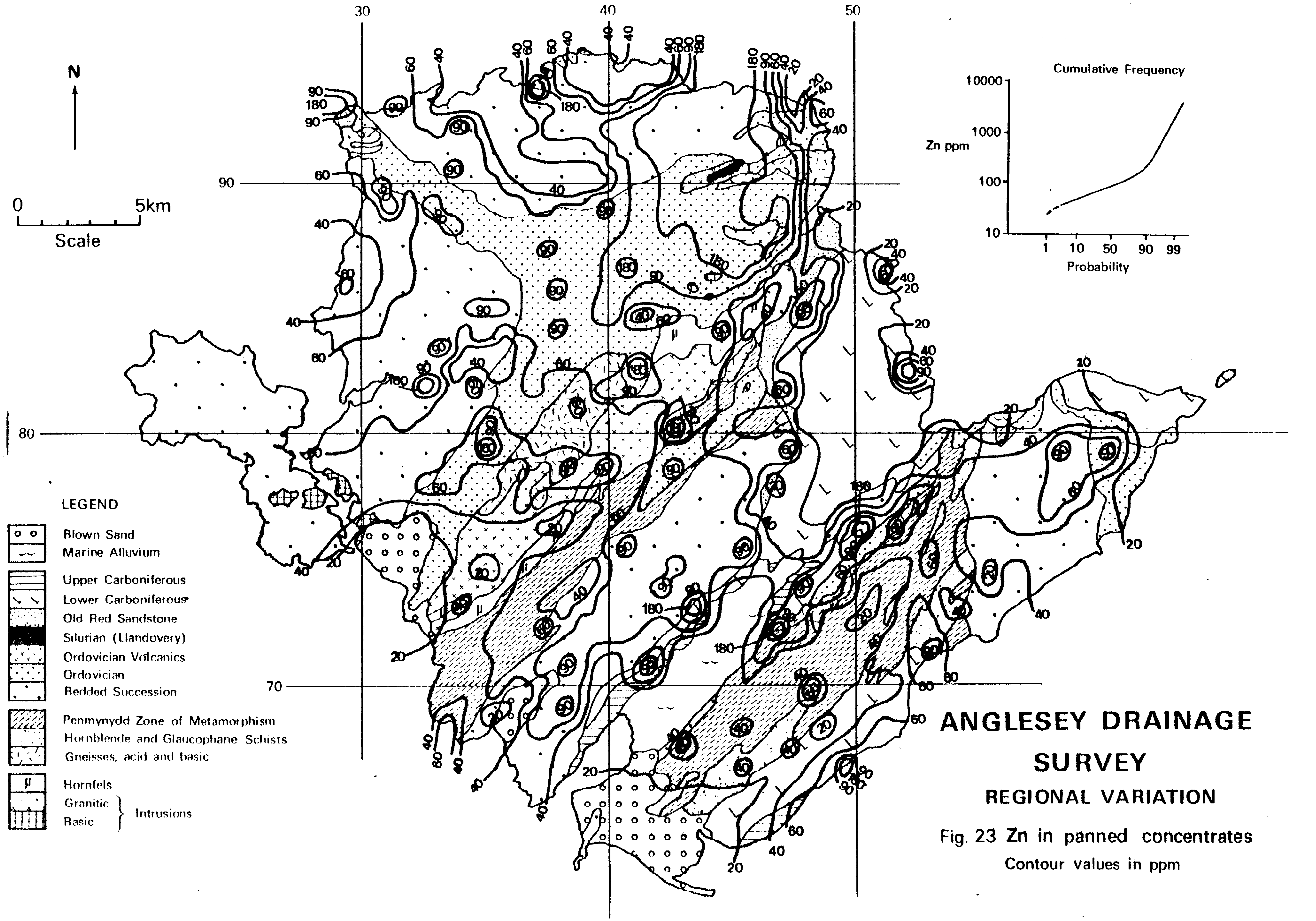


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 22 Zn in stream sediments

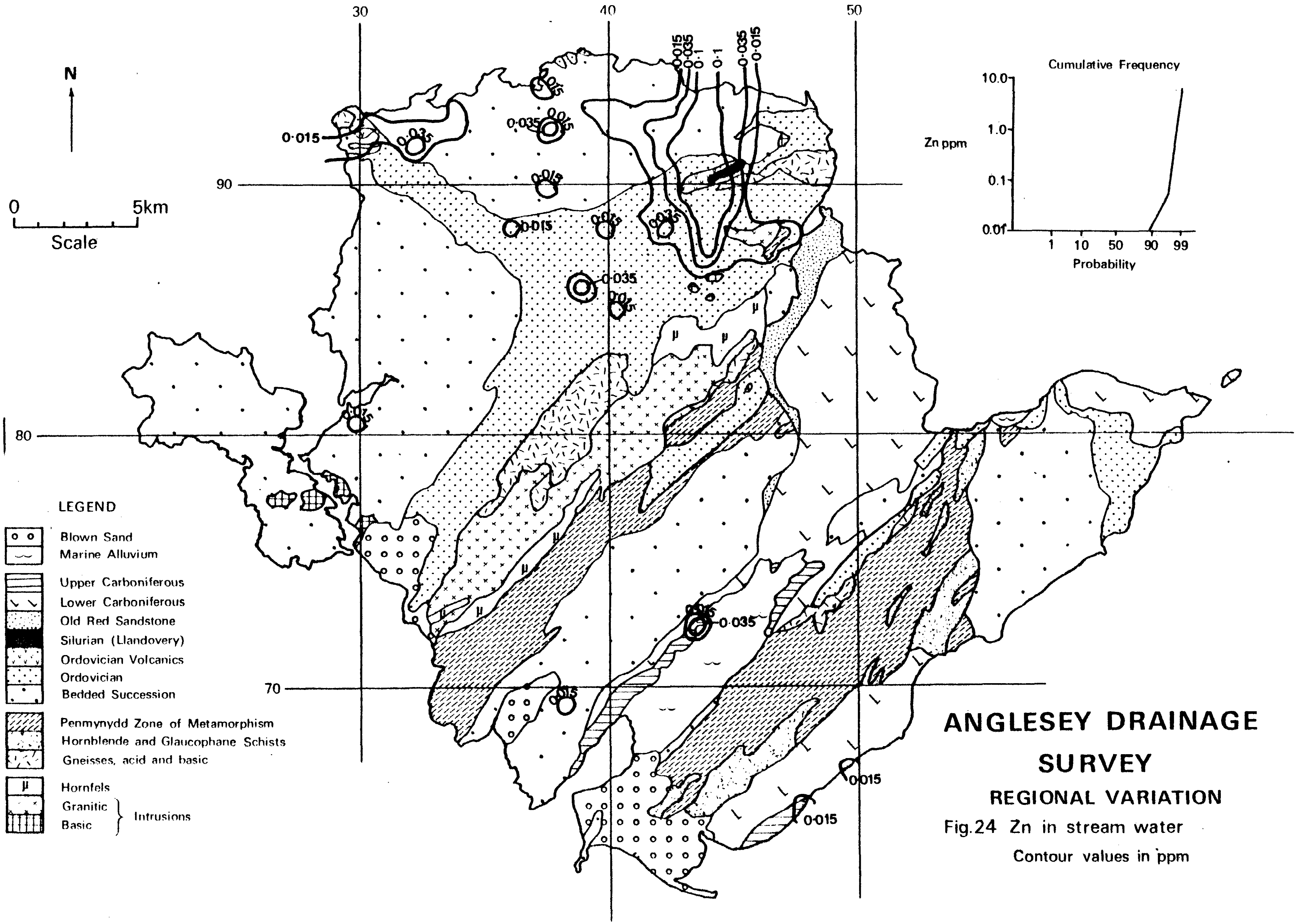
Contour values in ppm



ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 23 Zn in panned concentrates
Contour values in ppm

