Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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No. 22

Geochemical and geophysical investigations north-west of Llanrwst, North Wales

INSTITUTE OF GEOLOGICAL SCIENCES

Natural Environment Research Council

Mineral Reconnaissance Programme

Report No. 22

Geochemical and geophysical investigations north-west of Llanrwst, North Wales

Geochemistry

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Geophysics

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Notes on the geology of the area
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and mineralogical work
by D. J. Morgan, BSc, PhD

London 1978

A Report prepared for the Department of Industry

Mineral Reconnaissance Programme Reports

1 The concealed granite roof in south-west Cornwall

2 Geochemical and geophysical investigations around Garras Mine, near Truro, Cornwall

3 Molybdenite mineralisation in Precambrian rocks near Lairg, Scotland

4 Investigation of copper mineralisation at Vidlin, Shetland

5 Preliminary mineral reconnaissance of Central Wales

6 Report on geophysical surveys at Struy, Inverness-shire

7 Investigation of tungsten and other mineralisation associated with the Skiddaw Granite near Carrock Mine, Cumbria

8 Investigation of stratiform sulphide mineralisation in parts of central Perthshire

9 Investigation of disseminated copper mineralisation near Kimelford, Argyllshire, Scotland

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22 Geochemical and geophysical investigations north-west of Llanrwst, North Wales

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Summary

Reconnaissance stream sediment surveys, carried out both by IGS and by Noranda Exploration (UK) Limited, detected zinc anomalies in the Afon Dulyn. It seemed probable either that they reflected a hidden extension of the Llanrwst lead-zinc mining field, or that they were concentrations related in the first instance to hydrous oxide precipitates produced by changes in the secondary environment. To test which of these possibilities was the most likely, a more detailed drainage survey of the Afon Dulyn and Llyn Eigiau areas was carried out. Stream sediment, panned concentrate and stream water samples were collected from each of 28 sites and analysed for a range of elements which included copper, lead and zinc in all three sample types, and iron, manganese and barium in sediments and concentrates. Readings were taken of the pH in stream water and soil at many points in the area. In addition, ground magnetic traverses were surveyed in the Foel Fras and Drosgl areas where there are known to be positive aeromagnetic anomalies.

The analytical results were examined in some detail by various statistical methods, from which it was concluded that most of the high zinc in stream sediment results were related to hydrous oxide precipitates. The distribution of elements in a few samples showed some indications of mineralisation, but mineralogical examination of the panned concentrates from these sites found no mineral phases which could be related directly to mineralisation or contamination, zinc occurring mainly in iron oxide coatings. It is thus apparent that a source of zinc exists in the general area, perhaps on the wide interfluves, but it is not known whether this source is dispersed or concentrated (i.e. mineralisation).

The ground magnetic traverses indicated that the airborne anomaly over Foel Fras is a complex anomaly caused by the Foel Fras Volcanic Complex and Conway Rhyolite Formation whilst that near Drosgl is related to a diorite body.

It is considered that on the available evidence no further work can be justified, but further information will be provided by geological remapping being carried out in the area at present.

INTRODUCTION

This report describes an investigation of anomalous lead and zinc levels in stream sediment samples from the Afon Dulyn and Llyn Eigiau catchments found as a result of two geochemical drainage surveys. The first, by Noranda Exploration (UK) Limited, submitted under the Department of Industry Fiscal Incentive Scheme, concluded that the levels of lead and especially zinc recorded in the Afon Dulyn were too high to be solely the product of secondary environment precipitation effects (i.e. the scavenging and co-precipitation of metals such as barium, lead and zinc with iron and manganese hydrous oxides as a result of changes in physical conditions at or near surface). Although follow-up work was recommended in the report, none is known to have been carried out. The second drainage survey was by IGS during a programme of uranium exploration and zinc anomalies were again recorded in the Dulyn catchment and also in that of Llyn Eigiau. These were not followed up as other areas were considered to have greater potential in terms of uranium mineralisation.

The current interest of IGS in the area was stimulated by (a) the conclusion of Noranda Exploration (UK) that the anomalies were not solely the product of secondary environment effects, which were not tested by further work, and (b) the closeness of the anomalous area to known mineralisation in the Llanrwst lead-zinc mining area and the vein mineralisation exploited at Trecastell Mine (Dewey and Smith, 1922).

The Dulyn catchment lies about 8 km to the north-west of Llanrwst (Fig. 1). The land rises from near sea level in the east, where it joins the Conwy Valley, to over 1000 m on Carnedd Llywelyn in the west. In the area of this investigation the terrain is mountainous and vegetation is restricted to rough grassland and heather. Vegetation is

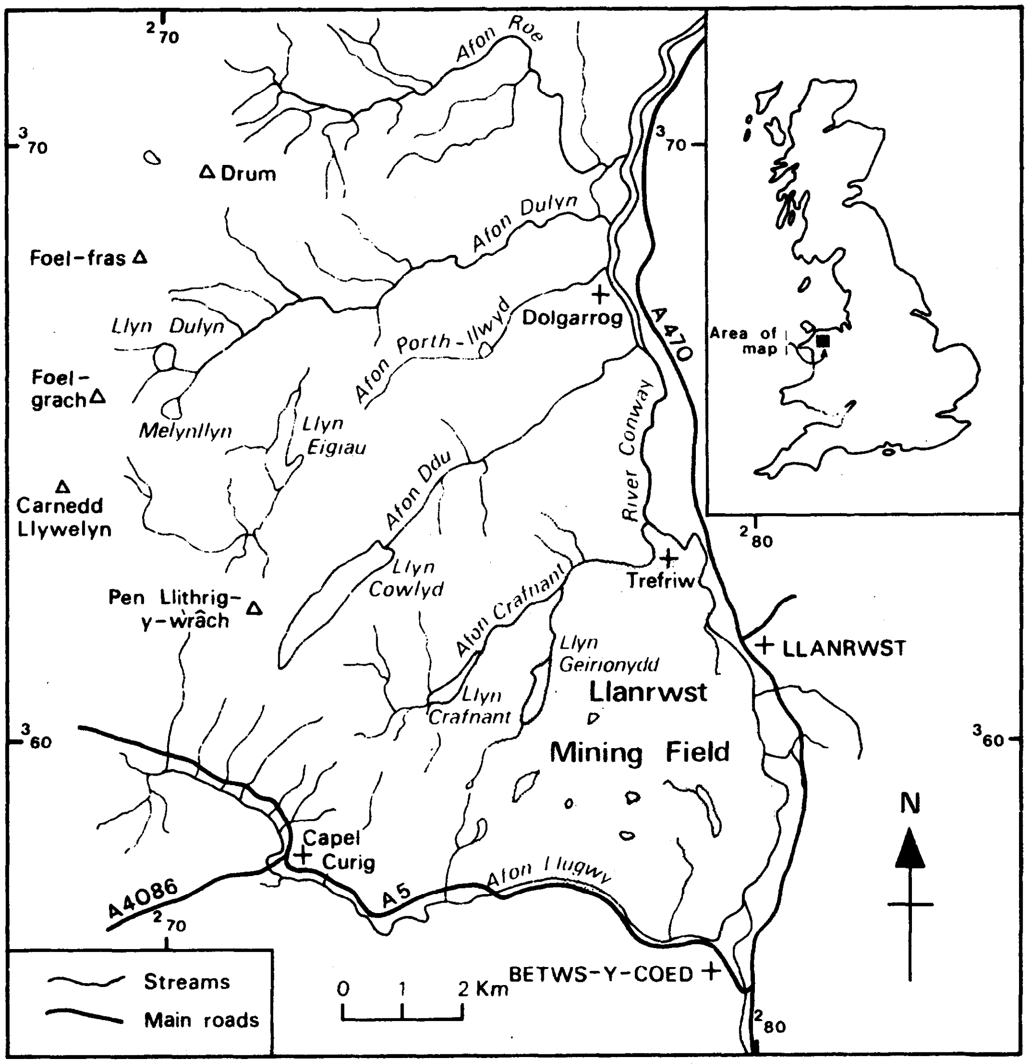

Fig. 1 Location of the Investigation

frequently underlain by peat in the upper part of the catchment, and so secondary environment effects leading to the scavenging and co-precipitation of certain metals on Fe and Mn sesquioxides might be expected. The natural drainage has been extensively modified in the last thirty years by hydro-electric and reservoir schemes. The effect of these modifications on the stream sediment is uncertain, but some large stream courses now only have a very low flow for most of the year. Tunnels cross stream catchments and there is the possibility of fine sediment being transported across interfluves.

