BRITISH GEOLOGICAL SURVEY
Natural Environment Research Council

Mineral Reconnaissance Programme

Report No. 92

A mineral reconnaissance survey of the Llandrindod Wells/Builth Wells Ordovician inlier, Powys

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A report prepared for the Department of Trade and Industry

Keyworth, Nottinghamshire 1987

CONTENTS

FIGURES

TABLES

SUMMARY

A reconnaissance drainage geochemical survey was carried out at a density of about 2 samples per km^2 of the Llandrindod Wells/ Builth Wells Ordovician inlier in Powys. The rocks of the area comprise a sequence of mudstones and shales ranging in age from the Llanvirn to the Caradoc containing volcanic horizons and a volcanic complex of acid/intermediate composition overlain in the south by a further volcanic sequence of more basic composition. An area of about 65 km^2 was sampled and from each site a wet screened minus BSI 100 mesh (< 150 micrometres) fraction and panned heavy mineral concentrate samples were obtained. Sieved sediment and concentrate samples were analysed for B, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Zr, Mo, Ag, Sn, Ba and Pb and Ca, Ti, Mn, Fe, Ni, Cu, Zn, Sr, Zr, Mo, Sn, Sb,Ba, Ce, Pb and U respectively. Several Pb and Zn anomalies were apparent many of which appeared to be associated with the outcrop of the main volcanic unit of the area and 4 of these were confirmed by further grab stream sediment and bank sampling. Drainage sampling was supplemented by 27 reconnaissance soil traverses mostly across the main outcrops of the volcanic rocks which tended to form the most elevated ground. The soil samples were sieved to give a minus 85 BSI mesh (< 180 micrometres) sample for analysis for Cu, Pb, Zn, Ni and either Mn and Fe or Ag and Co. Samples collected from an area of old lead workings in the west of the inlier failed to provide evidence of further vein mineralisation beyond the limits of the workings. Elswhere the biggest concentration of Pb and Zn anomalies and the greatest amplitude of anomaly (2000 ppm Pb) were located over the northern outcrop of the the main unit of tuffaceous volcanic rocks, particularly in the vicinity of the farm Pen Rhiw Frank.

A detailed geological, geochemical and geophysical survey of the Pen Rhiw Frank area was carried out using photogeological interpretation, further soil sampling and a combination of IP/resistivity, VLF, SP and magnetic surveys. Geological interpretation indicated that the area was divided into fault blocks and the geophysical work revealed a zone of high resistivity with roughly coincident low amplitude chargeability maxima and a VLF cross-over over part of the zone. There was also a general association of this zone with lead in soil anomalies and the presence of significant amounts of weathered pyrite in the limited outcrops. The lead in soil anomalies when contoured in the light of the photogeological interpretation can be seen as broadly following the local strike of the rocks. Four holes were drilled to investiage the source of the geochemical anomalies and to investiage any association between this and the observed geophysical anomalies. The holes were sited to test the down dip extension of apparently stratabound surface soil anomalies. Tuffaceous rocks of andesitic composition with a horizon of dacitic tuffs and minor vesicular andesitic lava were intersected in the holes. Mineralisation occurs in the form of secondary lead minerals within a poorly recovered soft clay-rich section 5.8 m thick near the top of one of the holes. Lead levels up to 0.52% over 3.4 m were found in the zone which is located at the interface between a dacitic tuff unit chemically distinct from the rest of the volcanic sequence and an andesitic lava probably of limited extent.The drill holes suggest that the dip of the strata is around 5 degrees rather than the 30 degrees deduced from the existing geological map of the area and so the holes were not sited at locations which were likely to intersect any stratabound mineralisation at depth below the zone of surface weathering. A further consequence of the flat dip of strata is that by accidents of topography extensive overburden anomalies could be produced from relatively minor statabound base-metal enrichments on the hill tops.

INTRODUCTION

Drainage and soil surveys were sampled in 1978 and 1979 over the outcrop of volcanic and sedimentary rocks known as the Llandrindod Wells (or Builth Wells) Ordovician inlier. There is no evidence of extensive base-metal vein mineralisation such as found in the Shelve Ordovician Inlier to the NNE or throughout the Central Wales Mining Field. Nevertheless by analogy with mineralised volcanic belts throughout the world the area was judged worthy of examination for metallic mineralisation especially of the stratabound variety. The area is included in the 1:50 000 topographical sheet 147 (Elan Valley and Builth Wells) and is covered by a special 1:25 000 gological map in the BGS series 'Classical areas of British Geology' (Earp, 1977).

Geochemical drainage data are presented in map form (Figures 2 – 23) illustrating the distribution of 15 elements in minus 100 BSI mesh (150 microns) stream sediments and panned heavy mineral concentrates. An area of 65 km was covered with a sample density of approximately two samples per square kilometre. Variation in topography and drainage resulted in a lower sampling density over the volcanic rocks, which were of potential economic interest, than was desirable. Accordingly a number of supplementary reconnaissance soil traverses were sampled, particularly over the volcanic rocks. These are presented either as line profiles or contoured plans for elements of interest.

GEOGRAPHY

The survey area (Figure 1) forms a NNE-trending belt of moderately rugged hills some 12 km long rising above the surrounding lowlands. The area itself can be divided into hills underlain by lavas and tuffs and lower undulating terrain underlain by shale sequences. The highest areas are on the Carneddau (400 m) in the south and Gilwern Hill (380 m) in the centre of the area but the most rugged area is around Llandegley Rocks at the NE margin of the area. The area is bounded to the north by the River Ithon which drains westward into the River Wye and cuts across the regional geological structure. To the east the area is drained by the River Edw and Camnant Brook while the River Wye flows close to the SW boundary.

The centres of population are the former spa towns of Builth Wells and Llandrindod Wells while the main occupation of the area is farming. Much of the land is covered with pasture or rough grazing.

GEOLOGY

Stratigraphy and lithology

The area has long attracted the attention of geologists although discoveries of mineralisation of potential economic interest have not been reported. Studies by Murchison ,Lapworth, Woods and Elles, predated a series of papers by Jones and Pugh (1941, 1946, 1948,

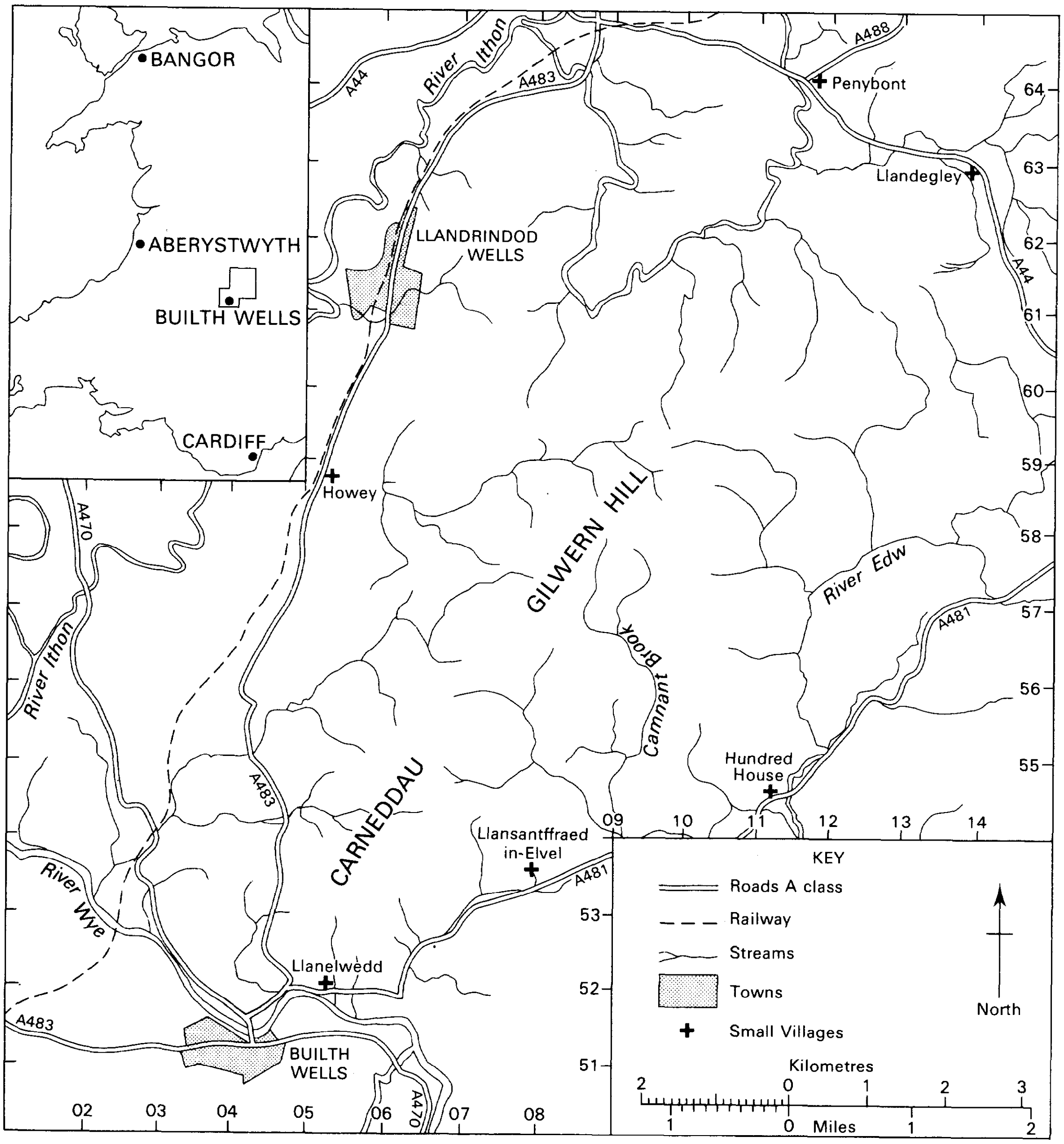

Figure 1a Geography of Builth Wells Inlier

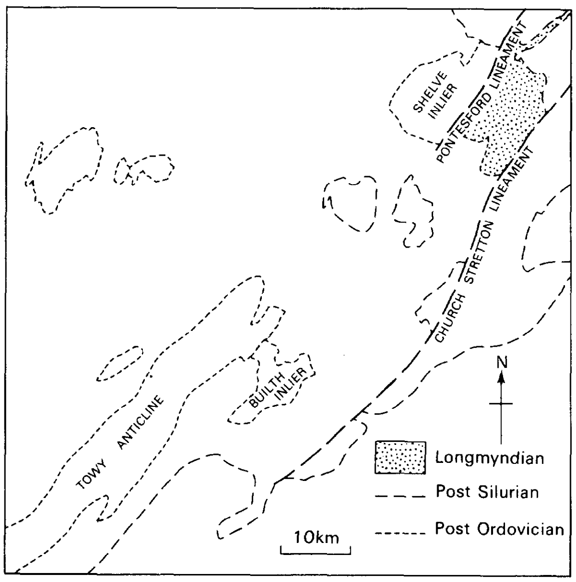

Figure 1b Structural location of Builth Wells inlier

etc.) which were based on mapping at the scale of 25 inches to the mile. These maps were simplified to the 1:10 560 scale and compliled into a 1:25 000 map of the inlier by Earp (1977). In addition there has been a more recent study of the volcanics by Furnes (1978). There have also been regional accounts of the geology and evolution of the Welsh Basin (Kokelaar and others, 1984, Woodcock 1984 and Bevins and others, 1984) which include limited data and discussion about the Llandrindod Wells/Builth Wells Ordovician inlier and its volcanic sequence. While use has been made of Furnes's descriptions and interpretation of the rocks base maps have been prepared using the geological units and boundaries of the 1:25 000 BGS map. A stratigraphical column for the area is given in Table 1. Shales above Main tuff group are collectively known as Upper Shales and shales below Main tuff Group are known as Lower Shales.