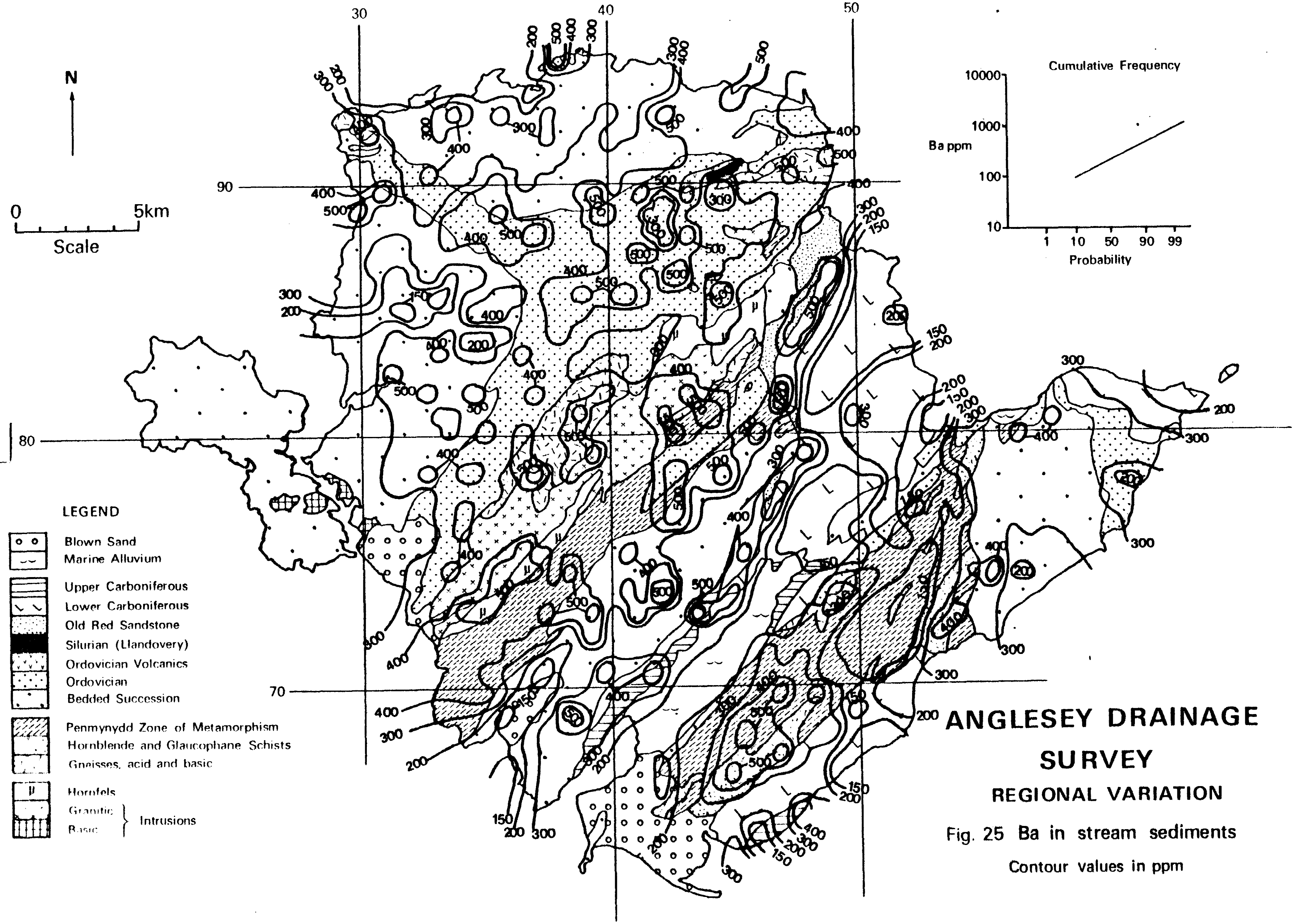


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig.24 Zn in stream water

Contour values in ppm

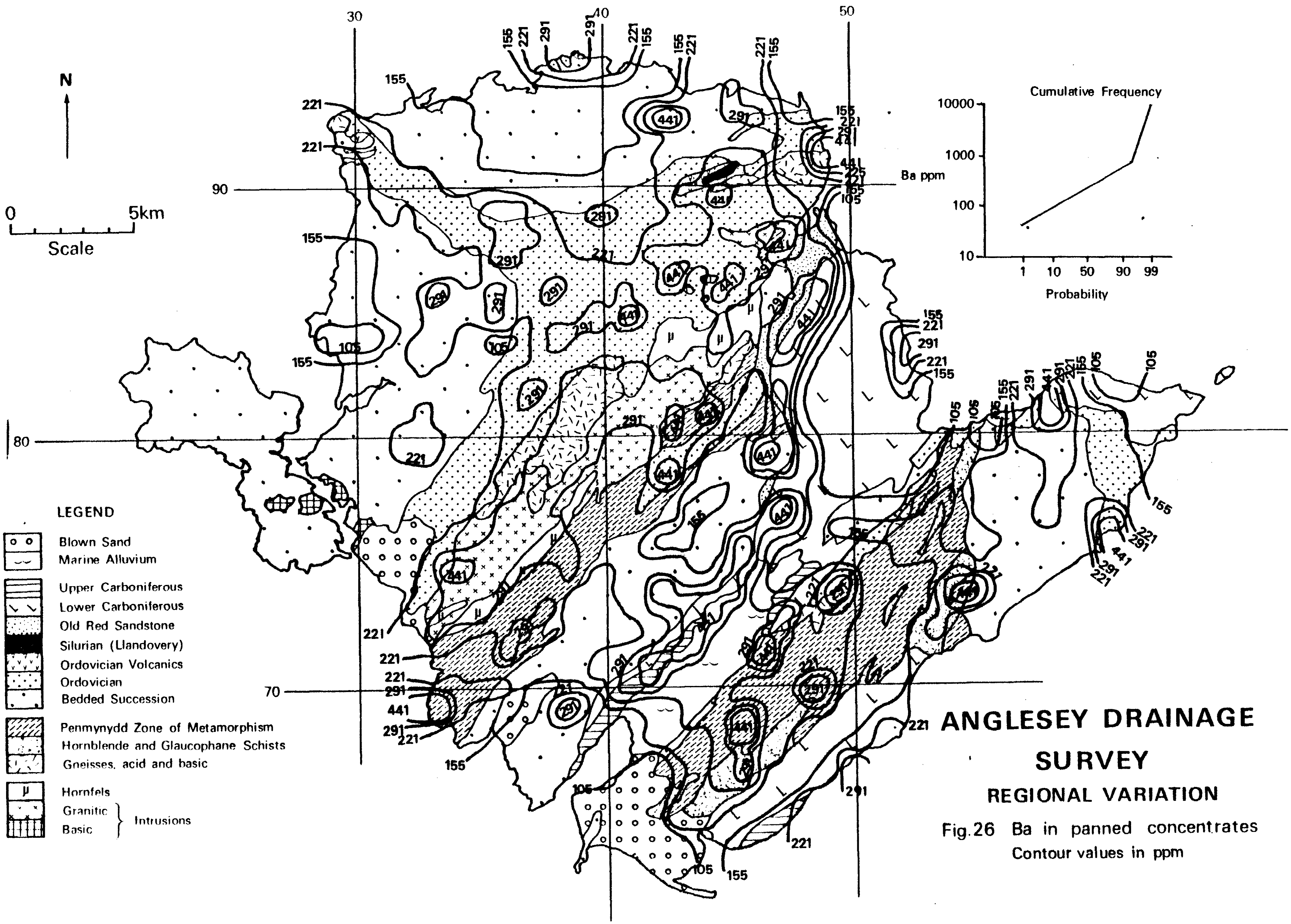