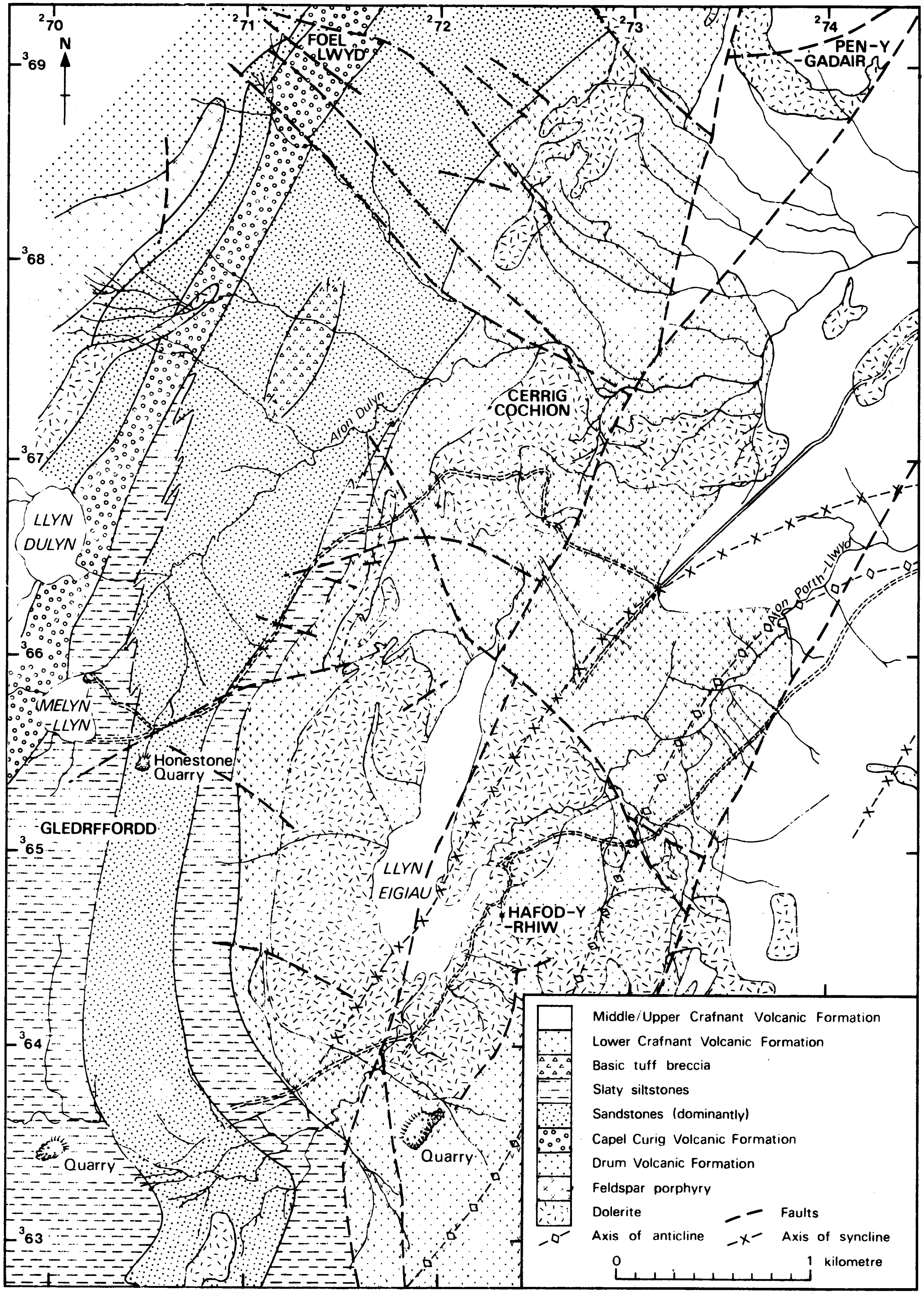

Fig. 2 Simplified Geology of the Dulyn Area

GEOLOGY

The geology of the Dulyn catchment (Fig. 2) is much obscured by drift, mainly boulder clay and peat. Exposure is good on the higher ground between Foel-Lwyd and Pen y Gadair in the north and from Gledrffordd to Cerrig Cochion in the south. Here the sequence is entirely of Ordovician (Caradoc) age, ranging from the Capel Curig Volcanic Formation to the Middle and Upper Crafnant Volcanic Formations. In this sequence the volcanic rocks are predominantly acid tuffs which, in the Middle and Upper Crafnant Volcanic Formations, are closely admixed with sediments. The sediments consist of sandstones and slaty siltstones. Basic tuffs occur at a few horizons and intrusive dolerites form a distinctive component of the geology at surface.

Most of the outcrops to the north of Llyn Eigiau show the sequence dipping steeply to the east-south-east. East of Llyn Eigiau the outcrop is complicated by folding. Faults are generally steeply inclined, normal faults, with no fixed relationship to folding. The prominent alignments of the Colwyd and Eigiau valleys appear to be fault controlled in part although little displacement occurs. There is no past mining activity or record of any significant mineralisation in the Dulyn catchment.

RECONNAISSANCE DRAINAGE SURVEYS

Noranda Exploration (UK) survey

'Grab' stream sediments (i.e. sediment samples not sieved at site) were collected over a wide area to the north and west of Llanrwst and analysed for copper, lead and zinc; many high lead and zinc and a few high copper values were recorded. The higher lead (> 100 ppm) and copper (> 40 ppm) values could be related to the known mineralisation west of Llanrwst, but high zinc values (>1000 ppm) were recorded both

in and around the old mining area and in the Afon Dulyn. It was concluded that the zinc values recorded (up to 5500 ppm) in the Dulyn area were too high to be solely the product of secondary environment effects, and further stream sediment sampling, soil sampling, and an IP survey were recommended. However, as far as is known, this work was not carried out. No results for iron or manganese in the sediments were given, which makes it difficult to evaluate the probable secondary environment contribution to the zinc content of these samples.

IGS survey

Stream sediment samples, wet sieved on site, were collected at a density of about 1 sample per 4 km^2 and analysed for a wide range of elements. Wet sieving, using more than the absolute minimum of water, has the effect of reducing the clay, organic and sesquioxide content compared with a grabbed sample. Threshold levels for the analytical results were determined from inflexion points on cumulative frequency curves constructed from the 25 samples collected in the area covered by the 1:25,000 Ordnance Survey Sheet SH 76. Copper and iron showed no distinct sub-populations and the geometric mean plus geometric deviation (i.e. the antilog of the standard deviation of log-transformed data) was arbitarily taken as the threshold level.

The results showed highly anomalous values of lead and zinc in samples derived from known mineralisation to the west of Llanrwst, and some anomalous values of zinc (>400 ppm), manganese ($>1\%$) and iron ($>14\%$) together with one high lead value (>100 ppm), in the Afon Dulyn and Llyn Eigiau catchments.

High zinc values generally occurred in samples containing high iron and manganese, which suggested that hydrous oxide precipitation effects were at least partly responsible for the zinc anomalies. The sample from

this survey which seemed most likely to be related to mineralisation, i.e. the highest zinc content not associated with high iron and manganese results, was collected at SH 7160 6358, from a stream draining an area south of Llyn Eigiau. This conclusion was supported by examining the inter-relationship of elements likely to be involved in hydrous oxide precipitation effects by various statistical methods.

Conclusions

Both surveys showed a group of high zinc values to the north of the known mineralisation. Detailed comparisons of the results from the two surveys are not possible because of the different sample points and sampling methods. As there is no significant contamination in the area, there are two possible explanations for the anomalies to the north of the known mineralisation in the Llyn Eigiau and Afon Dulyn catchments, firstly that they are the product of hydrous oxide precipitation effects, the zinc coming from a dispersed source, or secondly that they are reflecting hidden zinc mineralisation (i.e. a concentrated source) in the area, perhaps similar to the isolated occurrence of vein mineralisation formerly exploited at Trecastell Mine.

It was decided to try to determine which was the more likely source of the zinc anomalies, by the relatively low cost method of a more detailed drainage survey of the area showing anomalous zinc results, before embarking on more costly soil and IP surveys.

DETAILED DRAINAGE SURVEY

Method

Twenty eight sites in the upper part of the Afon Dulyn catchment and part of the Llyn Eigiau catchment were sampled. At each site samples of the water and stream sediment were taken and a panned concentrate sample made from part of the sediment sample using methods described 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 perchloric acid and analysed for Cu, Pb and Zn by AAS without further sample preparation. Stream sediments were wet-sieved at site to pass 8 mesh (2 mm nominal aperture), dried and then sieved in the laboratory. The -100 mesh (0.15 mm nominal aperture) fraction was taken and ground prior to analysis. Sub-samples of the ground, -100 mesh fraction were analysed for Cu, Pb and Zn by atomic absorption spectroscopy and for Mn, Fe and Ba by optical emission spectroscopy. Panned concentrate samples (about 20 g) were made at site from about 5 kg of the -8 mesh fraction of the stream sediment. These were dried and tema-ground in the laboratory before analysis for Cu, Pb, Zn, Mn, Fe, Ba, Ce, Ca, Ni, Ti, Sn and Ba by X-ray fluorescence.

Readings were taken of pH in soil, ground water and stream water near each sample site and at many other points in the area. The presence and strength of iron and manganese precipitates were noted, and rock outcrops in the vicinity of sample sites and measuring points were examined.

TABLE 1. Summary of analytical results

Element	Sample	Median	Mean	Max.	Min.
Cu	Sediment	15	17.32	35	5
Pb	"	60	66.78	110	30
Zn	"	420	522.1	2400	110
Mn%	"	1.439	2.589	25.40	0.119
Fe%	"	4.751	5.354	16.00	2.620
Ba	"	377	454.3	2500	180
Zn	Stream water	0.055	0.101	0.34	<0.01
Cu	Panned concentrate	16.5	45.78	831	7
Pb	"	35	41.42	175	7
Zn	"	126	164.6	451	80
Mn%	"	0.392	0.417	1.064	0.138
Fe%	"	9.18	9.459	14.703	5.865
Ba	"	280	287.7	592	152
Ce	"	106	149.0	660	47
Ca%	"	1.905	1.712	4.393	0.158
Ni	"	36.5	36.71	68	18
Ti%	"	3.03	3.717	9.073	0.482

Cu and Pb were analysed in stream water but values were all below the detection limits (approx. 0.02 and 0.05 ppm respectively).