Table 1 Stratigraphic subdivisions in Llandrindod Wells area

	Tuff and agglomerate
Caradoc Series	*Nematigraptus gracilis* shales
Llandeilo Series	*Glytograptus teretiusculus* shales
— — — —	Unconformity — — — — — —
	Upper *Didymograptus murchisoni* shales
	Main tuff group
Llanvirn Series	Rhyolitic tuffs
	Didymograptus bifidus beds

Situated east of the Towy Anticline (Figure 1b), the Landrindod Wells/Builth Wells inlier lies on the eastern margin of the Welsh basin but west of the major Church Stretton and Pontesford fault systems. The Lower Palaeozoic rocks of the Welsh Basin are thought to have accumulated on Continental crust and the Ordovician rocks to have been deposited in a marginal basin environment (Kokelaar and others, 1984). Roughly along strike 35 km to the NNE is the Shelve Ordovican inlier which contains rocks with a shelly fauna unlike the graptolitic fauna found in rocks of the Llandrindod Wells inlier.

Mudstones and shales ranging in age from Llanvirn to Caradoc occupy most of the Inlier and are intruded by a number of dolerite bodies, often albitised, up to 2 km in length. The lower shales of the *Didymograptus bifidus* zone contain thin volcanic horizons (Elles, 1939), well displayed along Camnant Brook [SO 096 557], but are mainly composed of argillaceous sediments with occasional beds of sandy grit. These rocks are thought to have been deposited in a distal turbidite environment (Furnes 1978). Above the main tuff group, shales of the *Didymograptus murchisoni* zone contain an appreciable quantity of volcanic ash in their lower sections (Elles, 1939). They pass conformably upwards through a sequence predominantly of shale and mudstone into similar lithologies forming the Llandelian and Caradocian Series. Elles (1939) observed thin volcanic horizons in all these zones. All three upper argilaceous zones are intruded by dolerite bodies, albitised in the south of the Inlier (Jones and Pugh, 1946). The largest intrusion, which is 2.5 km long, is found in the Caradocian to the NE of Llandrindod Wells.

The greater part of the outcrop of the main tuff group comprises a series of welded and unwelded pyroclastics of intermediate to acid composition and associated coarse clastic sediments. The pyroclastic rocks are usually unwelded pumicious lappilli tuffs with common lithic fragments of lava and shale. Invididual units range from 5 cm to 30 m in thickness and may occur as graded units or homogeneous units. They have been interpreted by Furnes (1978) as subaqueous pyroclastic flows. Welded tuffs are subordinate to unwelded tuffs and occur as 4–30 m thick heterogeneous units, dominated by pumice and vitric fragments. Although these units show many features considered reliable indicators of a subaerial environment of deposition, Francis and Howells (1973) recognized submarine ignimbrites in the Capel Curig Formation of North Wales and Sparkes and others (1980) have observed pyroclastic flows which have been emplaced and welded offshore from Dominica. These pass upwards into basic lavas which are well displayed at Llanelwedd Quarries [SO 049 522] and have been described by Nichols (1956). The erosional top shown by one basic flow taken in conjunction with the general absence of hyaloclastites or pillow formation strongly suggests subaerial eruption and emplacement of the basic flows. Acid lavas are common throughout the main tuff group and are shown on the BGS 1:25 000 geological map as 'massive keratophyre and platey andesite'. These lavas show low vesicularity, flow lamination and vary in thickness from a few metres to 240 m. A lack of surface structures usually associated with viscous lava could indicate subsequent erosion. No evidence has been observed for lava having been chilled or brecciated in water and it is probable that eruption was subaerial. From the above details it is likely that the palaeogeographic environment prevailing at the time of volcanism was a shallow marine setting with periodic upwarping due to magmatic activity.

The lavas are overlain by coarse sandstone and conglomerate, a sequence once thought to represent an Ordovician shoreline complete with sea stacks (Jones and Pugh, 1949) but more recently interpreted as a submarine canyon setting (Furnes, 1978). Dolerites found in these sequences may be inferred to represent subvolcanic intrusions associated with the volcanism which produced the tuff horizons in the overlying shale sequences.

In the basic lavas and volcaniclastic rocks of the upper volcanic sequence the assemblage albite + chlorite + sphene + /-pumpellyite + /-prehnite + /-calcite + /-white mica has been observed (Bevins, 1985), an assemblage present in other basic rocks in the Welsh Basin and thought to result from burial metamorphism (Bevins and Rowbotham, 1983). In addition metadomains dominated by pumpellyite or prehnite also occur in the same rocks (Bevins, 1985) but have not been observed elsewhere in the Welsh Basin. Monomineralic metadomains are thought to provide evidence of extensive element mobility such as is associated with hydrothermal activity and Bevins (1985) speculates that this provides evidence for the operation of a hydrothermal circulation cell driven by heat from high level magma chambers during the volcanic activity.

Structure

The outcrop pattern of the sequence has been repeated by several major NNE-trending anticlines and synclines which deform all units of the Inlier. Nevertheless, the Ordovician rocks become successively younger towards their western contact with the overlying Wenlockian. The contacts between the Silurian strata and the Inlier are discordant, either unconformable or discordant. Llandoverian strata have been reported by Jones and Pugh (1946) but are rare. A synthesis of the structure of the Welsh Basin (Woodcock, 1984) postulates that the present fold geometry probably resulted from the plastic deformation of cover rocks above major fault movement in the underlying continental basement and that the strike slip component of this was at least as important as any dip slip component. Woodcock (op cit) also reports that the extension south of the Pontesford lineament (Figure 1) cuts the NW part of the Landrindod Wells inlier and that faults with pre-Silurian dextral displacement can be seen. He also suggests that the volcanic centre comprising the Llandrindod Wells Ordovician inlier could have been formed above a 'leaky' transtensional strike slip fault which provided a conduit from the mantle.

Superficial deposits

During the period of maximum glaciation the area came under the influence of glaciers converging from Drygarn and Radnor Forest. The lower ground is usually mantled by glacial drift but the higher ground, underlain by the Builth Volcanic Series, is free of drift and covered with a thin layer of soil developed on a surface of periglacial shattering. The ground is well drained and marked by an unusual abundance of mole hills.

Previous mining activity

There has been very little mining activity in the area surveyed, which is in marked contrast to the intensity of activity in the Shelve Ordovician inlier, some 35 km NE along strike, and in the Cwm Elan area 20 km to the west. Lead is reported to have been worked near Llwynceubren Farm [SO 064 590], east of Llandrindod Wells, from the latter part of the 18th century until the mid 19th century (Hall, 1971). At the south end of a line of workings there are three shallow pits and adjacent dumps containing galena in association with abundant calcite but access to underground workings is now impossible. Exploration pits extend for 3 km along a northerly trend from these dumps. The workings are located in rocks of the main tuff group on the NW limb of an anticlinal flexure plunging to the SW and acid lavas (keratophyres) are exposed to the south. To the SE is the NE plunging anticline which exposes the *didymograptus* beds in the core.

A trial level, 25 m long, is found in the stream known as Murchison's section on the north side of Gilwern Hill [SO 096 589]. The footwall shows slickenside striae and probably represents a fault plane. Vein quartz is evident but no metallic minerals were observed. The locality is believed to have been explored for lead (Hall, 1971) although some local farmers maintain gold was the target. Lead was also believed to be the target of a shallow (2 m) trial level located at the northern end of Llandegley Rocks [SO 138 621] but no evidence of mineralisation is to be seen today.

MRP RECONNAISSANCE EXPLORATION

Geochemical sampling

As a first step in the survey samples were collected from natural sediment traps in all major streams and tributaries draining the Inlier. This resulted in 107 samples being obtained from a 65 km^2 area, a density of slightly under two samples per km^2. At each site sediment was wet-screened through nylon mesh to minus 8 BSI mesh (2000 microns) and further wet-screened to give a minus 100 BSI mesh (150 microns) fraction without the addition of further water. This fine fraction was allowed to settle and the supernatant liquid carefully decanted so as to minimise the loss of clay and fine organic material. The sample was then poured into a Kraft paper bag for subsequent drying and chemical analysis. A heavy mineral concentrate was also obtained at each site by panning 2–3 kg of sediment screened through 8 BSI mesh (2000 microns) by the classical gold panning technique to give 20 40 g of sample.

Follow-up drainage sampling was carried out on 11 streams, the locations of which are shown in Figure 23, by collecting grab samples of sediment from natural traps at sites spaced at 50 or 100 m intervals along stream courses. In addition a sample of soil was taken from each bank at a depth of about 25 cm. The sediment samples were dried and screened to obtain a minus 85 BSI mesh (180 microns) fraction for analysis. Bank samples were dried, dissagregated and dry screened to give a minus 85 BSI mesh (180 microns) fraction for chemical analysis.

Drainage is not sufficiently well developed on the higher ground underlain by the volcanic rocks to allow effective reconnaissance using stream samples alone. Consequently two soil traverses across the volcanic outcrop and four soil grids covering basic lavas, known mineralisation, a dolerite body and an area of the main tuff group where mineralisation was suspected, were sampled. Samples were collected using a 1.2 m long hand auger except in some areas of shallow soil over the volcanic rocks where a spade was used. The samples obtained using the auger usually represented C-horizon material though it is possible that some collected on the lower ground failed to penetrate boulder clay which overlies shales.

Chemical analysis

The analytical techniques employed for each sample type are shown in table 2. The analytical procedures have been developed by the Analytical Chemistry Group of the British Geological Survey and have been described in other reports in this series.

Treatment of data

Chemical data for drainage samples were investigated using simple single element statistical techniques with a view to the identification of sites showing anomalous concentrations of elements of economic interest. Most elements showed distributions closer to log normal than normal so that statistical calculations were performed on the log-transformed data. Exceptions were those elements for which most values fell close to or below the detection limit for the method employed (e.g. Mo).

Class intervals for the preparation of histograms were derived after the method of Le Peltier (1969) and cumulative frequency graphs were plotted on log-probability paper for all elements determined in each sample type. For straight line distributions the threshold for anomalously high values was usually chosen to include the top 2.5 per cent of the population, corresponding to the mean plus twice standard deviation for a simple lognormal distribution. In other cases class intervals were related to the breaks in slope shown by the distributions or were chosen empirically. Where analytical determinations showed most samples to contain levels less than the detection limit (e.g. Ag in sediments, Sb in pans) or an element was present over a narrow compositional range (e.g. Zr in pans) distribution maps were not prepared.