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 25 Ba in stream sediments

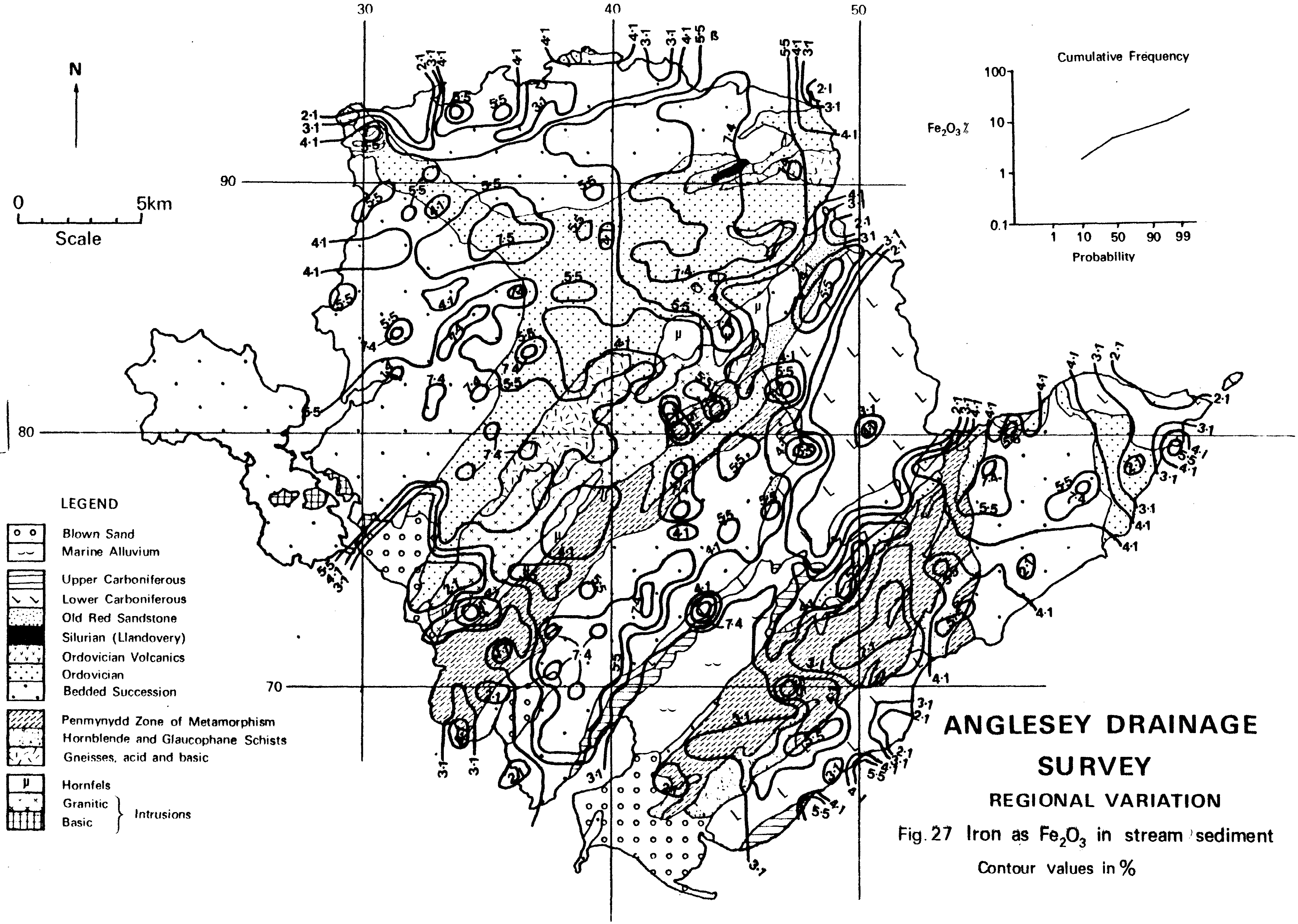
Contour values in ppm



ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig.26 