Sn and Sb were sought in panned concentrates, but all values were close to or below the detection limits (11 ppm Sb, 9 ppm Sn).

All results in ppm unless otherwise stated.

Results and discussion

Element distributions

Summary statistics of the stream sediment, water and panned concentrate results are shown in Table 1. It proved extremely difficult to determine the statistical distributions of the elements, and hence threshold levels. This was partly because of the small number of samples and partly because of the apparently complex form of some distributions. Several groups of elements showing similar distribution patterns are distinguished, and these are thought to be of geological significance:

(a) Copper in sediments and cerium and barium in panned concentrates show near lognormal distributions and there are no high values present which might be related to mineralisation. These are the simplest distributions - a single background population.

(b) Lead and copper in panned concentrates show near lognormal and normal distributions respectively, with a single very high value which could be related to mineralisation.

(c) The distributions of zinc, barium, iron and manganese in sediment also show a single exceptionally high value, but with the remainder of the distribution having a complex form. The single high value of all four elements comes from the same sediment sample, which was collected from a small tributary to the Afon Dulyn at SH 7112 6692. The stream contained large amounts of hydrous oxide precipitates. There is little doubt that, as these elements are the ones commonly associated with hydrous oxide precipitates, their complex distributions represent combinations of discrete populations related to background lithology, hydrous oxides, and possibly mineralisation.

(d) All other variables show indications of bimodal distribution, and include the majority of elements determined in panned concentrates. The maximum values (Table 1) for Ca, Ni, Fe and Mn in panned concentrates are not high compared with values recorded in rocks similar to those found in this area, and it is concluded that their bimodal form is caused by variations in the geological background. The basic intrusions are probably the source of the higher groups of values. Zinc and titanium in panned concentrates also fall into this group although the maximum values are somewhat higher than would generally be expected in the rocks of this area. The elevated values probably result from the concentration of a heavy mineral phase from the basic intrusions, such as ilmenite in the case of titanium, in the panned concentrates. Lead in sediments and zinc in water show a poorly defined higher group, with values which are above the expected background and therefore may be termed anomalous; these may be related to changes in the secondary environment and/or mineralisation.

Definition of class intervals

Classes in the sample population were determined graphically from inflexion points on cumulative frequency curves for each element (Lepeltier 1969, Parslow 1974, Sinclair 1974). Inflexion points were difficult to perceive in some instances because of the poorly defined distributions. Means and standard deviations were not used, because of the bimodal or complex nature of many distributions and difficulty in clearly identifying populations from such a small sample. It was found that elements showed breaks in their distributions at one or more of three percentile levels. Three classes or levels were therefore defined above background, a low level containing 45-60% of the samples, a middle level containing 15-25% of samples and an upper level containing the single high values (4%).

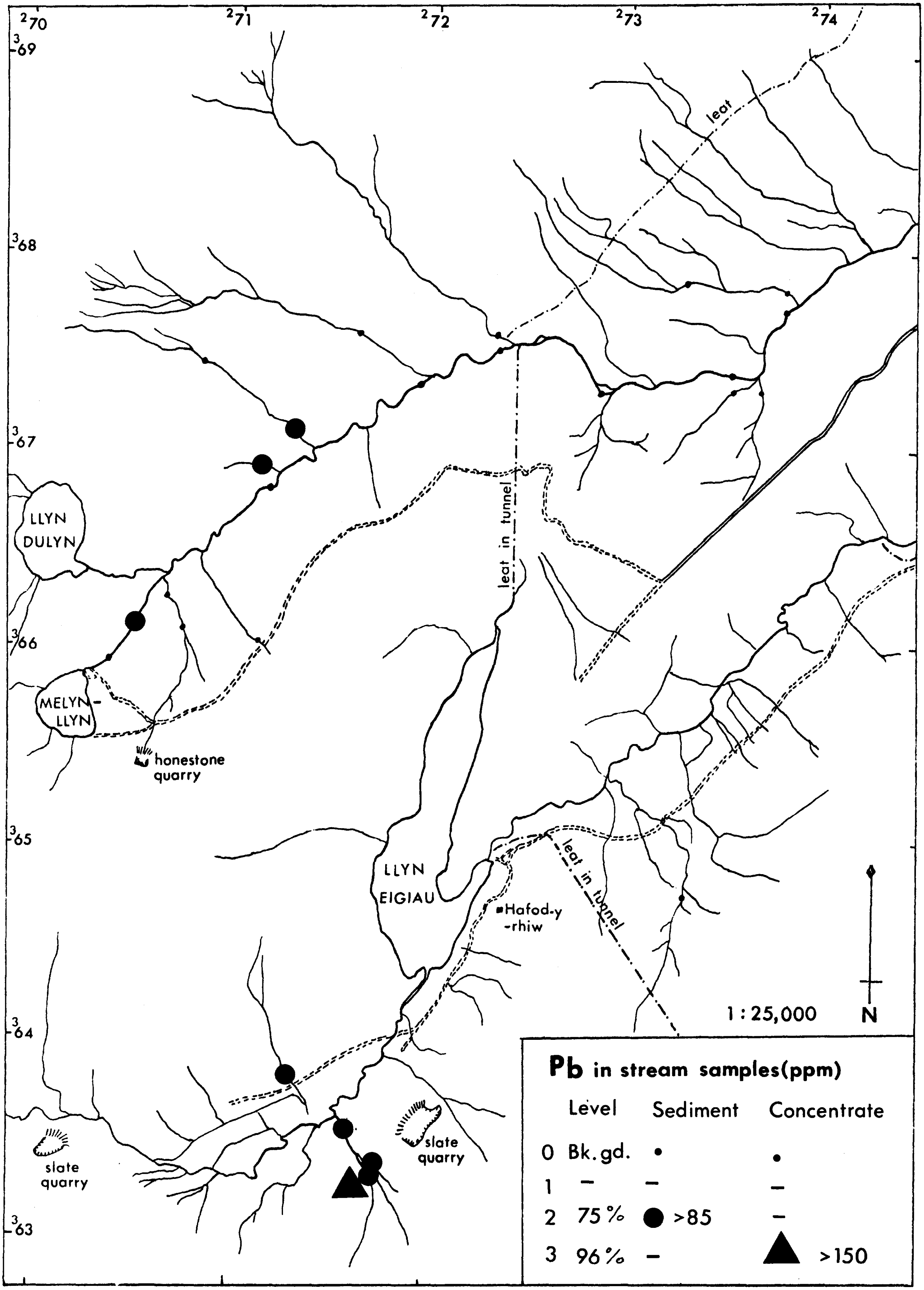

Fig. 3 Distribution Map of Lead in Stream Sediment and Panned Concentrate Samples

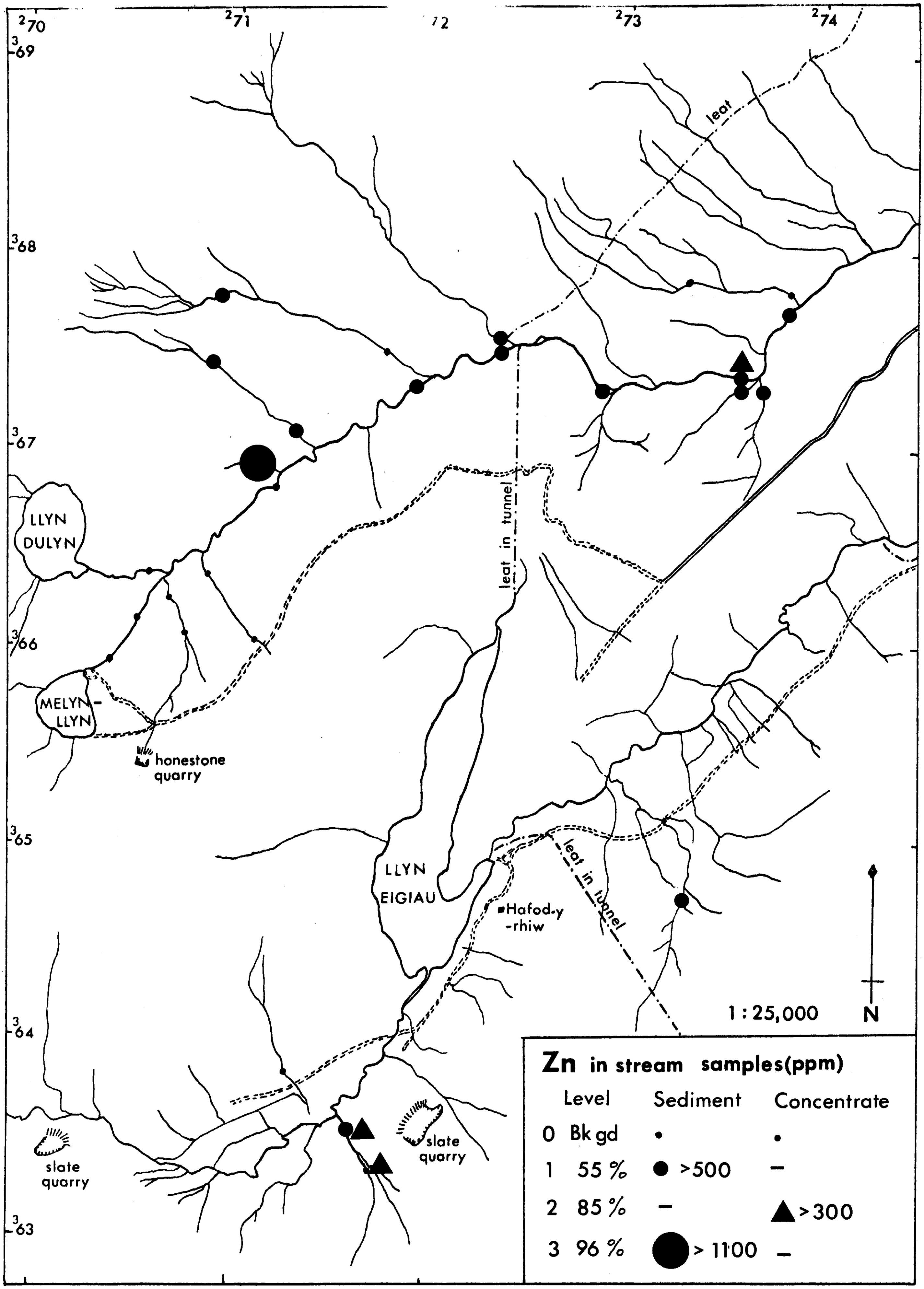

Fig. 4 Distribution Map of Zinc in Stream Sediment and Panned Concentrate Samples