Table 2 Analytical Techniques

	Analytical Method			
Sample	AAS (nitric acid)	AAS (perchloric acid)	OES	XRF
– 100 mesh sediment	Cu, Pb, Zn, Ag, Co, Ni		B, Sn, Cr, V, Mn, Zr, Ba, Fe	As, Mo
Soil	Cu, Pb, Zn, Ag, Co, Ni	Cu, Pb, Zn, Ni, Mn, Fe	B, Sn, Cr, V, Mn, Zr, Ba, Fe	As, Mo
Panned concentrate				Ce, Ba, Sb, Sn, Pb, Zn, Cu Ca, Ni. Fe, Mn, Ti, Mo

Table 3 Characteristics of element distributions

	Range	50%ile	97.5%ile
B ppm	23 – 156	74	125
Ca% pan	0.07 – 2.52	0.25	1.65
Ti% pan	0.31 – 3.34	0.65	2.50
V ppm	37 – 135	90	135
Cr ppm	< 10 – 117	40	90
Mn ppm	279 – 11800	1260	6400
Mn ppm pan	180 – 3160	600	1500
Fe%	1.65 – 7.03	4.00	5.60
Fe% pan	2.31 – 12.10	6.00	10.00
Co ppm	10 – 105	26	50
Ni ppm	15 – 65	33	60
Ni ppm pan	6 – 65	24	53
Cu ppm	5 – 30	16	
Cu ppm pan	1 – 172	9	90
Zn ppm	90 – 450	180	400
Zn ppm pan	51 – 785	148	420
As ppm	5 – 22	11	18
Sr ppm pan	40 – 470	150	390
Zr ppm	165 – 492	265	400
Zr ppm pan	110 – 270	172	240
Mo ppm	< 1 – 6		
Mo ppm pan	< 1 – 5		
Ag ppm	< 1 – 1		
Sn ppm	< 1 – 16		
Sn ppm pan	< 1 – 269	8	180
Sb ppm pan	< 1 – 25	3	12
Ba ppm	214 – 985	400	825
Ba ppm pan	< 1 – 1951	410	1270
Ce% pan	0.07 – 2.52	0.25	1.65
Pb ppm	30 – 710	41	400
Pb ppm pan	5 – 2491	36	550
U ppm pan	< 1 – 30		

Table 3 shows characteristics of the distribution of each element determined.

Single element class interval distribution maps are shown for B, Ca, Ti, V, Mn, Fe, Co, Cu, Zn, Sr, Zr, Sn, Ba, Ce and Pb in sieved stream sediments or panned concentrates or both sample types in Figures 2 to 21 in atomic number order. Other elements showing only limited variation have not been plotted. The cumulative frequency plots are shown on each map. Upper class intervals are based on threshold levels as obtained above and for lower limits on breaks in the distribution such that 15–30 per cent of the total data were presented for each element.

Drainage reconnaissance

Boron (sieved sediment)

The majority of samples containing relatively high levels of boron are derived from the outcrop of the Upper Shales and particularly the *Glyptograptus teretiusculus* zone. This correlation with an argillaceous unit may indicate that boron is associated with illite clay. The relatively low levels present and the flat gradient of the cumulative frequency plot suggest that a significant amount of tourmaline, which could be associated with hydrothermal activity, is unlikely to be present.

Calcium (panned concentrate)

The cumulative frequency plot for calcium shows evidence for two distinct populations with a significant increase in gradient for the upper one. Samples with higher levels of calcium are concentrated along the upper part of the Afon Edw and south westwards generally along the outcrop of the lowermost Lower Shales. The highest levels of Ca are associated with the southern outcrop of the *Glyptograptus teretiusculus* beds. These patterns probably reflect significant differences in abundance of calcium-rich minerals, perhaps sphene in view of the correlation between Ca and Ti in the panned samples, within the sedimentary rocks.

Titanium (panned concentrate)

The distribution of samples with relatively high levels of Ti resembles closely that of Ca and suggests that both elements could be present mostly as sphene. The most likely source of sphene in the area are the albite dolerites but there is no apparent correlation between the location of Ca/Ti-rich samples and the mapped bodies of albite dolerite. The presence of basic tuff horizons within the Lower Shale sequence could also account for the distribution pattern. The proportion of Ca to Ti in the samples from the southernmost outcrop of the *Glyptograptus* shales is possibly greater than the samples from the east of the area perhaps due to the presence of a different mineral assemblage.

Vanadium (sieved sediment)

There is a relatively small range of vanadium contents illustrated by the flat cumulative frequency graph. Higher levels tend to occur in samples derived from the shale sequences rather than the volcanic rocks. Some correlation between relatively high vanadium and iron is apparent in the sieved sediment data which could be a secondary environmental effect with vanadium scavenged on iron oxide in the stream sediment. The source of the relatively high levels near Llansantffraed-in-Elvel is unknown.