Ba in panned concentrates
Contour values in ppm

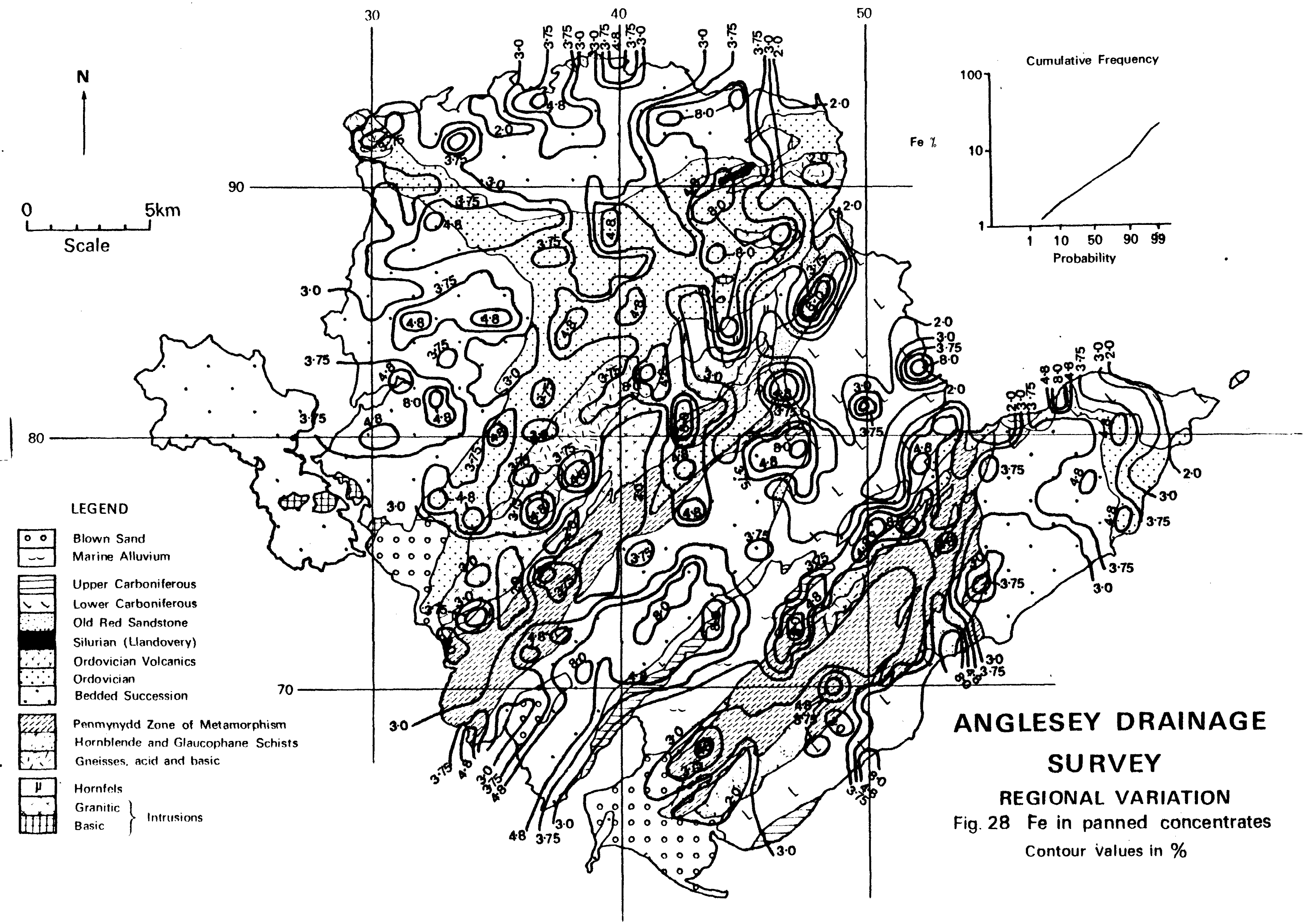


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 27 Iron as Fe_2O_3 in stream sediment