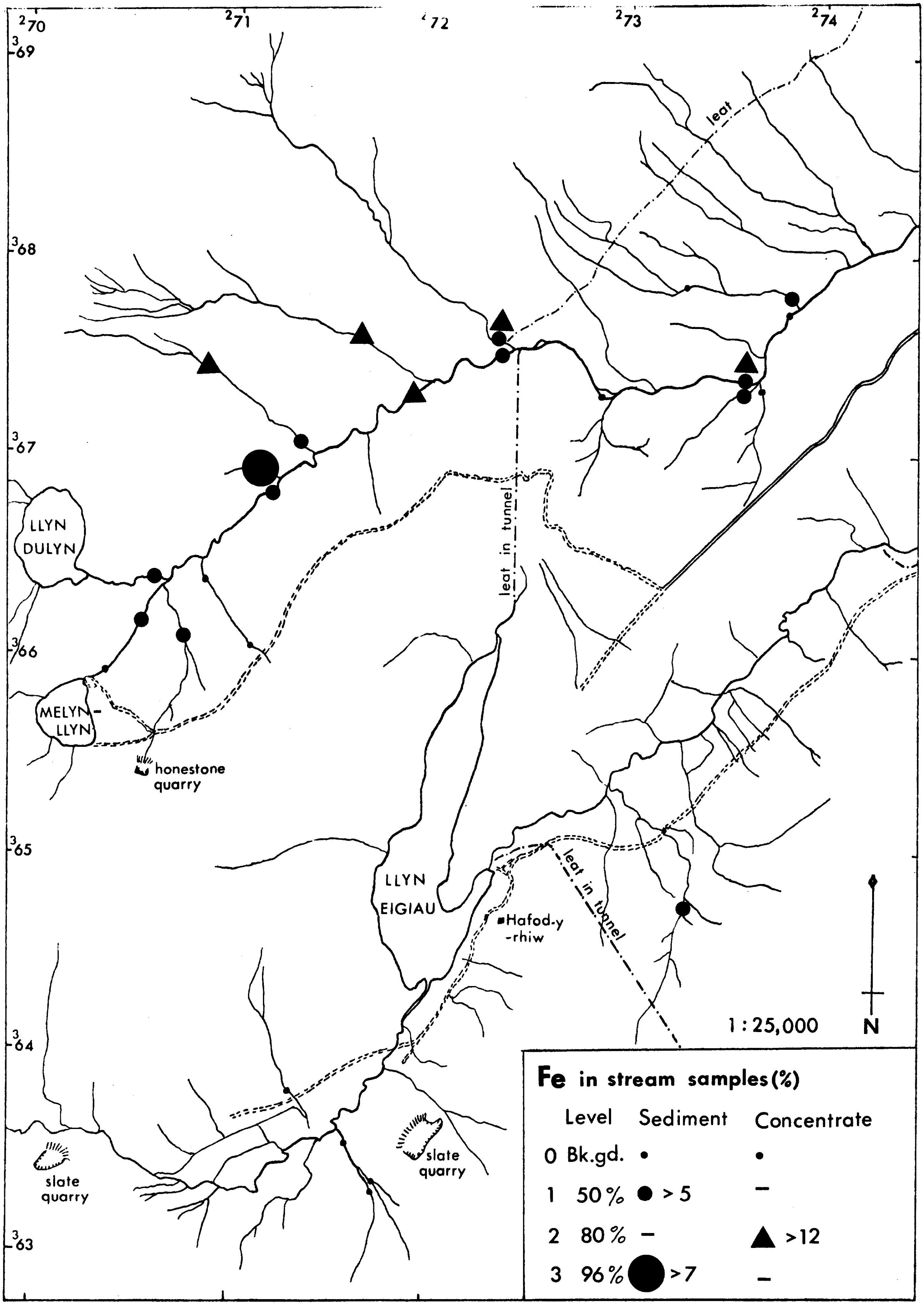

Fig. 5 Distribution Map of Iron in Stream Sediment and Panned Concentrate Samples

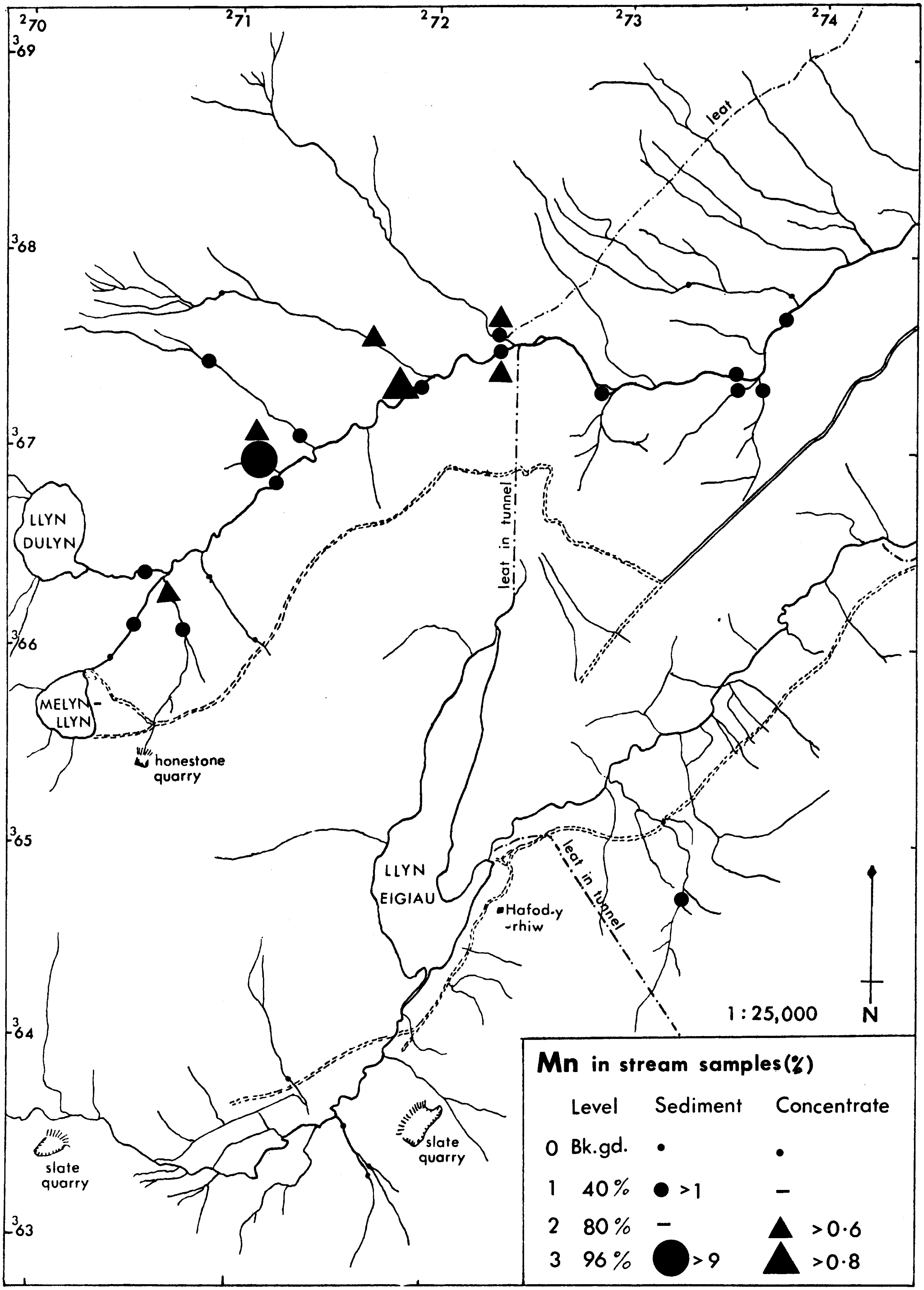

Fig. 6 Distribution Map of Manganese in Stream Sediment and Panned Concentrate Samples