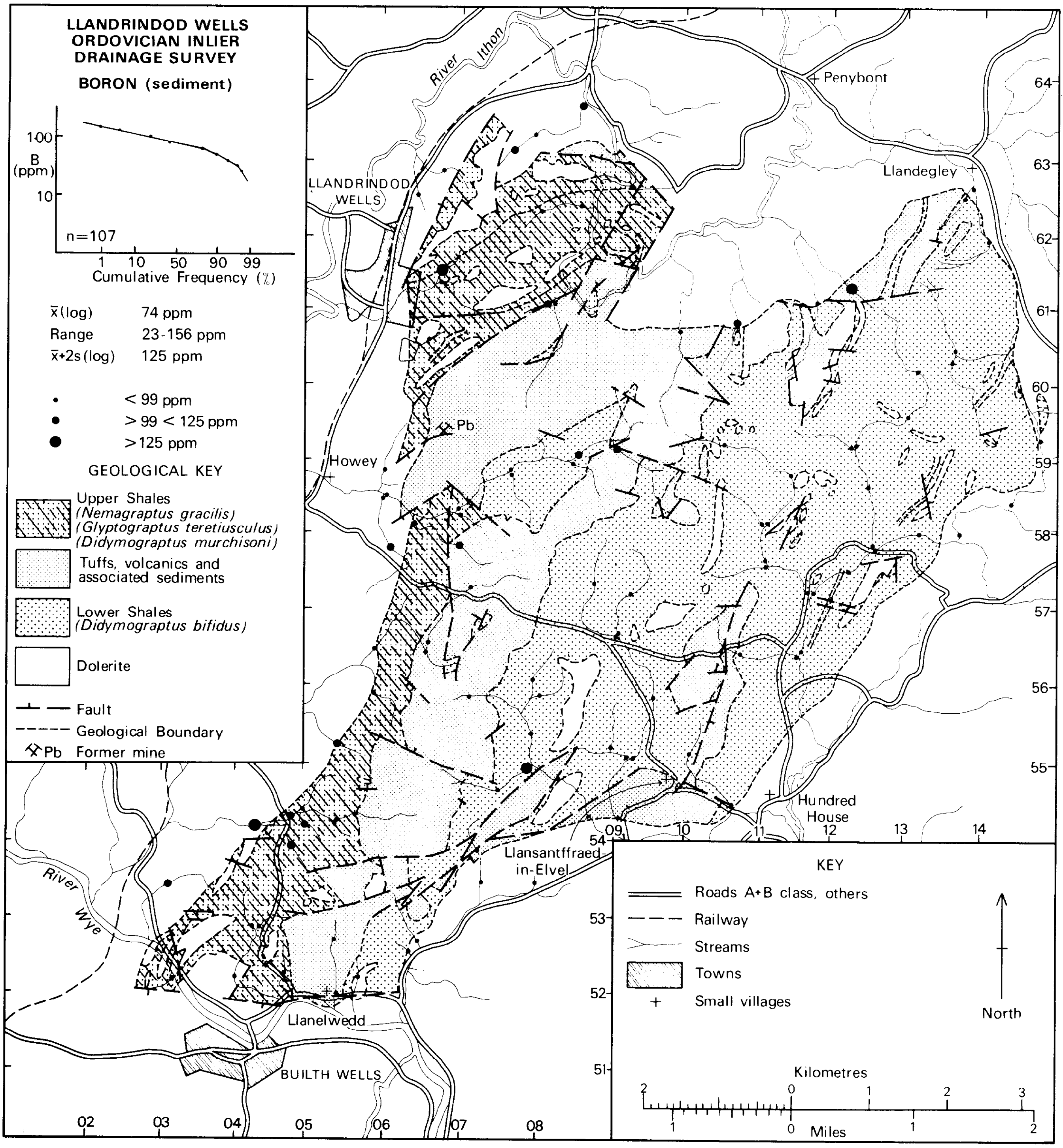

Figure 2 Distribution of boron in sieved stream sediment samples

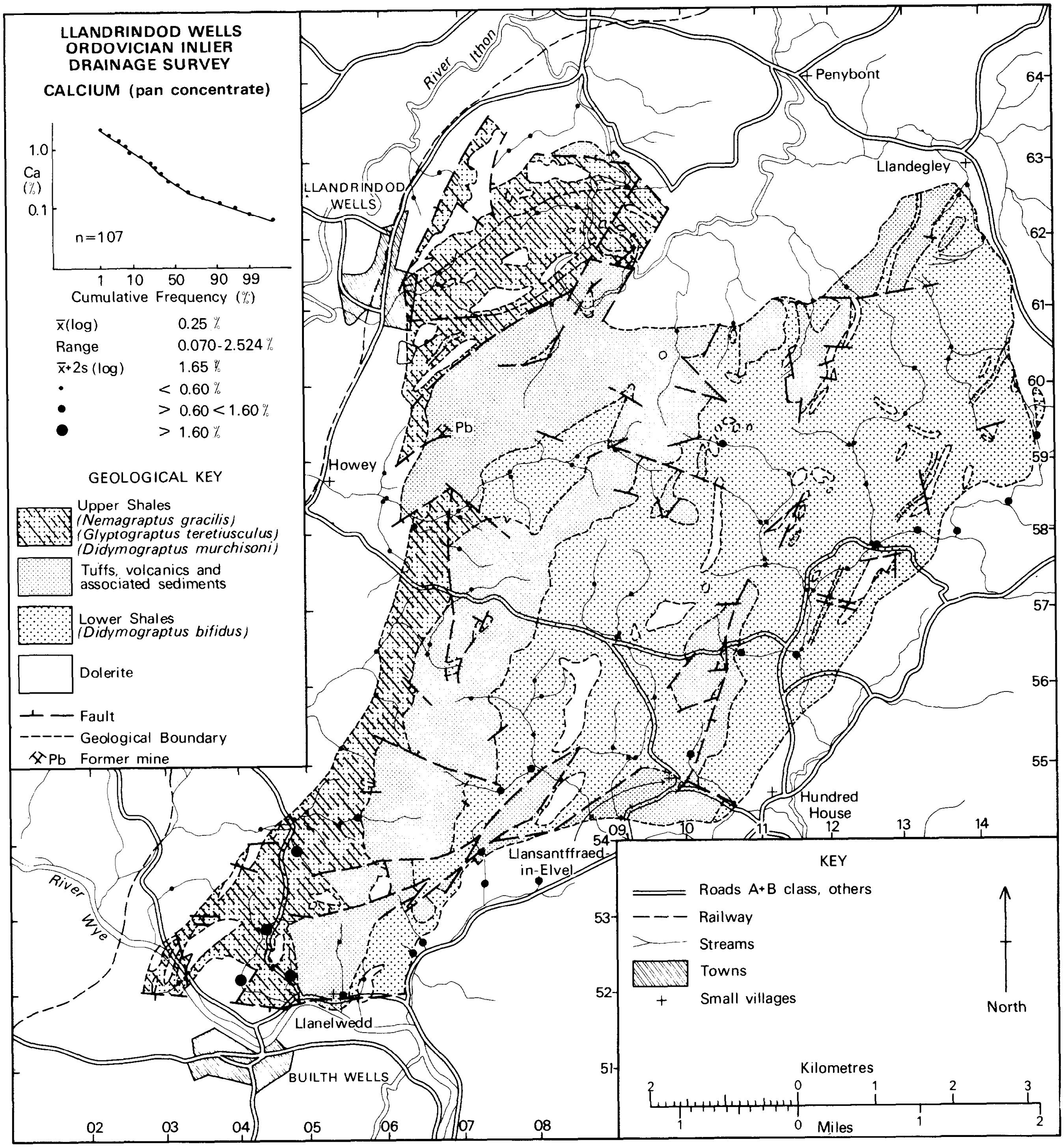

Figure 3 Distribution of calcium in panned concentrate samples

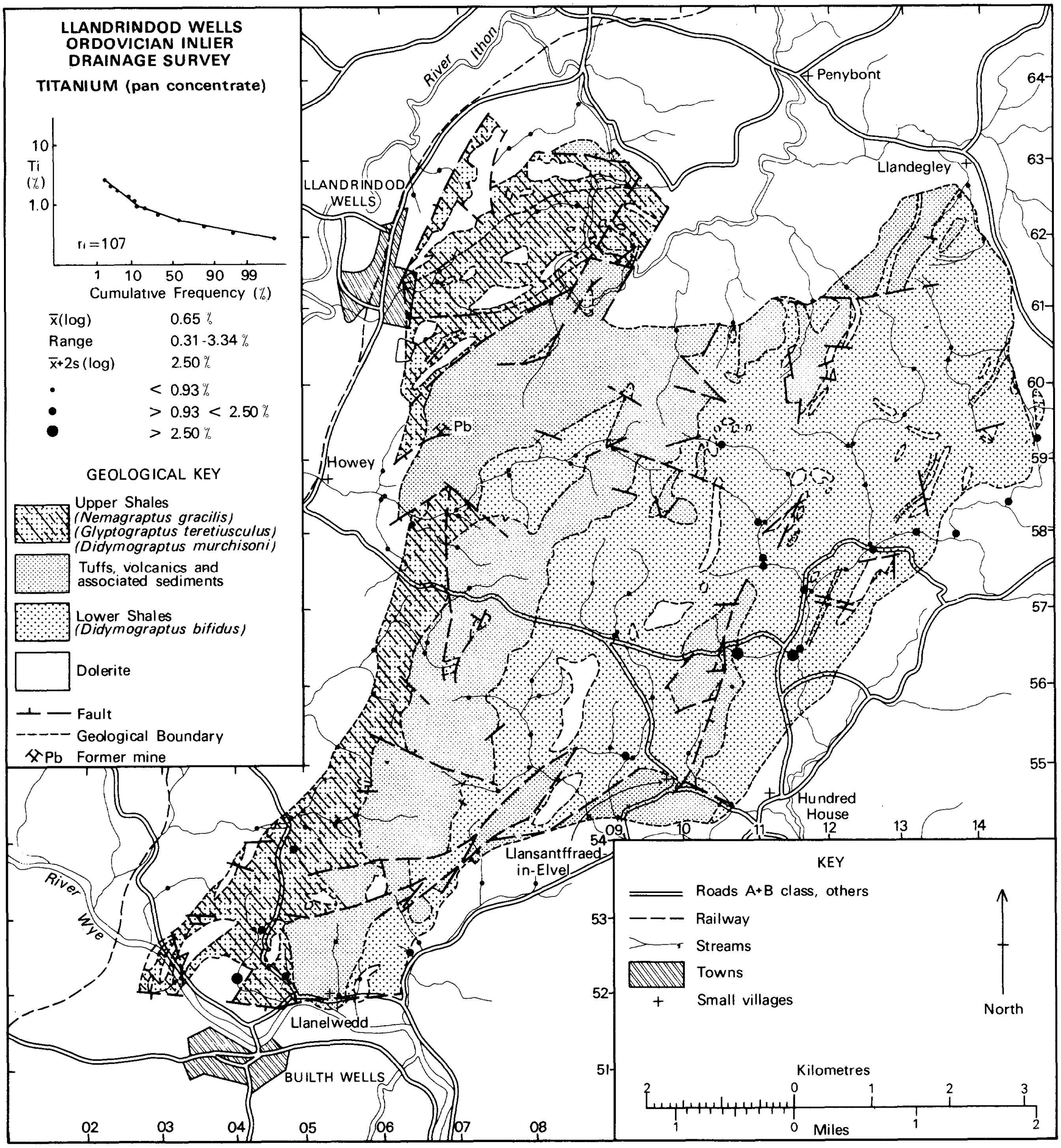

Figure 4 Distribution of titanium in panned concentrate samples

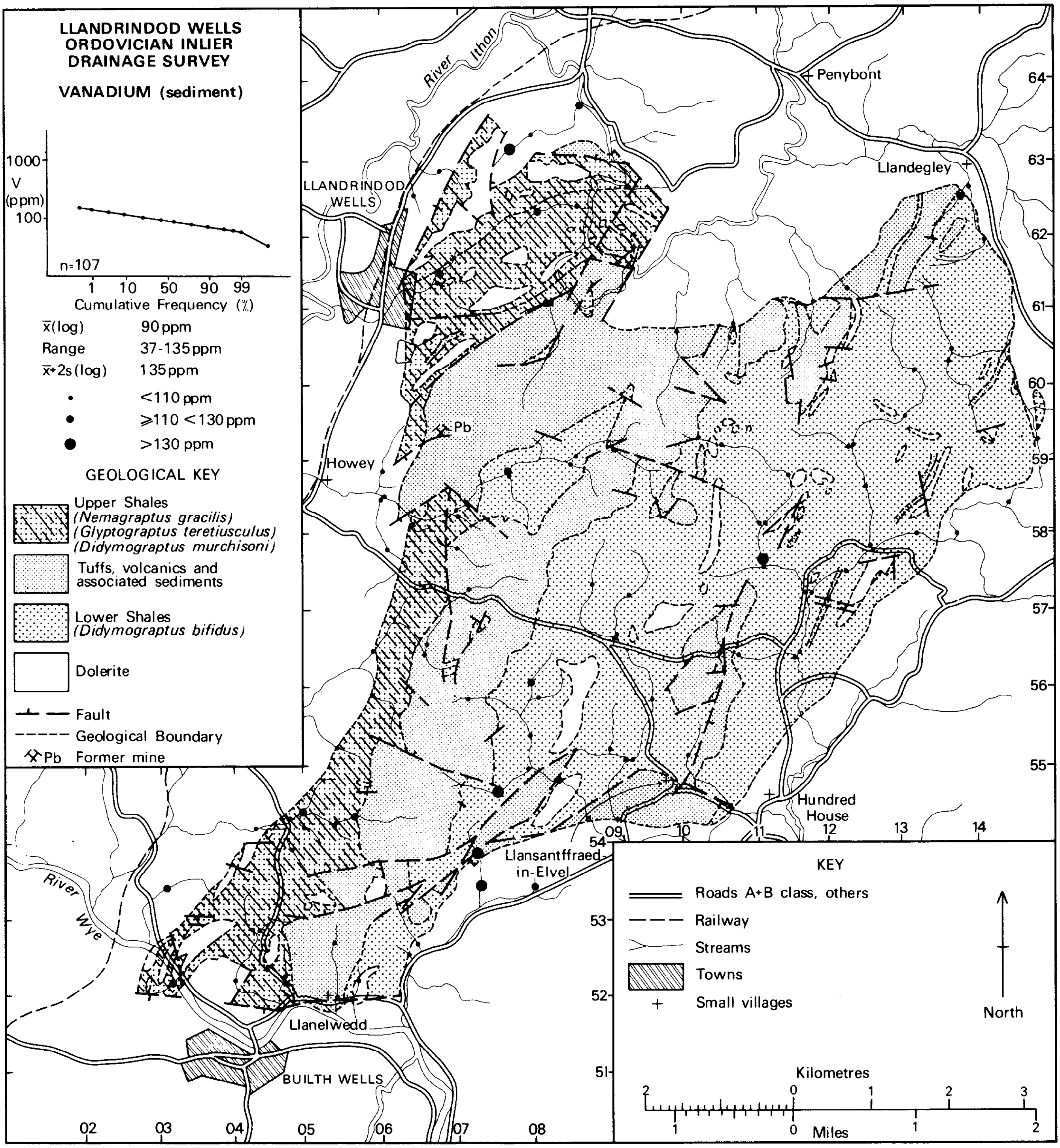

Figure 5 Distribution of vanadium in sieved stream sediment samples

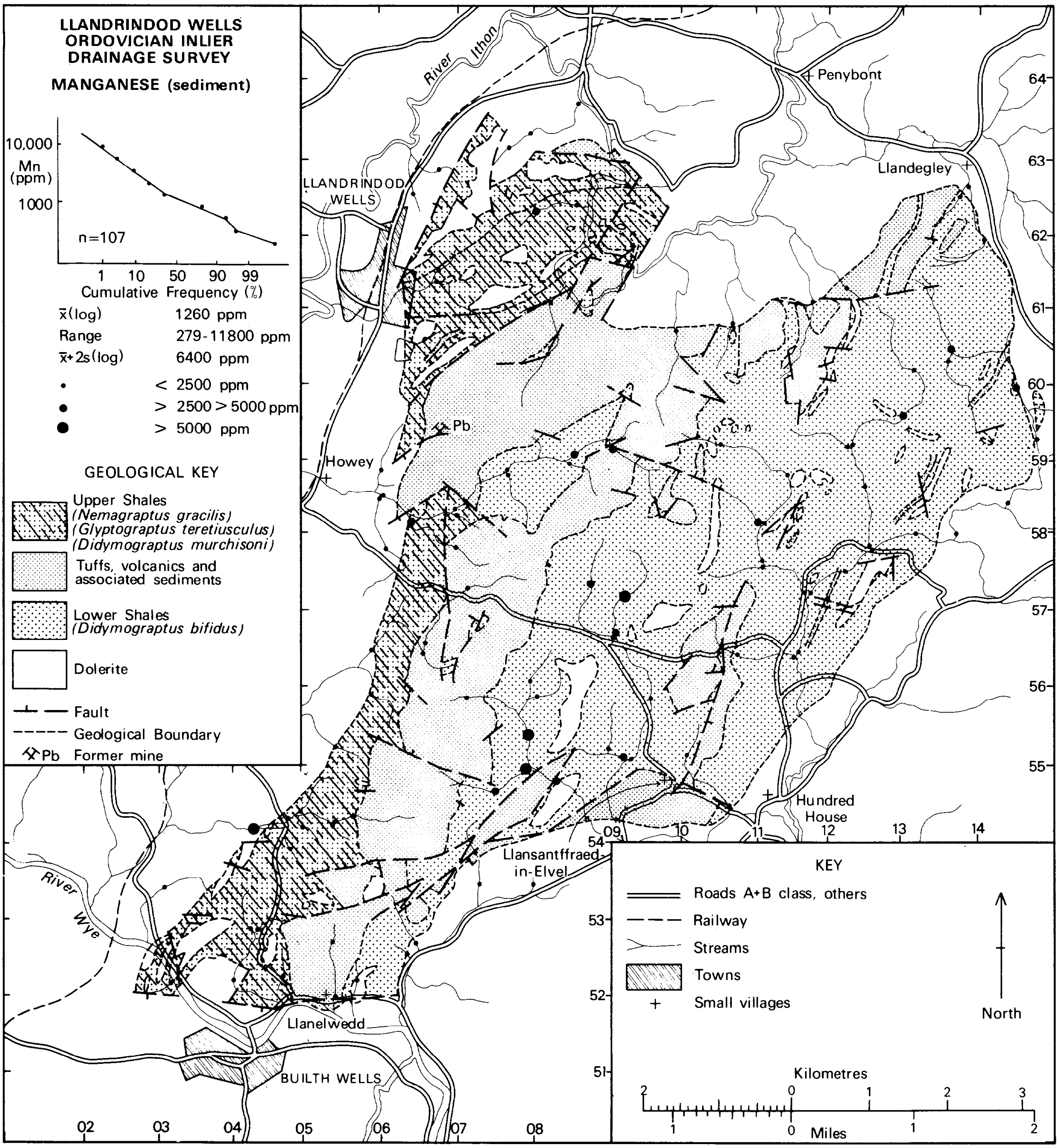

Figure 6 Distribution of manganese in sieved stream sediment samples

Manganese (sieved sediment)

Most of the samples containing relatively high levels of manganese are derived from the peaty areas underlain by the Lower Shales. This association is probably a reflection of the preferential secondary environmental precipitation of Mn in such terrain where drainage is relatively impeded relative to the areas underlain by the volcanic rocks. Several of the corresponding concentrate samples are relatively enriched in Mn but to a much less extent which suggests that the Mn is present dominantly as coatings to the grains and rock fragments rather than as discrete Mn-rich mineral grains. Apart from this Mn in concentrate shows some correlation with the samples richest in TiO_2.