Contour values in %

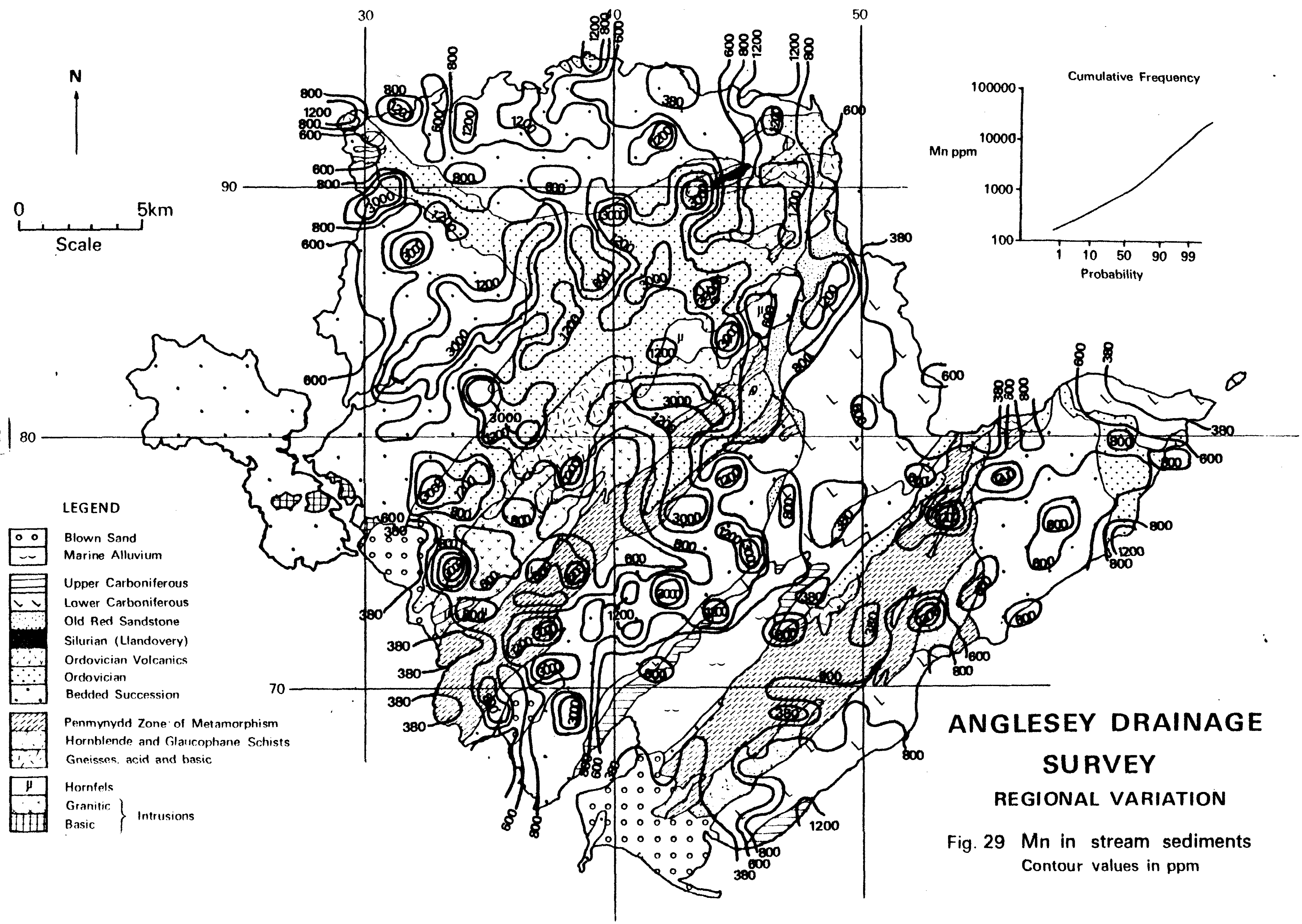


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 28 Fe in panned concentrates