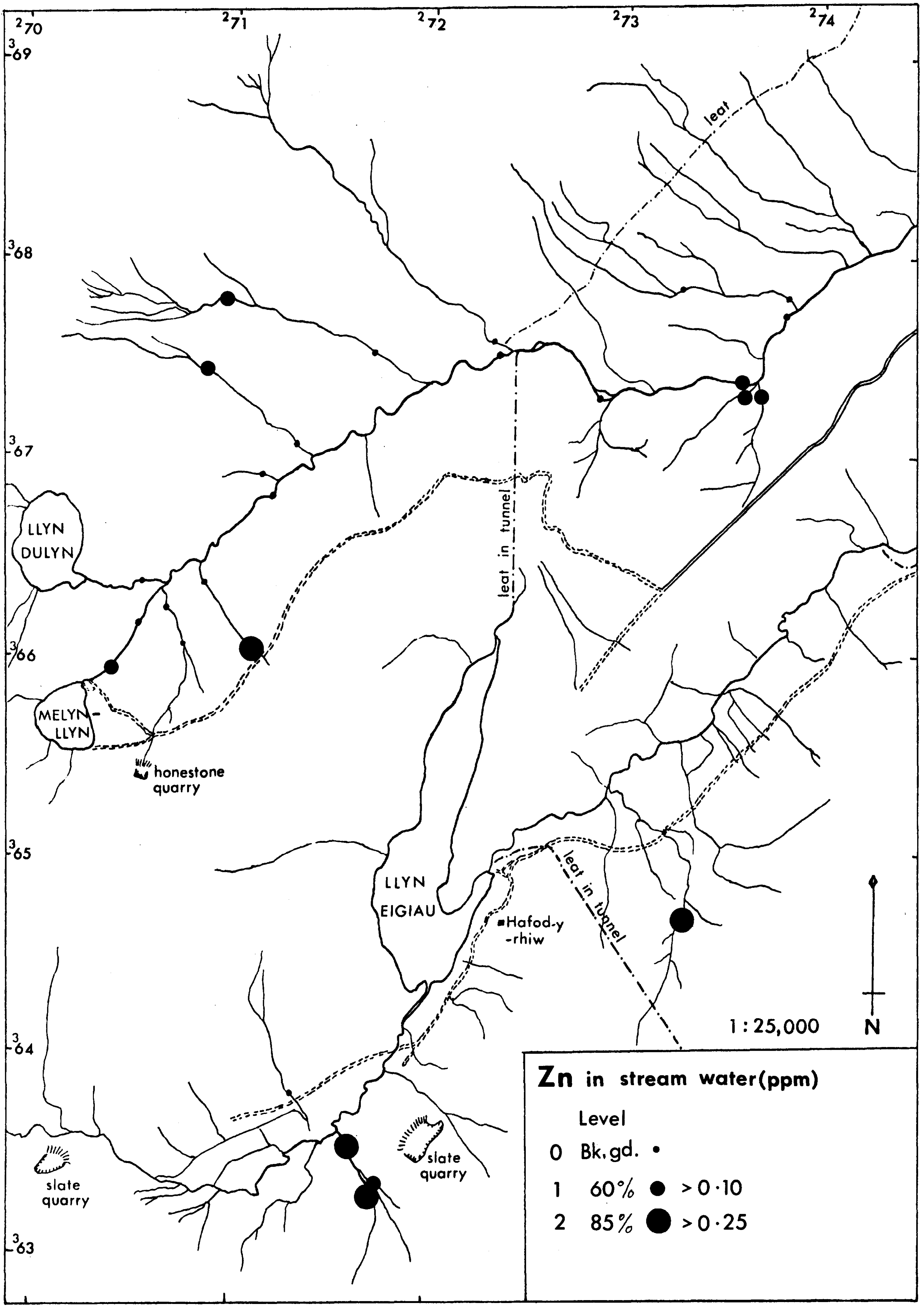

Fig. 7 Distribution Map of Zinc in Stream Water Samples

Not all three breaks are seen in all element distributions, and divisions are not made where breaks do not exist. This rather arbitary method of sub-division was chosen in view of the complex but poorly defined distributions. From the above comments on the distributions it is evident that for all elements the levels above background reflect a combination of the results of hydrous oxide precipitation, high background populations, and possible mineralisation.

The results for lead, zinc, iron and manganese in sediments and panned concentrates, divided into discernible classes, are plotted in Figs. 3-6. The zinc in stream water results are shown in Fig. 7.

Element levels in stream samples

A comparison of element concentrations in sediments and panned concentrates shows that the levels of manganese and zinc are much higher, and barium somewhat higher, in sediment samples compared with the panned concentrates from the same sites, which indicates that the bulk of these metals are in the light fraction of the sediment. The high levels of zinc in some sediment and water samples indicates that zinc is highly mobile in the aqueous environment. Fig. 7 shows that the majority of zinc-rich water samples come from small streams draining peaty areas in the upper reaches of the Dulyn catchment, whilst many of the high zinc in sediments results (Fig. 4) come from in or near the main stream. There is also an area of overlap, some samples containing high zinc in both sediment and water. This pattern, coupled with the higher zinc levels in sediments compared with concentrates, suggests that zinc is present in solution in ground water in the upper parts of the catchment, which is dominated by acid, peaty soil, and is 'precipitated' in the more

alkaline and highly oxidised environment downstream. The 'precipitation', which is most marked in the main stream and the lower part of the area, is probably induced or enhanced by iron and manganese hydrous oxide precipitates. Measurements of pH in soils and stream water support this hypothesis, with values of pH in the range 3.5-5.5 being recorded in peaty soils in the upper catchment and in the range 4.2-5.5 close to the main stream. Stream water pH was in the range 6.0-7.2 and varied least in the main stream where it was 6-6.5; higher values tended to occur in the tributaries. The lack of more acid values in even small upland tributaries indicates the rapid adjustment of ground water to the surface environment. The higher group of three values containing more than 300 ppm zinc in panned concentrate (Fig. 4) may simply reflect a high background, but they are also the most likely indicators of mineralisation in the immediate vicinity.

Copper values are generally low in both sediment and concentrate samples, which give a similar range of values with the exception of the sample from SH 7335 6785 which shows a very high copper content in panned concentrate (830 ppm) and therefore might well be due to mineralisation in the area although no sulphide minerals were observed in the pan. Copper levels in water are all below the detection limit of 0.02 ppm.

Lead values in sediments and concentrates are not unusual, with generally slightly higher values recorded in sediments than concentrates, probably because of some lead in the relatively light feldspar, hydrous oxide and/or organic phases. The sample from SH 7166 6340 (Fig. 3) differs from this pattern, showing weak enrichment of lead in the panned concentrate (175 ppm). Lead values in stream water are all below the detection limit of 0.05 ppm.

Barium levels are also generally higher in sediments than concentrates. This indicates that most of the barium is probably in feldspar, and that there is no appreciable amount of baryte in the area. The higher barium levels in sediment most probably relate in part to co-precipitation with iron and manganese as they show a close correlation.

Other elements, not so likely to be directly related to mineralisation in this area,give expected background levels except for titanium: eight panned concentrates contain 5-9% Ti. It is suspected, as was mentioned above, that this group of high values is related to a distinct lithology such as the basic intrusions, but this could not be verified as all the sites showing the high values were in or near the main stream where the sediment is largely derived from drift cover and no obvious relationship with a particular lithology on the geological map was evident. Antimony and tin values in panned concentrates were all close to or below the detection limit, supporting the field observation that the streams are not badly contaminated.

Inter-element relationships

Statistical methods based on normal distributions have been used, even though the data was often not normally distributed; the robustness of the methods was relied upon to give an indication of strong element relationships and weak or tenuous results were generally ignored. Lognormal distributions have been log transformed. The product-moment correlation matrix showed a very strong (99% confidence level) correlation between zinc, manganese, barium and iron in sediment. This reflects the distribution curves and the involvement of these elements in hydrous oxide precipitation processes. Calcium, titanium, iron, manganese and cerium in panned concentrates also showed strong (99% confidence level)

Table 2. Factor loading graph for drainage sample results.

Factor Loading	Factor 1	Factor 2	Factor 3	
		Zn_s Mn_s		
+0.9		Fe_s Ba_s		
	Ba_p			
+0.8			Pb_p Zn_p	
+0.7	Zn_w			
+0.6				
+0.5		Pb_s	Ni_p	
— — —	— — —	— — —	— — —	95% Significance Level
+0.4	Pb_s		Pb_s	
+0.3			Zn_w	
0				
-0.3				
-0.4				
— — —	— — —	— — —	— — —	95% Significance Level
-0.5	Ca_p			
	Ce_p			
-0.6	Fe_p			
-0.7				
-0.8	Mn_p			
-0.9	Ti_p			

Subscript: p = in panned concentrate, s = in sediment,
w = in water.

positive correlation, probably reflecting background lithological variations. Zinc and lead in panned concentrate, which may be related to mineralisation, showed strong positive correlation, whilst zinc in panned concentrate also showed a positive correlation (95% confidence level) with zinc in water and barium in panned concentrate. Other variables showed no strong affinities. Copper in sediment and concentrate showed no relationships at the 95% confidence level with any other elements, whilst lead in sediment showed a correlation at this significance level with all three groupings mentioned above. Results on log-transformed data (where appropriate) gave results similar to those for raw data, which is some indication of the robustness of the method when dealing with strong relationships.