Iron (sieved sediment)

Higher levels of iron in the sieved sediment samples are predominantly associated with the outcrop of the Lower Shales and may reflect the oxidation of pyrite associated with these rocks and the secondary environmental precipitation of hydrous iron oxides in areas of impeded drainage.

Iron (panned concentrate)

Samples with relatively high levels of iron occur mostly within the areas underlain by the Lower Shales and particularly over the Upper Shales and volcanic rocks to the east of Llandrindod Wells. In the latter area there is a

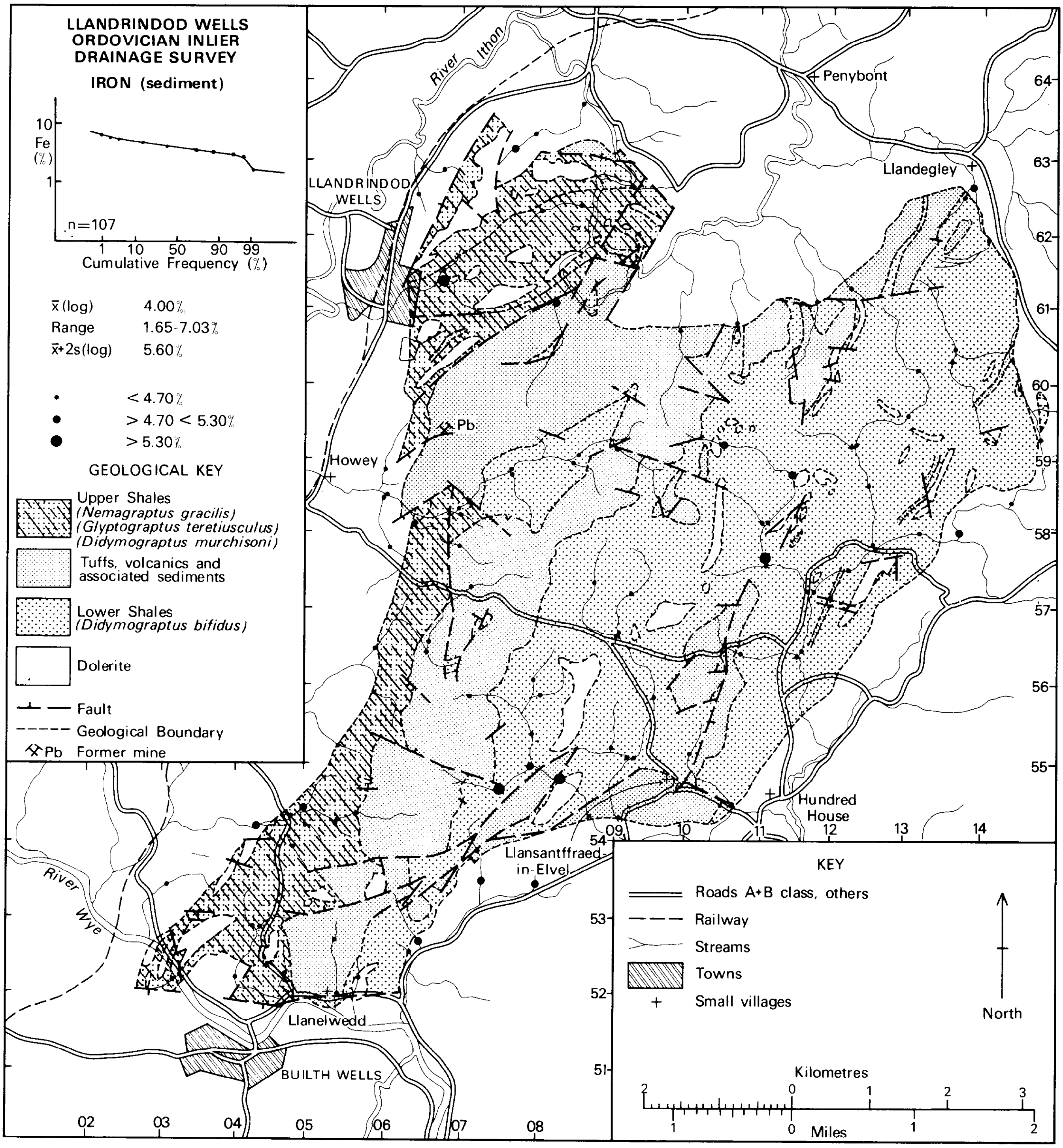

Figure 7 Distribution of iron in sieved stream sediment samples

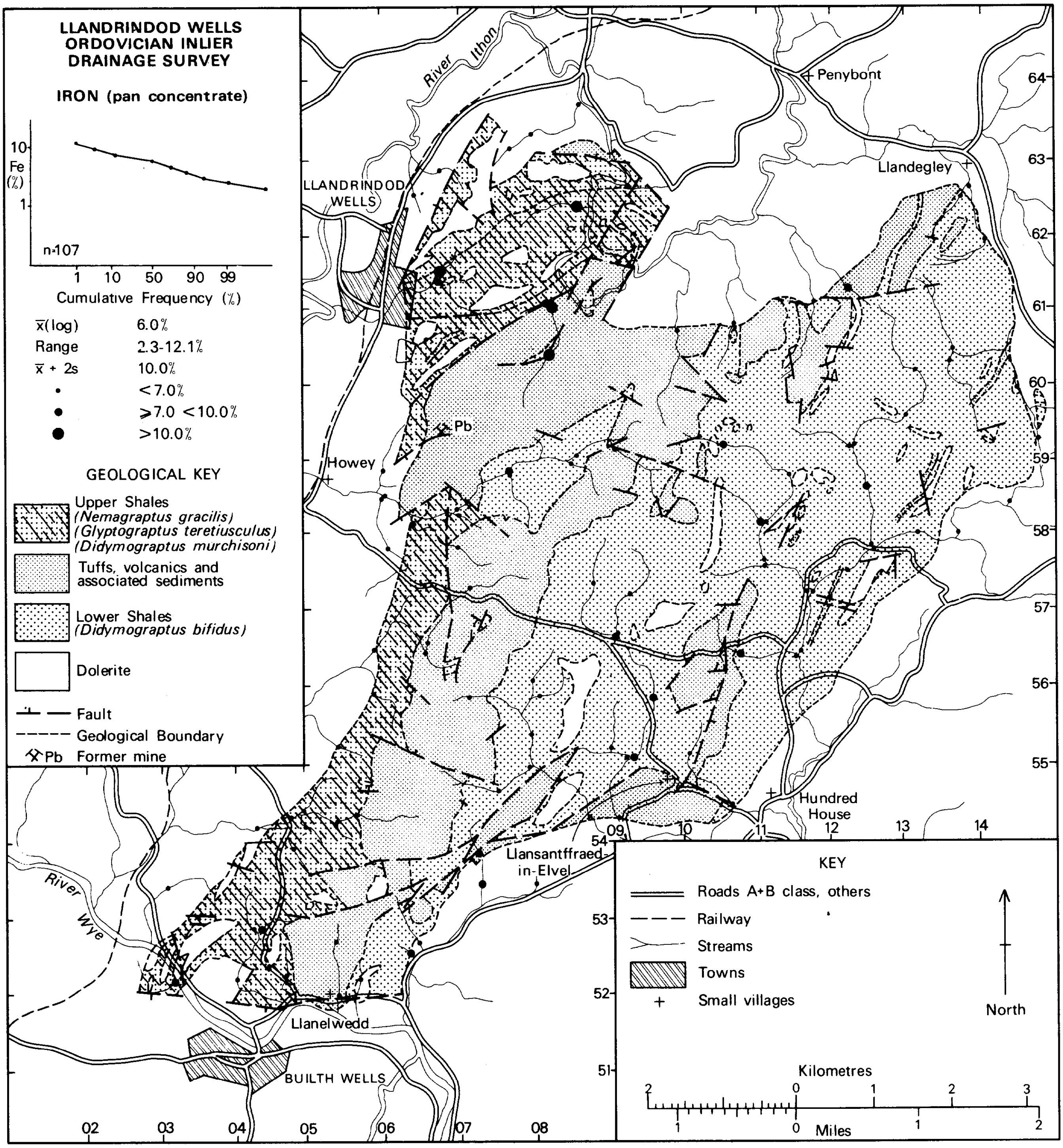

Figure 8 Distribution of iron in panned concentrate samples

positive correlation between iron and lead which may be a reflection of a significant pyrite or oxidised pyrite content in the samples especially as these are not rich in Ti as would be expected if they reflected oxide derived from basic igneous rocks.

Cobalt (sieved sediment)

There is a strong positive correlation between Co and Mn levels in the sieved sediment, reflecting the strong association of the two elements in the manganese oxide precipitate fraction of the samples. The two Co-rich samples from south of Llandegley are richer in Co relative to Mn than others and form part of a small anomalous population the source of which is unclear.

Copper (sieved sediment)

The range of copper in sieved sediments is low. There is some suggestion that the outcrop of the Upper Shale sequence is marked by a slight enrichment of Cu. The source of the four samples in the south of the area with the highest Cu contents is unclear but it is possible that they are related to E-W faulting which is prominant in southern part of the Inlier. None of the follow-up work has provided evidence of copper mineralisation.