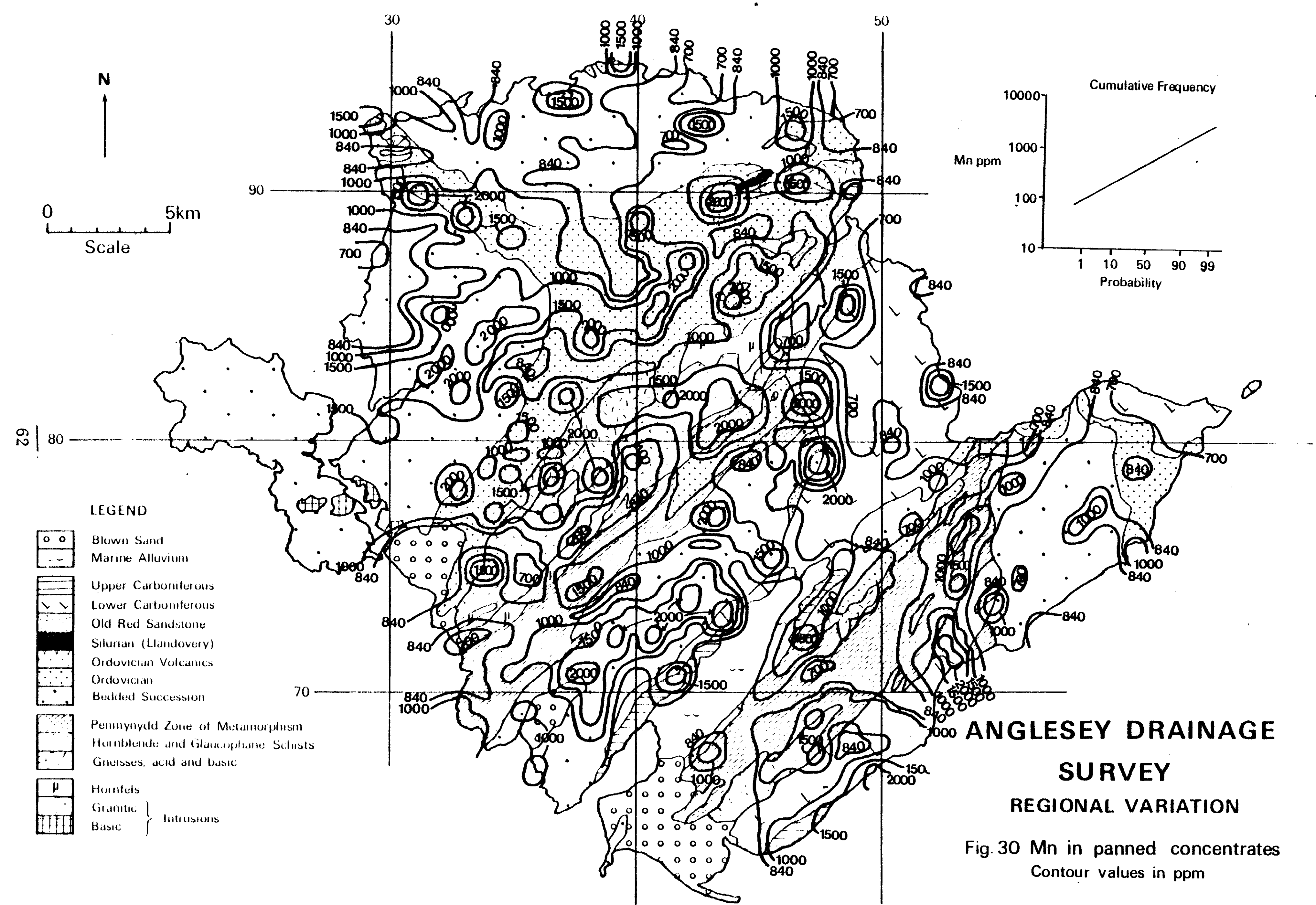
Contour values in %



ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 29 Mn in stream sediments
Contour values in ppm

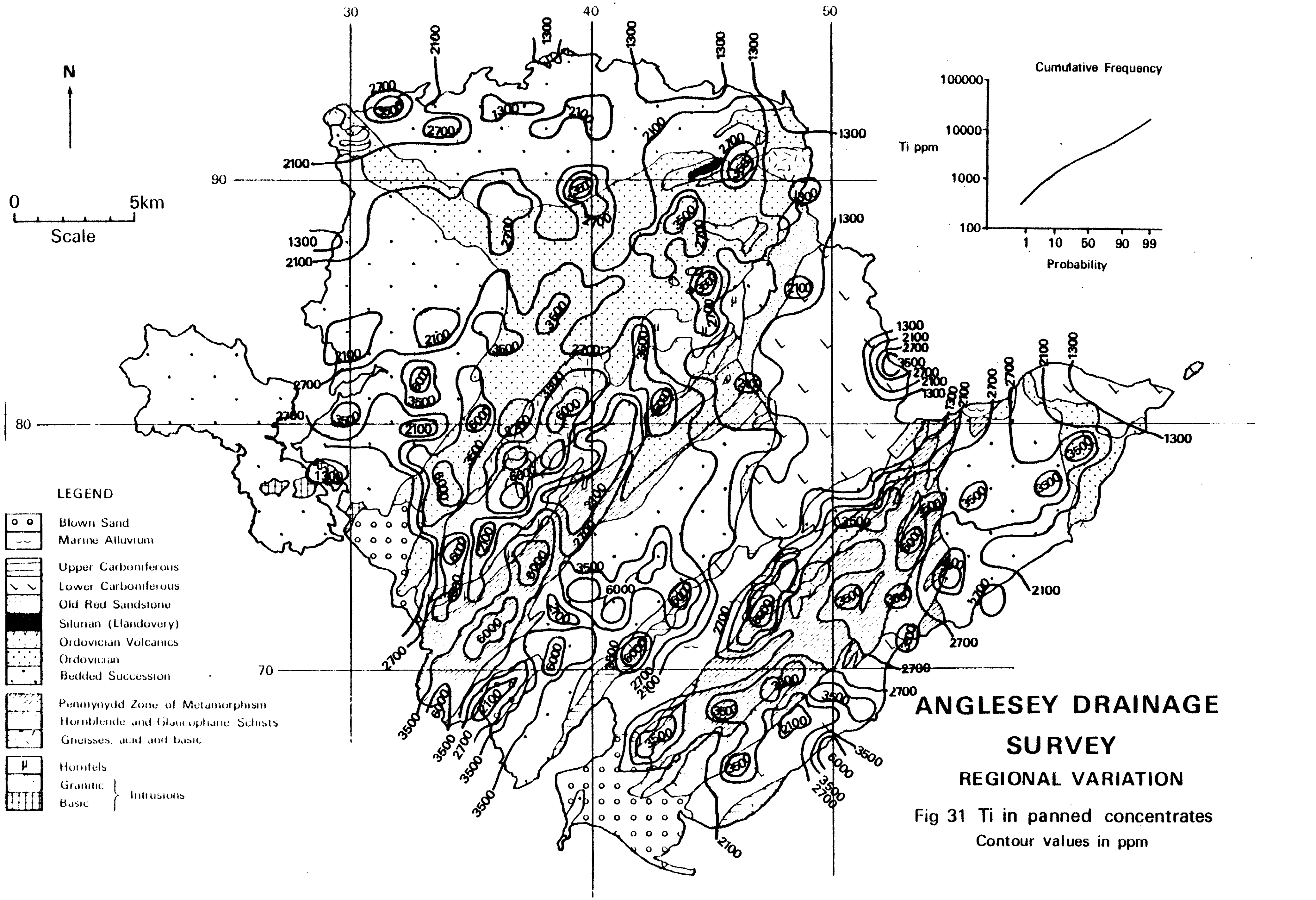


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig. 30 Mn in panned concentrates