The strong inter-element relationships are shown extremely clearly by factor analysis models. The geologically significant variation is well displayed by a three factor model accounting for 65% of the total variation (Table 2). A great deal of the remaining variation is accounted for by nickel in panned concentrates and copper in sediments and concentrates. The significance level (95% confidence) was determined by the method of Kaesler (1969). Factor one is considered to be largely variation caused by lithological variations in the bedrock and drift, with barium in panned concentrates representing acid (potash feldspar bearing) rocks and the elements with which it is negatively associated representing more basic rocks. The presence of zinc in water here is a curious feature, and increasing the number of factors does not change its position. The significance of this is not certain, but it may be related to mineralisation associated with acid rocks or, more likely, it may simply reflect differences in the pH of soils overlying acid and basic rocks. Factor two is clearly an

expression of elements involved in hydrous oxide precipitation processes, whilst factor three is interpreted as reflecting mineralisation.

Detection of samples reflecting mineralisation

Examination of the factor scores for the third factor from the above analysis indicated samples which were most likely to be related to lead-zinc mineralisation upstream of the sample site. Two other methods were also used to try to isolate samples likely to reflect bedrock mineralisation rather than hydrous oxide precipitates; these were: (a) regression analysis and (b) calculation of the ratio:

$$\frac{Zn/Zn_m + Pb/Pb_m}{Mn/Mn_m + Fe/Fe_m}$$

where the subscript m denotes the median value of the variable concerned. This ratio has been found to be an effective means of distinguishing metal anomalies associated with hydrous oxide precipitates from those due to the presence of discrete mineral phases (Ball, T.K., pers. comm.) Distribution analysis had also given indications of the samples most likely to contain mineralisation. A comparison of the samples identified by these four different methods as most likely to be related to mineralisation showed that those collected at SH 7356 6739 and SH 7160 6353 were picked out by all four methods, and those from SH 7168 6343 and SH 7166 6340 by three methods. Three of these samples came from the same stream, which drains into Llyn Eigiau in the extreme south of the sampled area. This was the only stream from which any sulphide (pyrite) was identified in the panned concentrates, and a

prominent quartz vein could be seen in the cliffs above these sites. Statistical results therefore agreed with field observations. The other sample came from the lower part of the Dulyn (SH 7356 6739), and no sulphides were recorded in the pan or indications of mineralisation seen in the area. It is interesting that the sample which contained the high copper in panned concentrate was not shown by the statistical methods as likely to be mineralised. However, to cover all possibilities, this sample together with the panned concentrate from the site in the lower part of the Dulyn and one of the three samples from the stream draining into Llyn Eigiau were submitted for detailed mineralogical examination.

Mineralogical examination

Portions of the three concentrates were separated in methylene iodide (density 3.3) and the 'sinks' further divided into five fractions of decreasing magnetic susceptibility. All these, together with the 'float' fraction, were examined by X-ray fluorescence (XRF), to give an indication of the elements present and their relative proportions in each fraction. In all three samples significant amounts of zinc were found in the 'float' and in the non-magnetic and weakly magnetic fractions of the 'sinks'. An extensive search of all fractions under the binocular microscope, aided by XRF checks on single grains, failed to identify any discrete zinc minerals. However, it was noted that grains coated with secondary iron oxides gave a zinc response during XRF examination and it therefore appears that zinc occurs as a sorbed phase in the iron oxide coatings.

Only traces of copper were detected in the various fractions of all three samples and no copper minerals were found. It was concluded that the single high copper value was a spurious result. This agreed with the statistical analysis, which did not pick the site out on the basis of its general pattern of element composition as likely to be related to mineralisation.

No trace of metallic or other contamination was found in the samples and it was therefore concluded that the high copper, lead and zinc levels in these samples (which had been considered the most promising indicators of mineralisation), could not be directly related to mineral phases reflecting mineralisation, but were again the product of hydrous oxide precipitation processes.

Conclusions

1. The zinc in sediment anomalies in the Afon Dulyn appear to be related to hydrous oxide precipitates and are not indicative of the presence of zinc mineralisation in the vicinity of the anomalous sites.
2. The samples which appeared most likely to reflect bedrock mineralisation came from a small stream feeding Llyn Eigiau in the extreme south of the area examined (SH 717 634). Weak lead and zinc anomalies were recorded in panned concentrates in this stream, pyrite was identified in the pan, and in-situ quartz veining was seen in the nearby interfluvial area, but mineralogical examination again showed that the lead-zinc anomalies were associated with hydrous oxide precipitates.
3. The relatively large amount of zinc in some stream waters and sediments indicates an above average concentration of this element in the general area, perhaps in the surrounding interfluvial areas. Whether these high values are related to a dispersed or concentrated

(mineralised) source cannot be determined on the available information, partly because of poor exposure in the Dulyn catchment. Exposures examined showed no clear signs of mineralisation.

RECONNAISSANCE MAGNETIC SURVEY

Introduction

Inspection of the aeromagnetic map of Great Britain (Sheet 2, Geol. Survey, 1965) shows a pronounced positive anomaly in the Foel Fras area (NG Ref. 269368). In order to determine the nature of this anomaly about 18 line km of ground magnetic traverses were surveyed. It was hoped that the location of ground magnetic anomalies might help to define possible sources of the geochemical anomalies in the catchment of the Afon Dulyn.

Magnetic surveys

Aeromagnetic survey

Fig. 8A shows the total field aeromagnetic anomaly in the Foel Fras area compiled from observations made at a mean terrain clearance of 1000 feet (305 m) along north-south flight lines spaced approximately 2 km apart.

The main feature of the anomaly field is a broad high (+ 180 nT) around the summit of Foel Fras with a local maximum (+ 210nT) 3km further west on the northern slopes of Drosgl.

High horizontal gradients occur in the magnetic field north-west of Foel Fras in the region of Aber Falls and south-east of the summit around Pen y Castell (SH 725688). Both these areas also have large topographic gradients suggesting these could be responsible for part of the magnetic effects.

Quantitative interpretation of the magnetic field is made difficult by:

(i) inadequate geological control, especially in the area west of grid line 270 km E not covered by recent geological mapping,

(ii) the lack of measurements of susceptibility and remanence, and

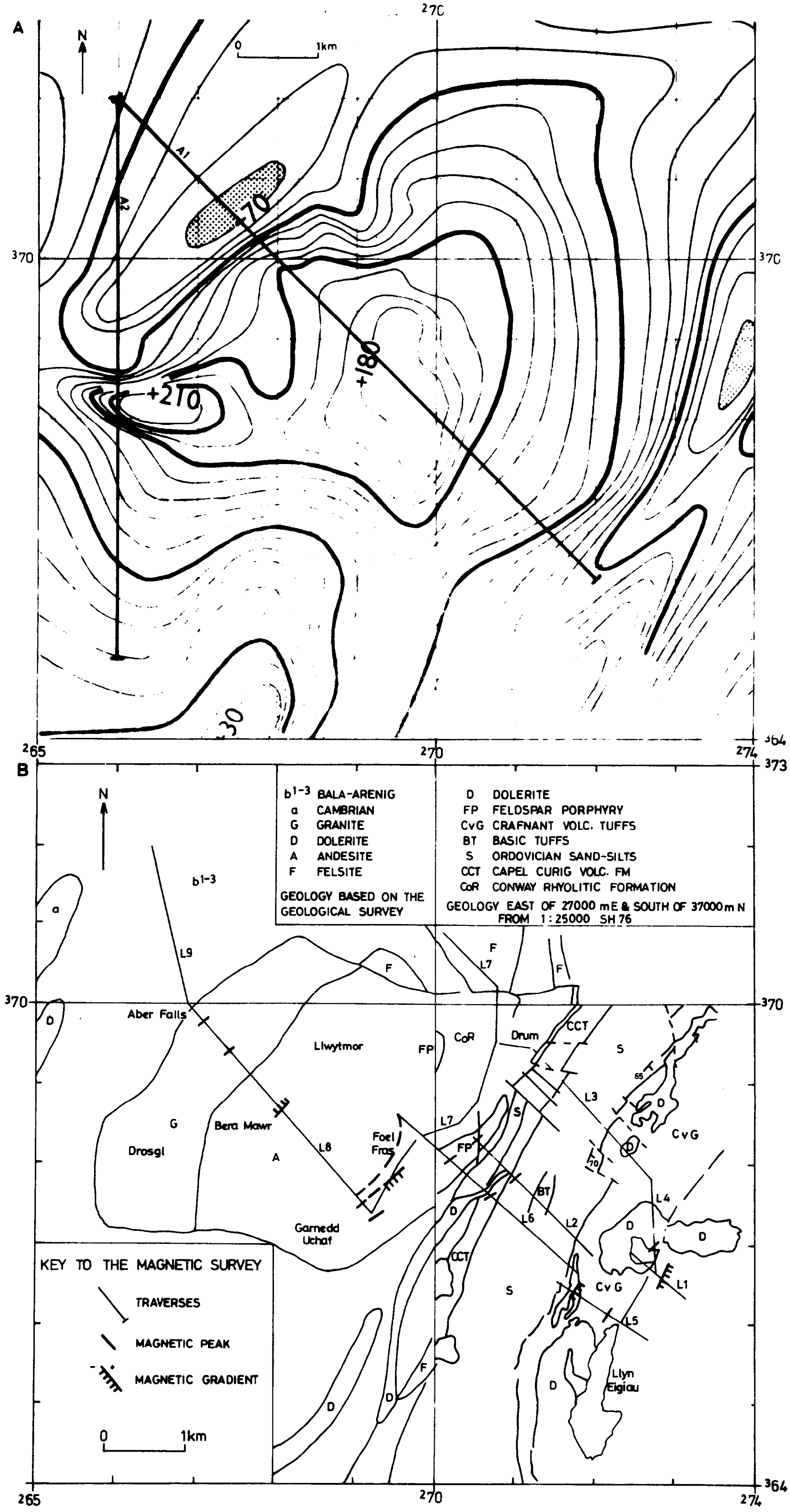

FIG. 8. A. TOTAL FIELD AEROMAGNETIC ANOMALY IN THE FOEL FRAS AREA
MEAN TERRAIN CLEARANCE 1000 FEET (304 m)
CONTOURS AT INTERVALS OF 10 nT
B. GROUND MAGNETIC TRAVERSES IN THE FOEL FRAS AREA

(iii) the difficulty of separating individual anomalies.