Copper (panned concentrate)

The range of copper in panned concentrate samples is much greater than that in the sieved sediments and this can be seen in the much steeper gradient of the concen-

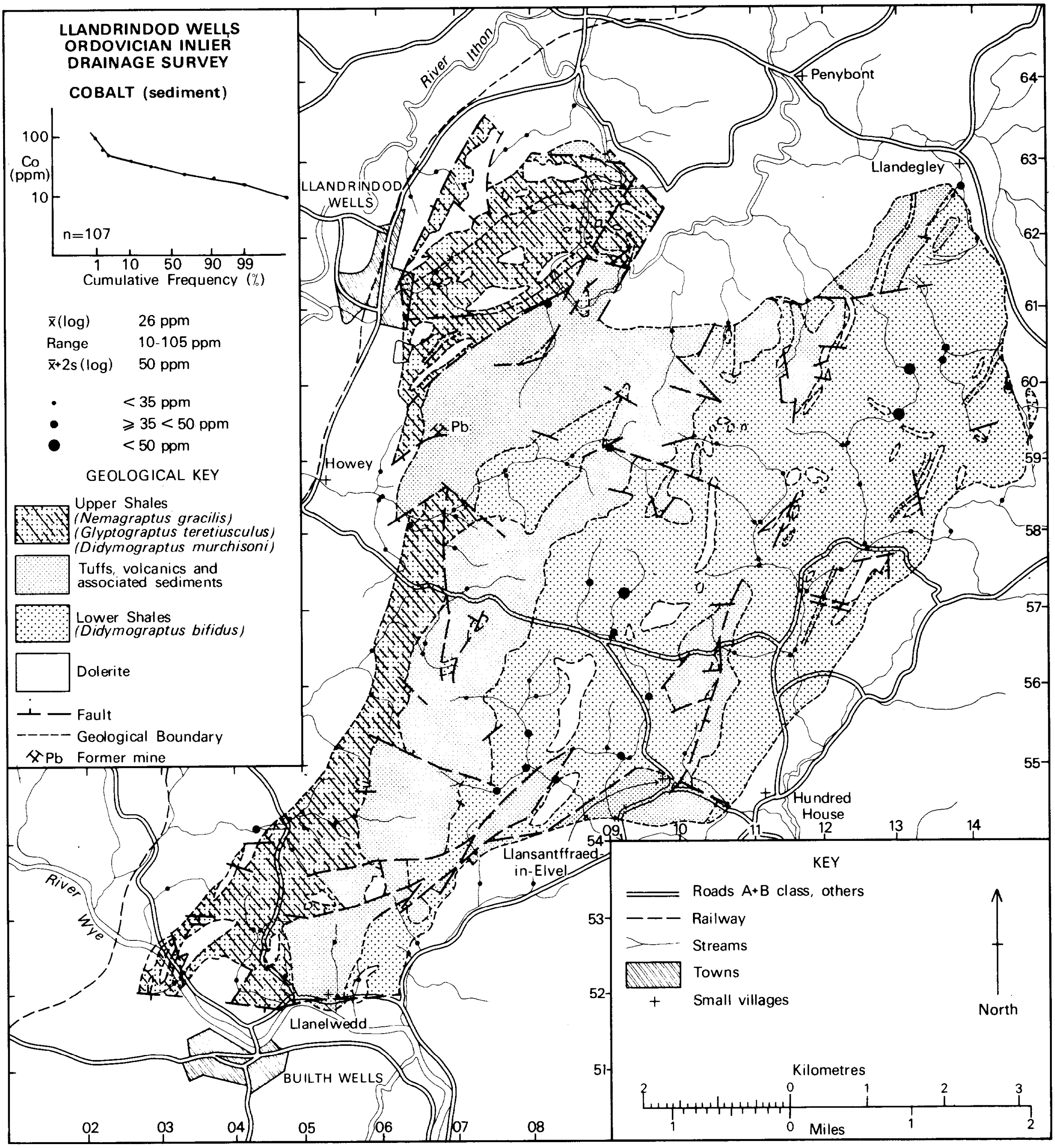

Figure 9 Distribution of cobalt in sieved stream sediment samples

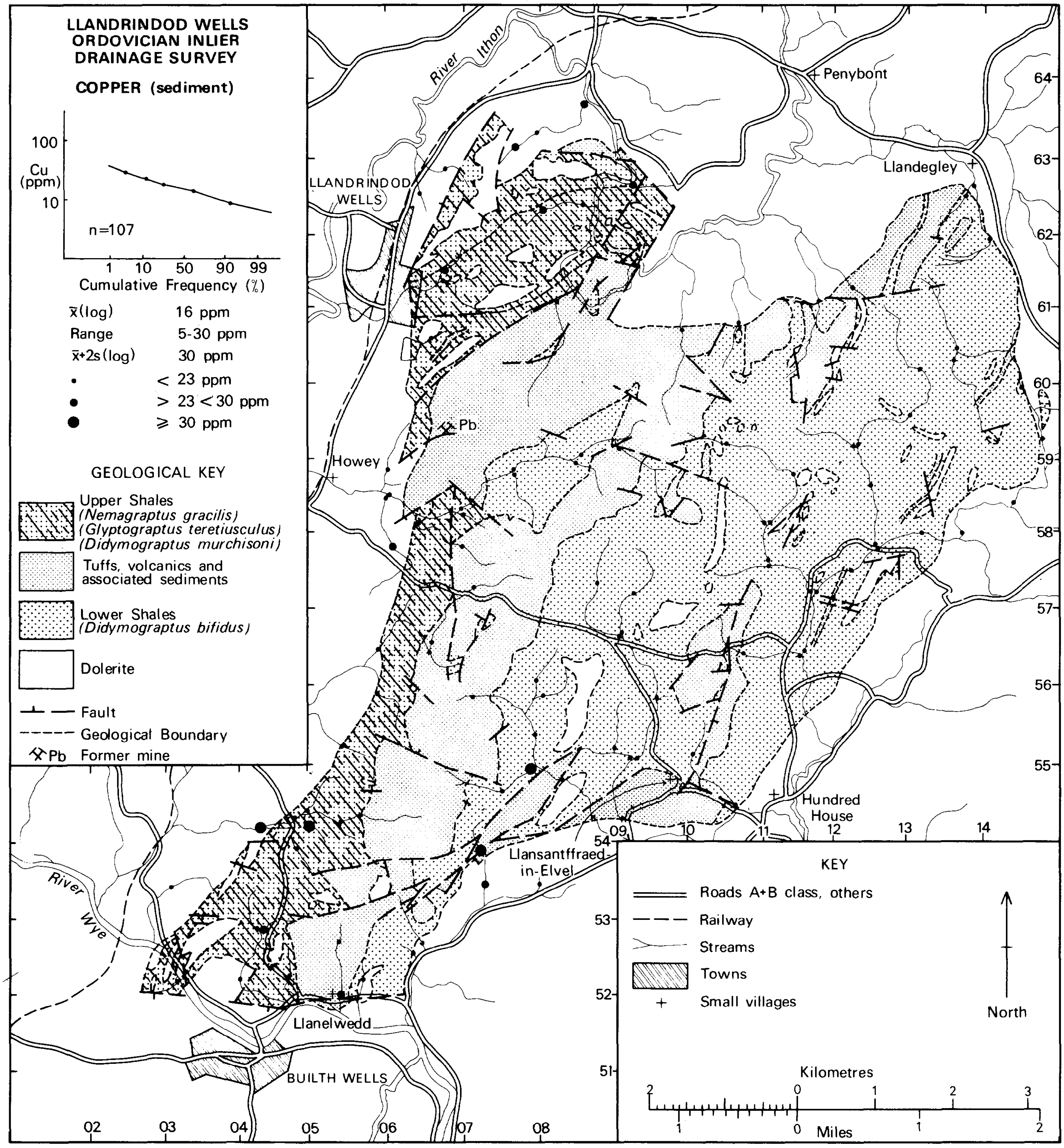

Figure 10 Distribution of copper in sieved stream sediment samples

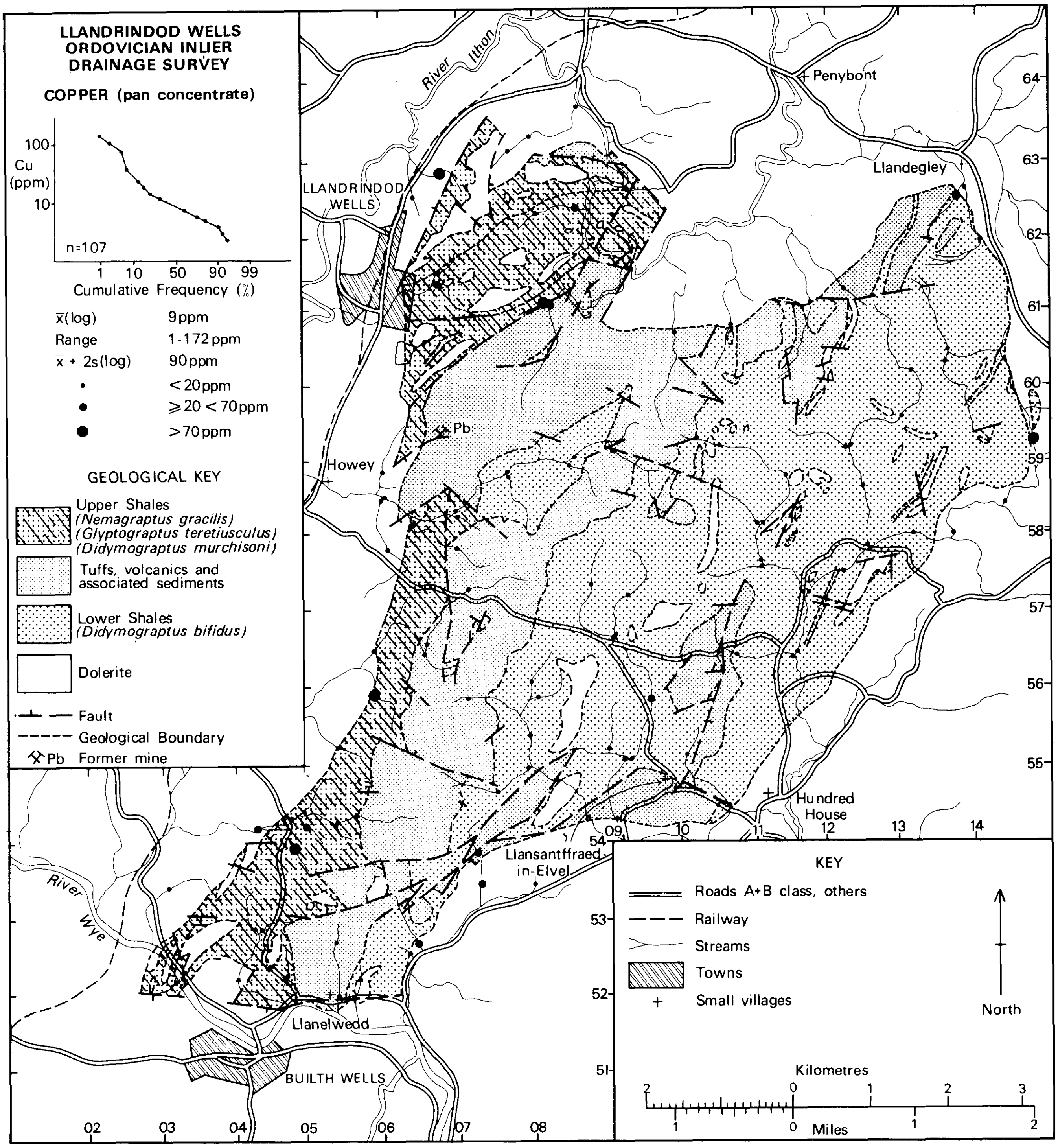

Figure 11 Distribution of copper in panned concentrate samples

trate cumulative frequency plot. The agreement between the two sample types is low with only three sites, all in the south of the area, showing coincident anomalies and no sites with coincident anomalies of the highest class. It is probable that some isolated concentrate anomalies which have no corresponding sieved sediment anomalies reflect metallic contamination, though this has not been checked by microscopic examination of the samples. This is also suggested from the association of Cu with relatively high levels of Sn in some though not all of the anomalous concentrate samples. Two Cu-rich samples without associated tin anomalies are from sites on Silurian rocks close to the margin of the inlier though the source of these is not clear.