Contour values in ppm

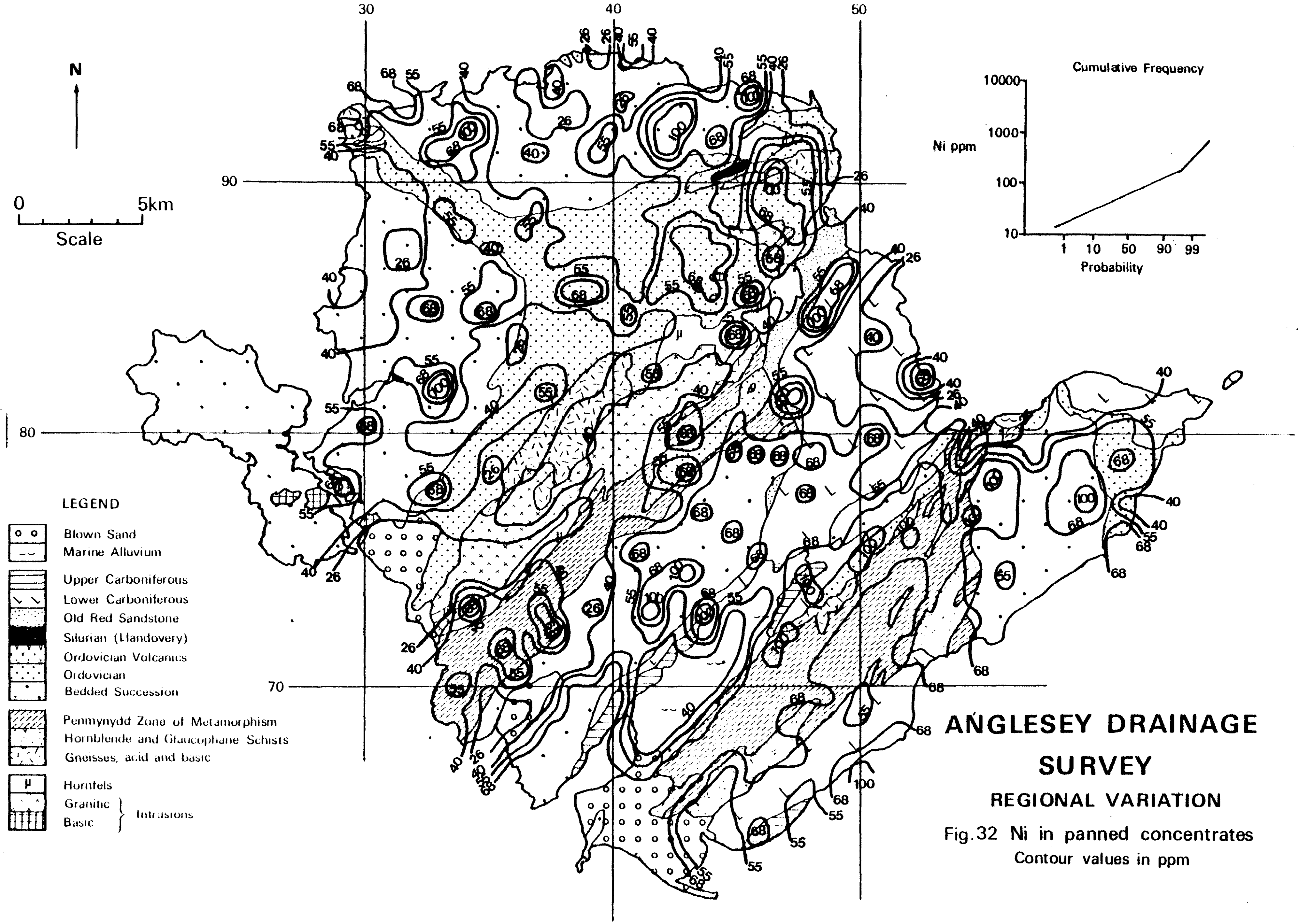


ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig 31 Ti in panned concentrates