From recent geological mapping of the 1:25,000 sheet SH76 (south-east corner of Fig. 8B) the lithology mapped as 'andesite' by the original geological survey is redefined as part of the Foel Fras Volcanic Complex and Conway Rhyolite Formation together consisting of rhyolite, rhyolite tuffs and trachy-andesite tuffs, with feldspar porphyry. According to Berridge (1976, pers. comm.) the Foel Fras - Llywtmor - Bera Bach area is a volcanic complex (the Foel Fras Volcanic Complex) dominated by lavas and tuffs of quartz-latite composition, bounded to the north-west by a diorite intrusion extending from Drosgl across the top of Aber Falls. This diorite can be considered the source of the maximum aeromagnetic anomaly (line A2, Fig. 9) which is superimposed on a broader anomaly due to the volcanic formations. Depth rules for profile interpretation (Åm, 1972) suggest that a dyke-like structure crops out on the northern slopes of Drosgl and has an effective north-south width of about 600 m. To the east its extension is not apparent in the aeromagnetic map.

Fig. 9 also shows the aeromagnetic profile A1, with an inferred geological section, the position of the north-west margin of the Foel Fras and Drum Volcanic Formations coinciding with a high horizontal magnetic gradient.

These anomalies are not two dimensional and occur within an inhomogeneous volcanic formation, so that with no measured susceptibilities and little geological control, computer modelling has not been attempted.

Ground magnetic survey

Ground magnetic observations were made over about 18 km of traverse line, mostly to the south-east of Foel Fras (Fig. 8B). The average station spacing was between 100 and 200 m, although the field was observed, but not

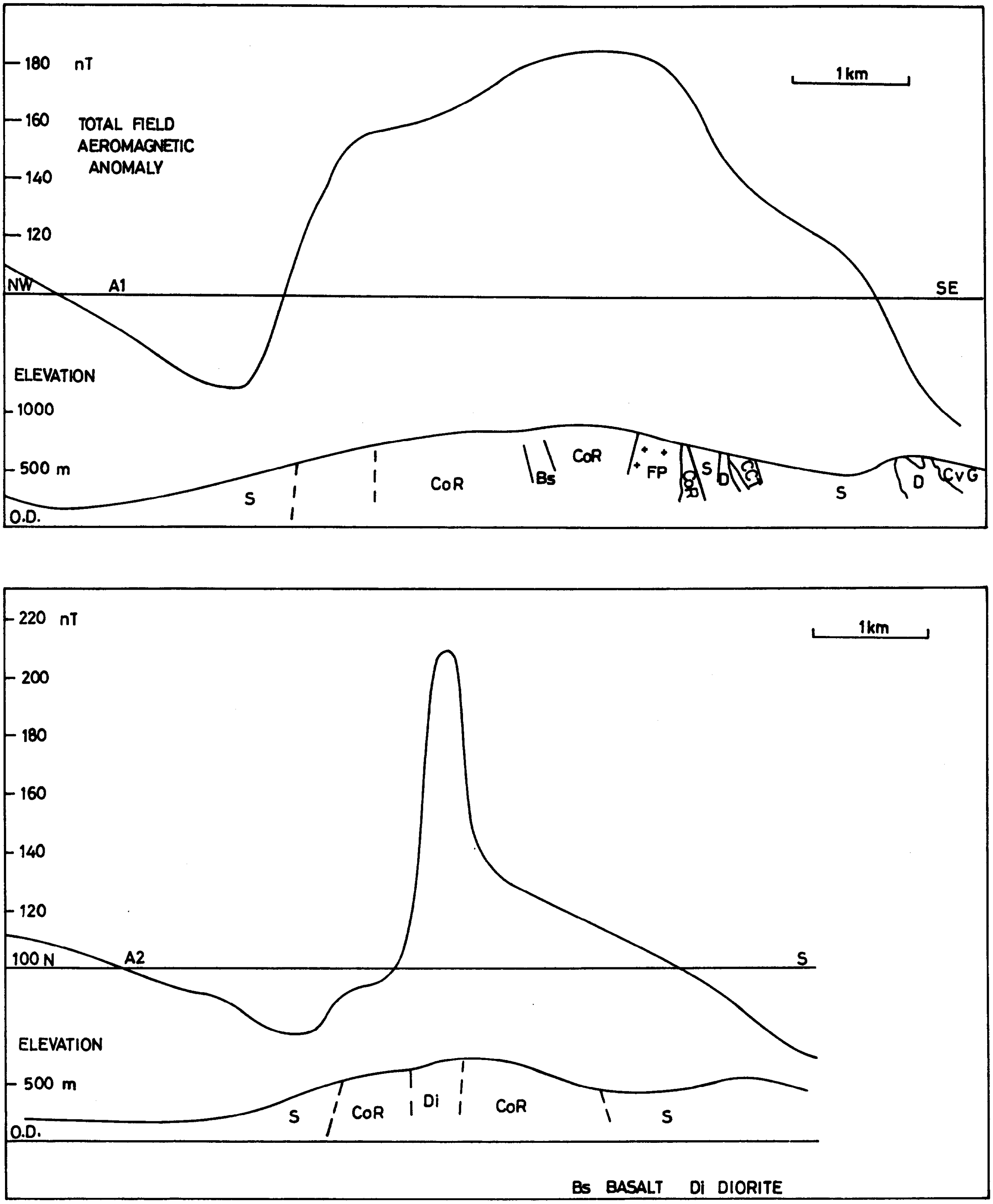

FIG.9. AEROMAGNETIC PROFILES IN THE FOEL FRAS AREA

LOCATION IN FIG8A
GEOLOGY AS IN FIG.8B

recorded, between stations. For convenience, the magnetometer bottle was not always mounted on the staff; corrections for this, for observer variations, and for diurnal drift were made where possible.

Most profiles show gradual rather than abrupt changes in the magnetic field, with occasional dyke-like magnetic anomalies superimposed (Fig. 10). A significant rise in the regional magnetic field occurs on traverse line L1 with a change of about 500 nT in 400 m. Similarly between traverses L1 and L5 a rise of over 300 nT occurs towards the south-west. These changes are related to the dolerite masses exposed around Llyn Eigiau (SH 720650).

Along traverse L2 (Fig. 10) a strong anomaly with an amplitude exceeding 1000 nT can be seen at SH710678 and is attributed to a magnetic dyke-like body dipping towards the south-east. Depth estimates from this profile suggest a maximum depth of burial of 40 m. This anomaly is close to the mapped boundary between the volcanic formation and sediments although alignment with a similar but smaller anomaly further north-west on traverse L6 suggests a strike similar to that of the exposed dolerite.

No major magnetic anomalies or steep gradients were observed along traverses L3 and L4.

Traverse L7 is close to the topographic ridge between Drum and Garnedd Uchaf and shows no major anomalies north-east of Foel Fras, although the latter is a local magnetic high, but magnetic structures north-west of the summit and across the col to the south (L6, L4, Fig. 10). The results from traverse L8 also indicate a fairly broad magnetic feature on the north-west slopes of Foel Fras, striking south-west and possibly related to an outcrop of basalt observed 150 m NE of the summit of Garnedd Uchaf.