Zinc (sieved sediment)

There is a general association between relatively high levels of Zn in the stream sediments and the peaty ground developed over the Lower Shale sequence. Thus there is a good correlation between Zn and Mn levels. Samples from the upper part of the stream to the east of Howey have high levels of Zn relative to Mn and probably reflect mineralisation and this may also apply to the sample from NW of Pendre [088 574].

Zinc (panned concentrate)

The cumulative frequency plot of Zn in panned concentrates shows a sharp increase in gradient at around the 350 ppm level which probably reflects the presence of a

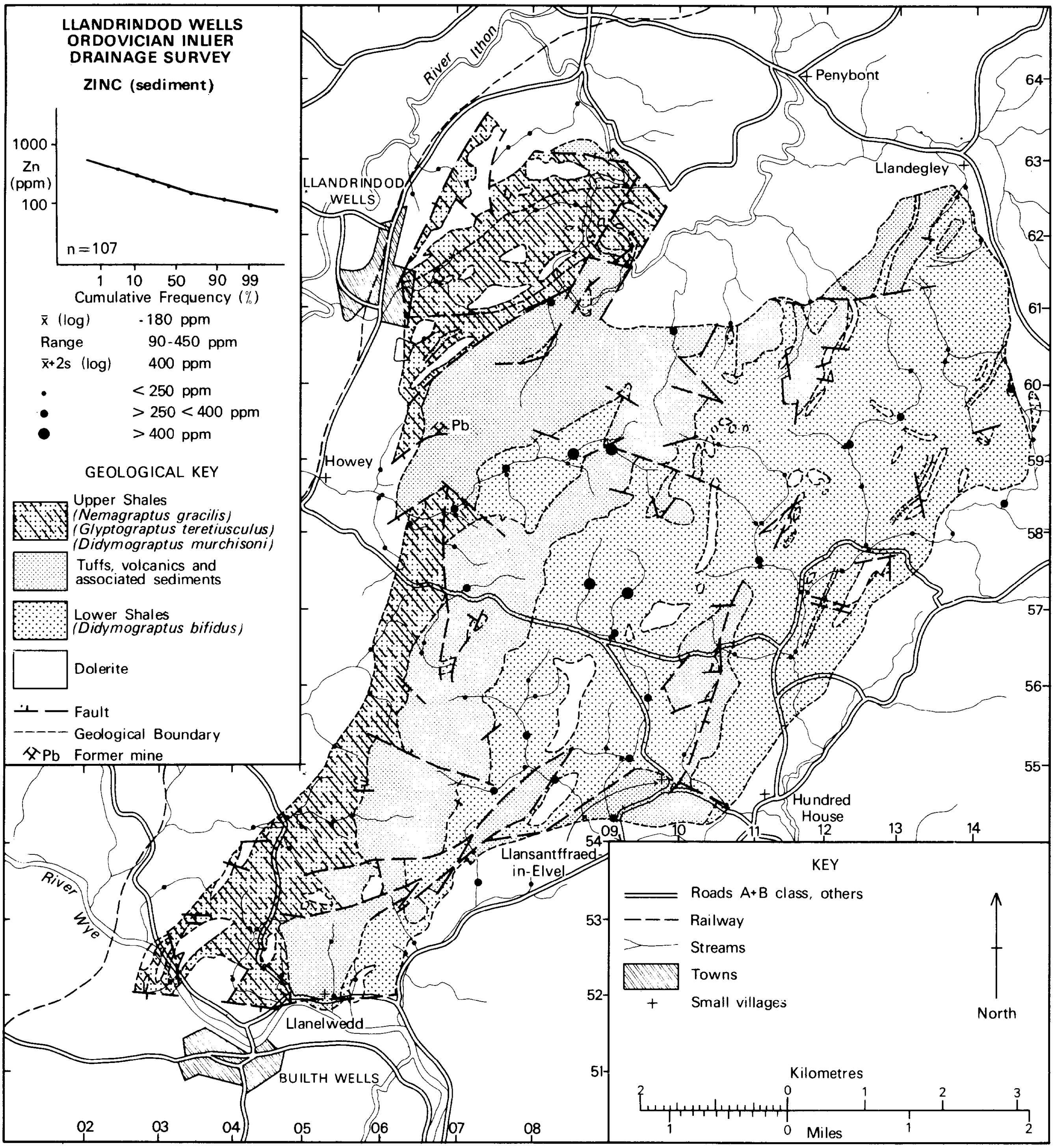

Figure 12 Distribution of zinc in sieved stream sediment samples

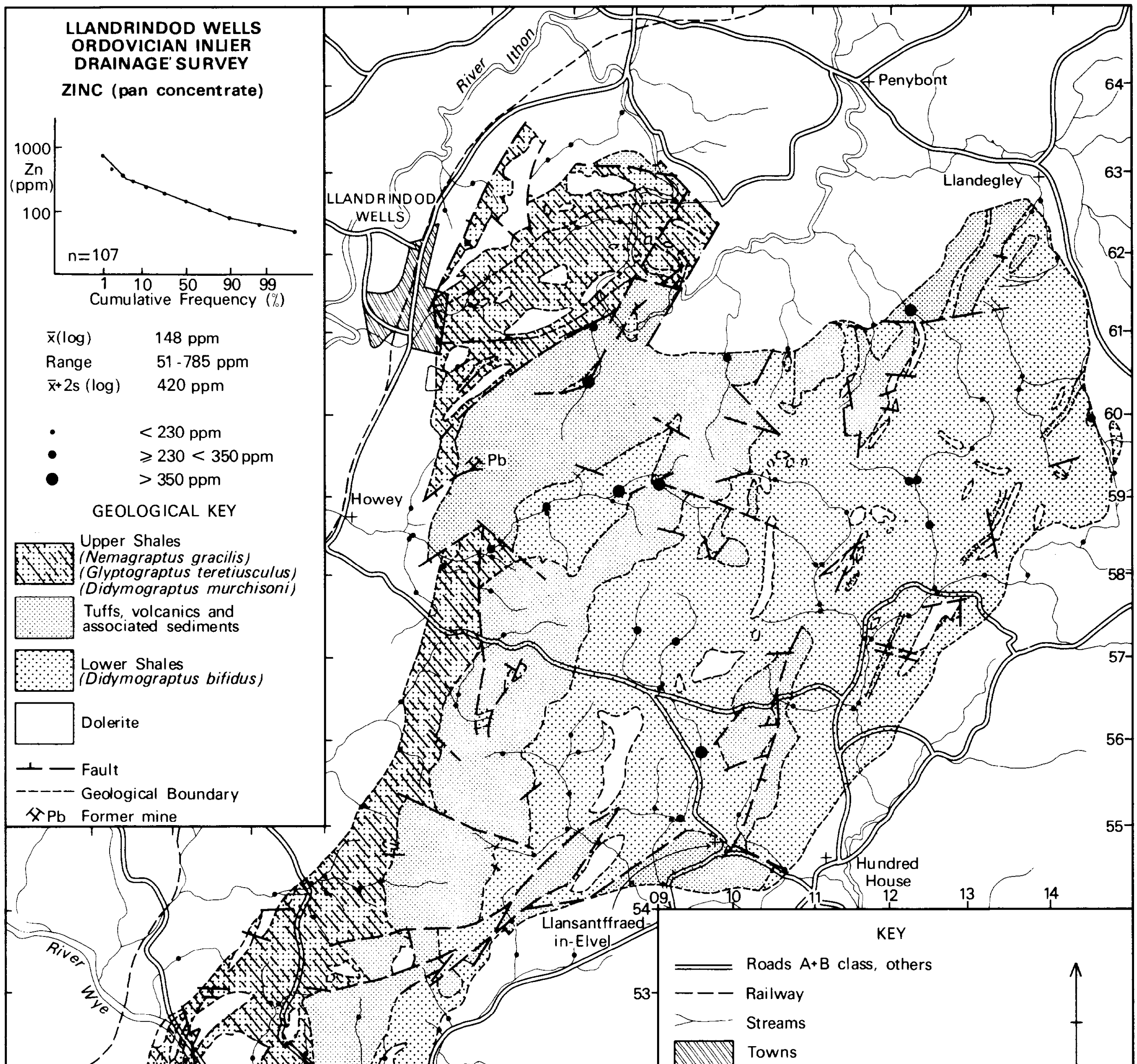

Figure 13 Distribution of zinc in panned concentrate samples

significant amount of sphalerite in an upper population. The samples from the upper part of the stream to the east of Howey almost certainly reflect mineralisation especially as the corresponding sieved sediments are also anomalous. This is also supported by the follow-up drainage and bank sampling described below. The anomalous sample from south of Cwm-brith Bank [082 602] and the sample from further downstream also probably reflects mineralisation, especially in view of the spectrum of anomalous elements present, though the follow-up grab and and bank sampling failed to provide supporting evidence for this. Overall there is an indication of a general association between Zn anomalies and the northern part of the outcrop of the main tuff group. The source of the other isolated concentrate zinc anomalies is uncertain but it is possible that samples derived from the Lower Shales to the north of Pendre [088 574],[093 571] also reflect mineralisation in view of the relatively high levels of Zn in some of the corresponding sieved sediment samples.

Strontium (panned concentrate)

Samples with relatively high levels of Sr occur mostly in the southern part of the area. There is some agreement between Sr and Ca, especially in samples derived from the Lower Shales and three samples are also relatively rich in Ba. Lack of agreement between Sr and Ti-rich samples suggests that sphene is unlikely to be the main Sr-bearing Ca-rich mineral present in the samples.