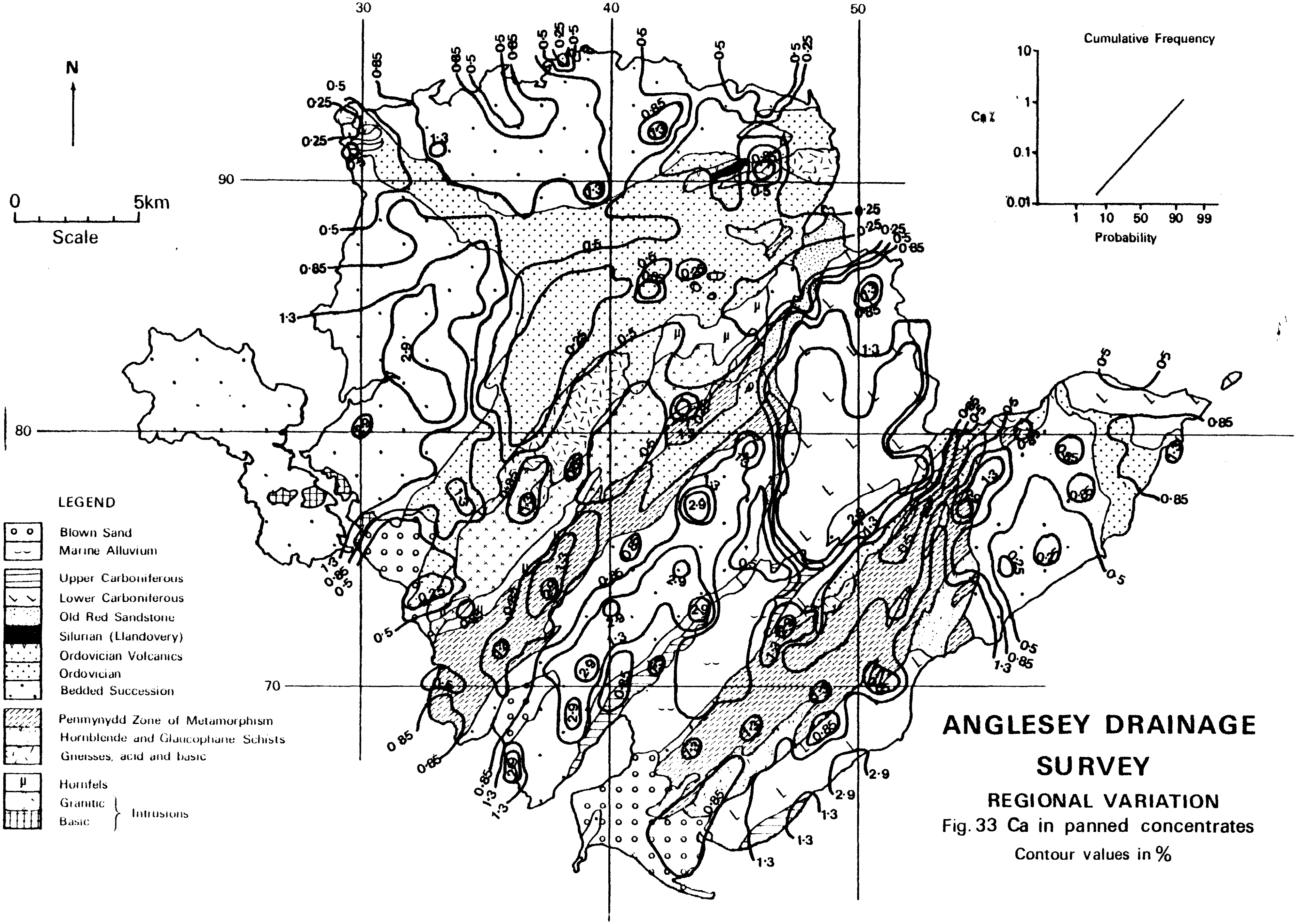
Contour values in ppm



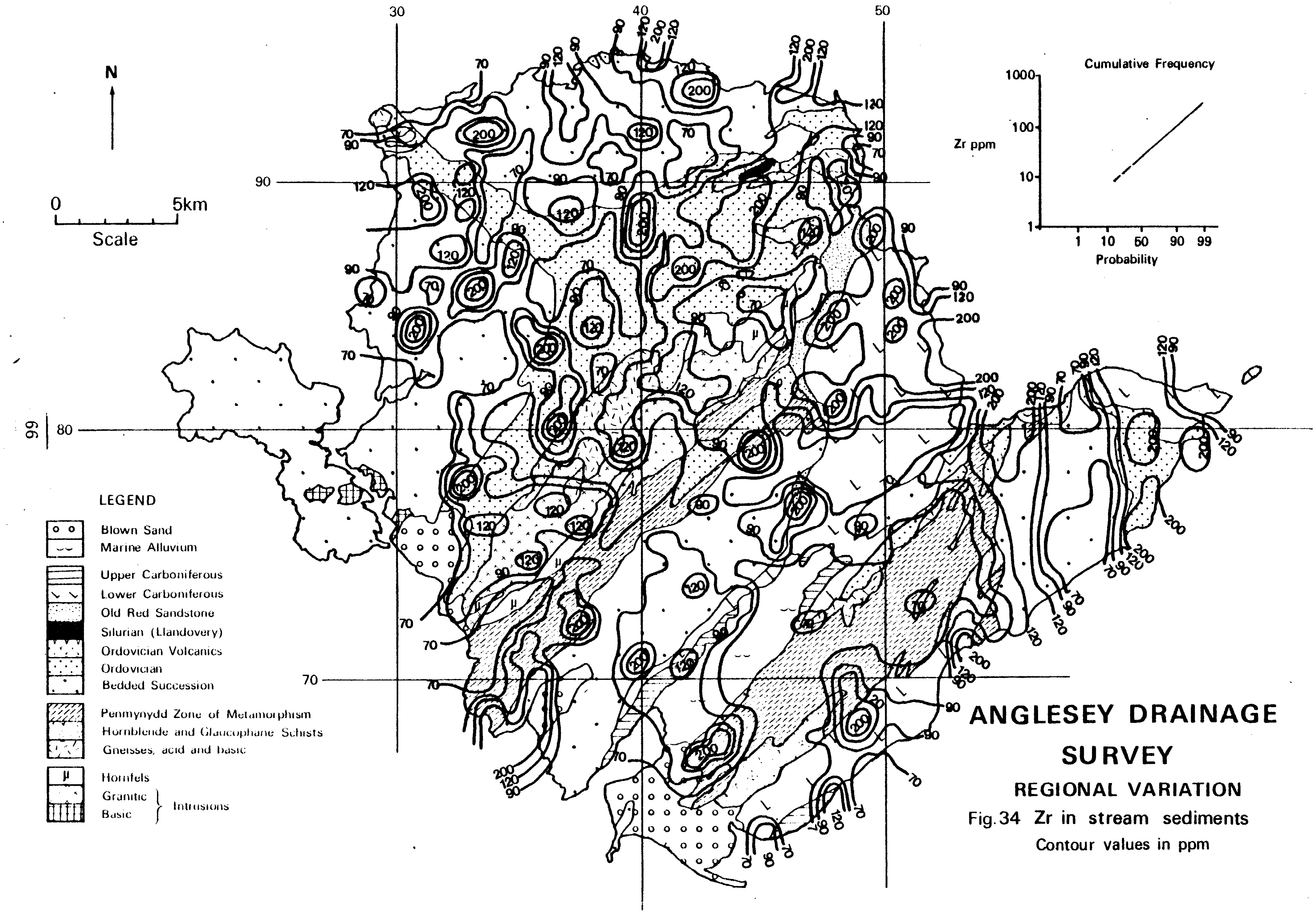
ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig.32 Ni in panned concentrates
Contour values in ppm



N
0 5km
Scale
Cumulative Frequency
Ca %
Probability
LEGEND
Blown Sand
Marine Alluvium
Upper Carboniferous
Lower Carboniferous
Old Red Sandstone
Silurian (Llandovery)
Ordovician Volcanics
Ordovician
Bedded Succession
Penmynydd Zone of Metamorphism
Hornblende and Glaucophane Schists
Gneisses, acid and basic
Hornfels
Granitic
Basic
Intrusions
ANGLESEY DRAINAGE
SURVEY
REGIONAL VARIATION
Fig. 33 Ca in panned concentrates
Contour values in %



ANGLESEY DRAINAGE SURVEY

REGIONAL VARIATION

Fig.34 Zr in stream sediments

Contour values in ppm

APPENDIX 6 *MINERALOGICAL EXAMINATION OF PANNED CONCENTRATES*

Fifty six panned concentrates were examined. In each case the sub-sample remaining after XRF analysis was first separated into 'sink' and 'float' fractions using methylene iodide (density 3.3 g/ml). A hand magnet was used to remove magnetite and metallic iron from the 'sink' fraction and the remainder separated into four fractions of decreasing magnetic susceptibility using an Eclipse variable magnet. All five fractions were examined semi-quantatively by XRF in order to locate the source of the metal anomalies and the relevant fractions then examined under the microscope. XRF was used to check the metal contents of individual grains or groups of grains and identifications checked as required by X-ray powder photography. The results are summarised in Table 6.