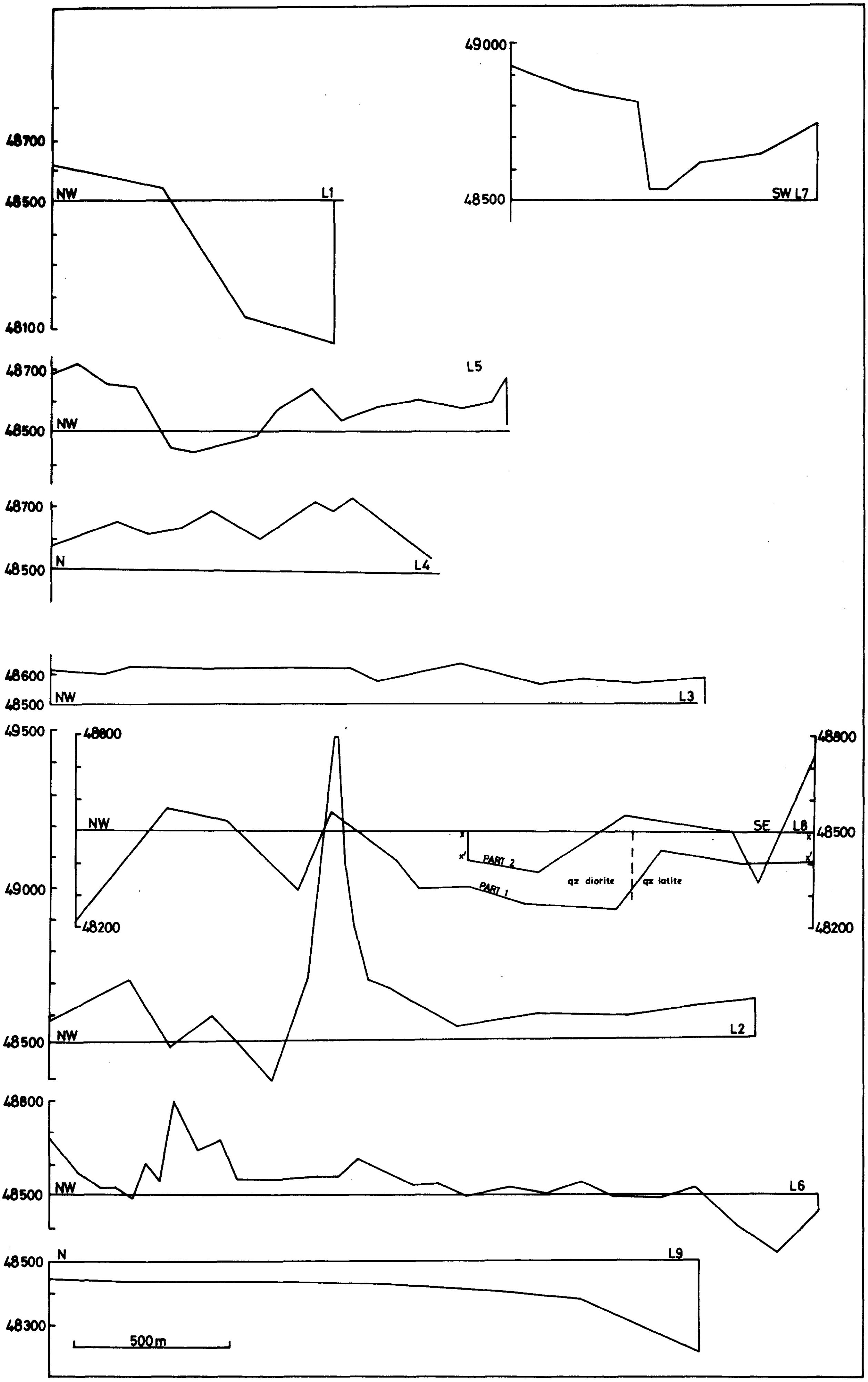

FIG.10. GROUND MAGNETIC TRAVERSES IN THE FOEL FRAS AREA
LOCATIONS FIG.9A
TOTAL MAGNETIC FIELD ANOMALIES IN nT

At approximately SH 682 687 on L8 a gradient in excess of 200 nT per 100 m coincides exactly with the boundary between massive quartz-latite of the Foel Fras Complex to the east and associated tuffs, lavas and sediments of the Complex to the west,the latter occupying a narrow strip between the quartz latite and the Aber-Drosgl quartz-diorite. Further to the north-west, two magnetic anomalies suggest that dyke-like structures cut across the profile. Approximate positions for the northern margins of these bodies are SH 673 693 and SH 669 698 respectively.

No significant magnetic gradients or anomalies were recorded on traverse L9(Fig. 10) north-west of Aber Falls.

Conclusions

Because of insufficient detail in the ground survey data, interpretation was restricted to observation of large magnetic gradients and local maxima. Most of the ground traverses suggested magnetic boundaries at or close to the ground surface.

The positive aeromagnetic anomaly over Foel Fras is a combination of the effects of a body of magnetic rocks (The Foel Fras Volcanic Complex and Conway Rhyolite Formation), of variable susceptibility and of topography.

The frequency and extent of magnetic variations in the Foel Fras Volcanic Complex and Conway Rhyolite Formation are poorly defined by the present reconnaissance survey. To locate the magnetic boundaries around and to the north-west of Foel Fras would require a close network of traverses with close station interval which cannot be justified at present.

The aeromagnetic anomaly between Drosgl and Aber Falls is the result of a diorite body bordering the Foel Fras Volcanic Complex. This body may extend and broaden eastwards at depth.

GENERAL CONCLUSION

The presence of zinc anomalies in stream sediment and of magnetic anomalies in the area were confirmed, but neither could be directly related to mineralisation and further work cannot be recommended at the present time. A reappraisal of this conclusion will be needed when geological remapping being carried out in the area is completed.

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APPENDIX Geochemical data

Stream sediment analyses (all values in ppm)

No.	Grid Reference	Cu	Pb	Zn	Mn	Fe	Ba
1	SH 7067 6631	15	50	110	3684	37322	195
2	SH 7054 6618	25	100	380	21089	56352	216
3	SH 7072 6618	15	70	120	14883	55138	297
4	SH 7112 6692	20	110	2400	253970	160029	2502
5	SH 7130 6706	15	100	1100	78517	65117	679
6	SH 7236 6750	20	70	1100	46008	67188	548
7	SH 7235 6758	15	60	550	40506	62707	562
8	SH 7356 6739	20	50	500	12860	46088	250
9	SH 7358 6732	15	50	750	55935	67092	532
10	SH 7372 6733	15	60	550	22719	46830	504
11	SH 7335 6785	20	40	140	1195	48601	225
12	SH 7385 6777	15	40	140	1953	54032	292
13	SH 7060 6636	25	80	400	21574	67008	257
14	SH 7086 6638	10	50	140	2112	26203	353
15	SH 7121 6684	15	60	400	24102	60011	320
16	SH 7196 6735	15	60	500	23843	47771	233
17	SH 7173 6755	15	50	320	6012	45839	180
18	SH 7035 6594	20	70	250	4942	36703	228
19	SH 7107 6605	5	50	210	2995	40891	421
20	SH 7095 6738	20	70	650	13580	43767	477
21	SH 7098 6777	35	50	380	5659	47787	408
22	SH 7160 6353	15	110	560	4675	42524	422
23	SH 7168 6343	15	100	440	3918	45226	461
24	SH 7166 6340	20	90	230	2203	40415	343
25	SH 7131 6380	15	90	360	3501	33129	398
26	SH 7330 6470	15	60	840	20659	61671	601
27	SH 7288 6729	20	50	500	18123	47239	357
28	SH 7382 6770	15	30	600	13912	46533	461

Water analyses (all values in ppm)

No.	Zn	Cu	Pb
1	< 0.01	all values <0.02 ppm	all values <0.05 ppm
2	0.01		
3	0.01		
4	< 0.01		
5	0.01		
6	< 0.01		
7	< 0.01		
8	0.18		
9	0.21		
10	0.18		
11	< 0.01		
12	< 0.01		

(continued)

Water analyses (all values in ppm) - continued

No.	Zn	Cu	Pb
13	<0.01	all values	all values
14	<0.01	<0.02 ppm	<0.05 ppm
15	0.05		
16	0.07		
17	0.06		
18	0.24		
19	0.29		
20	0.10		
21	0.19		
22	0.32		
23	0.20		
24	0.34		
25	0.06		
26	0.31		
27	<0.01		
28	<0.01		

Panned concentrate analyses (all values in ppm unless otherwise indicated)

No.	Cu	Pb	Zn	Mn%	Fe%	Ba	Ce	Ca%	Ni	Ti%
1	20	24	117	0.602	9.086	152	660	1.040	24	9.073
2	29	36	125	0.276	9.594	348	147	1.902	30	2.685
3	14	16	91	0.365	7.522	231	348	0.920	22	4.910
4	14	35	111	0.686	11.227	192	109	2.426	36	5.387
5	8	27	104	0.372	10.047	276	47	1.161	29	2.150
6	15	22	210	0.622	9.039	297	90	1.909	37	2.737
7	20	48	127	0.679	13.772	284	80	2.110	41	2.963
8	22	34	423	0.571	14.703	221	116	1.704	44	3.686
9	10	23	115	0.248	6.394	307	76	4.393	68	3.095
10	7	7	104	0.271	6.548	223	87	3.134	45	3.898
11	830	35	89	0.464	10.806	154	166	2.288	41	5.788
12	21	19	80	0.388	8.163	168	103	3.853	38	5.636
13	18	25	113	0.448	8.362	193	182	3.025	35	5.907
14	23	35	106	0.177	7.234	349	227	0.394	26	1.934
15	9	28	109	0.478	8.146	260	132	2.483	27	5.496
16	23	67	167	1.064	14.616	164	314	3.041	46	8.864
17	16	47	135	0.605	13.317	193	129	1.982	34	7.157
18	23	35	122	0.324	7.539	308	88	2.399	22	4.090
19	7	17	142	0.138	5.865	439	71	0.238	18	0.750
20	17	46	171	0.555	12.128	403	91	0.697	35	2.902
21	8	17	151	0.207	6.148	376	76	0.211	21	2.720
22	26	105	451	0.259	10.041	417	96	0.158	48	0.482
23	29	82	340	0.191	8.953	387	98	0.161	40	0.504
24	30	175	234	0.199	9.291	412	76	0.167	48	0.528
25	14	48	192	0.395	9.310	310	212	0.692	41	2.965
26	10	34	210	0.231	6.875	592	91	1.696	53	1.267
27	10	37	105	0.381	9.716	189	132	1.714	36	2.832
28	8	36	165	0.479	10.397	210	129	2.026	43	3.677

Water analyses (all values in ppm) - continued

No.	Zn	Cu	Pb
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