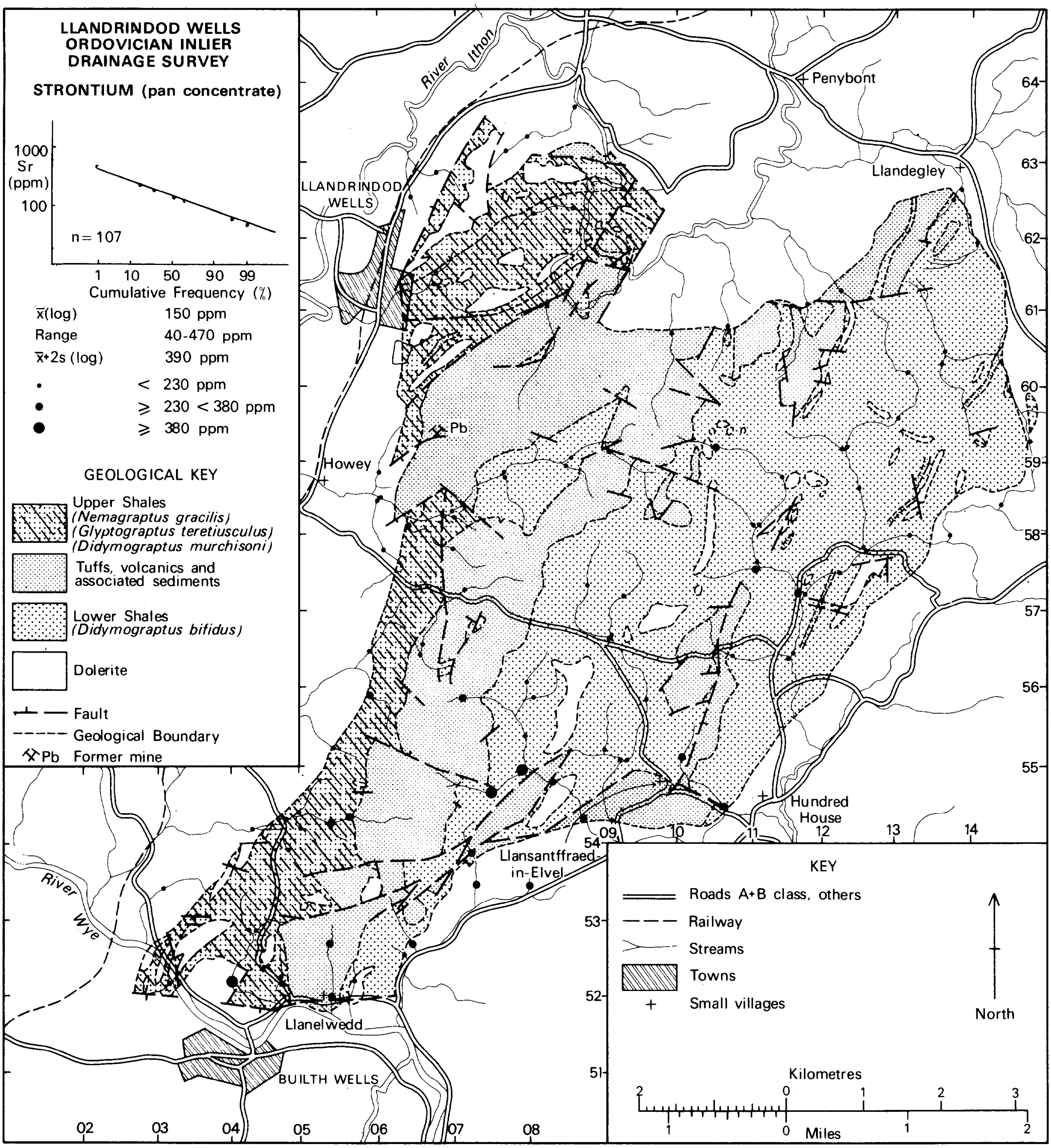

Figure 14 Distribution of strontium in panned concentrate samples

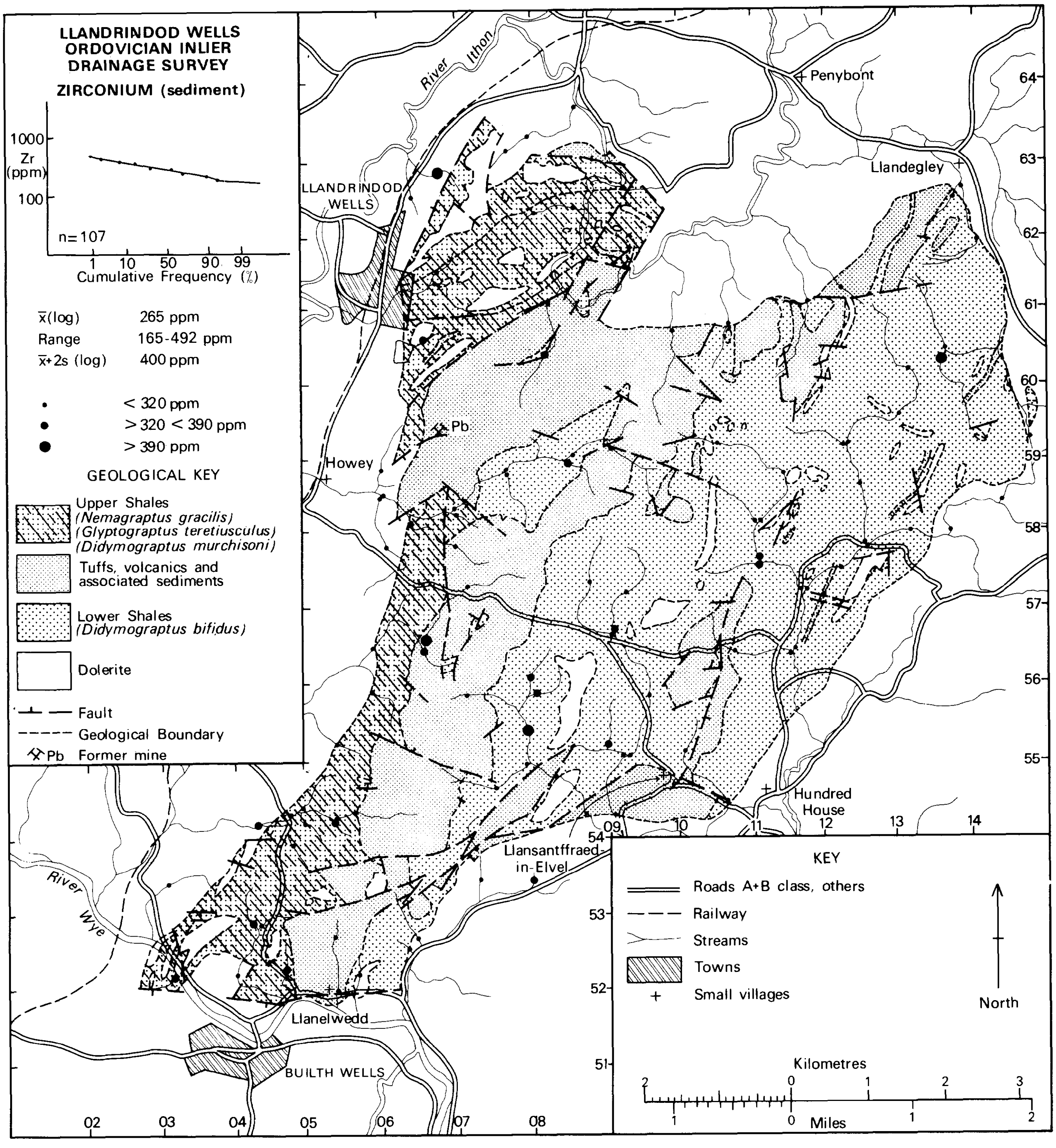

Figure 15 Distribution of zirconium in sieved stream sediment samples

Zirconium (sieved sediment)

There is a relatively small range of Zr contents in the sieved sediments and a scatter of relatively high values across the whole area.

Tin (panned concentrate)

Several relatively tin-rich samples occur, many, but not all, of which are close to roads. Since levels of tin in common rocks and their consituent minerals and in base-metal mineralisation are very low, tin anomalies serve as indicators of metallic contamination of human origin. Mineral examination of the concentrates is required to confirm that all other associated metal anomalies are also in contaminants.

Barium (sieved sediment)

Ba-rich samples are scattered throughout the area. Many of the samples are probably derived from mineralisation as they coincide with concentrate anomalies and with enrichments in other metals.The relatively high level of Ba in the sieved sediment relative to the concentrate in some samples e.g. at Cwm-brith Bank [083 611] suggest that any baryte present is relatively fine-grained or more likely that other lighter minerals such as mica containing Ba may be present.

Barium (panned concentrate)

The range of Ba in panned concentrate is not high compared with many areas of Britain and it is therefore

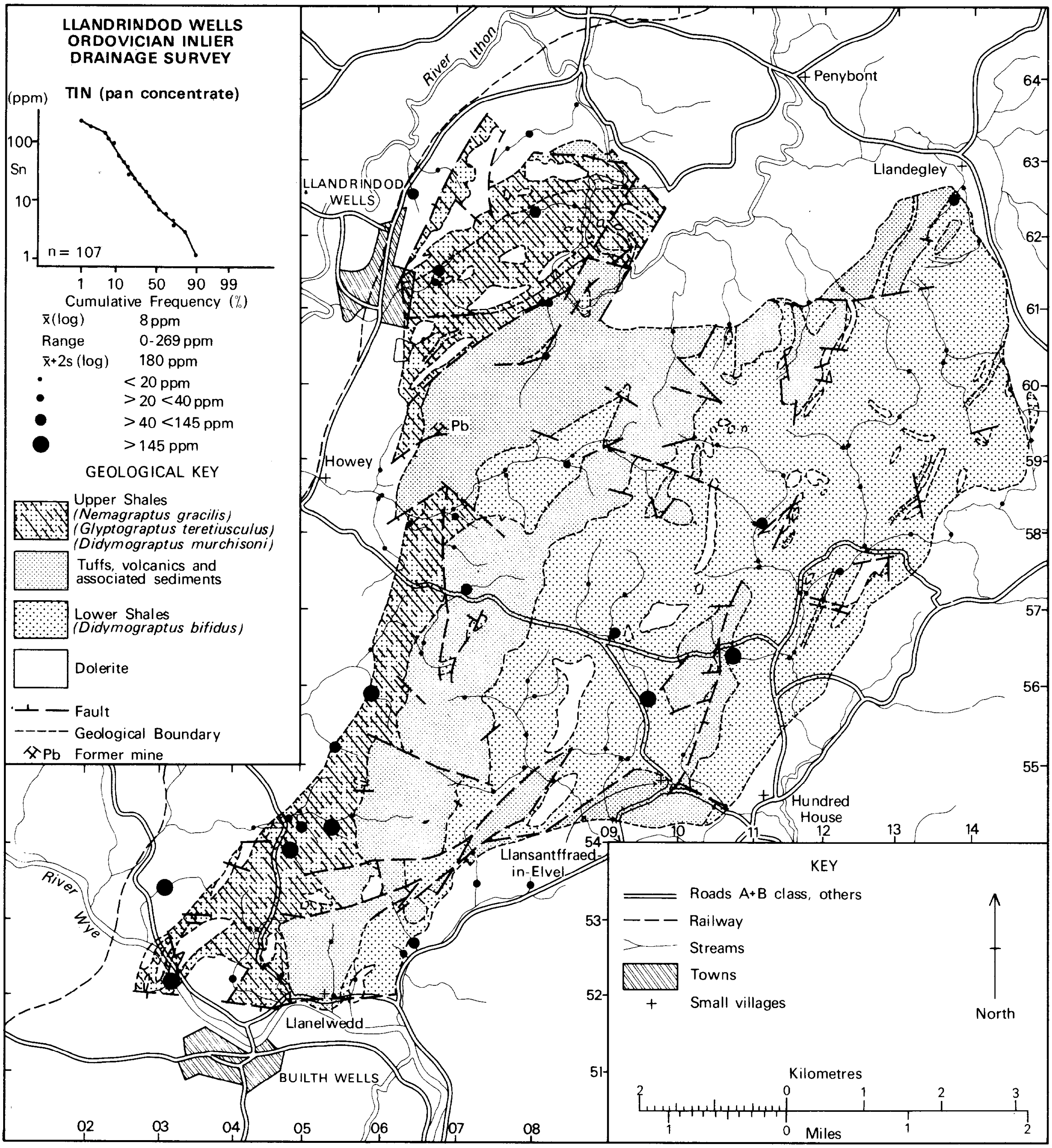

Figure 16 Distribution of tin in panned concentrate samples

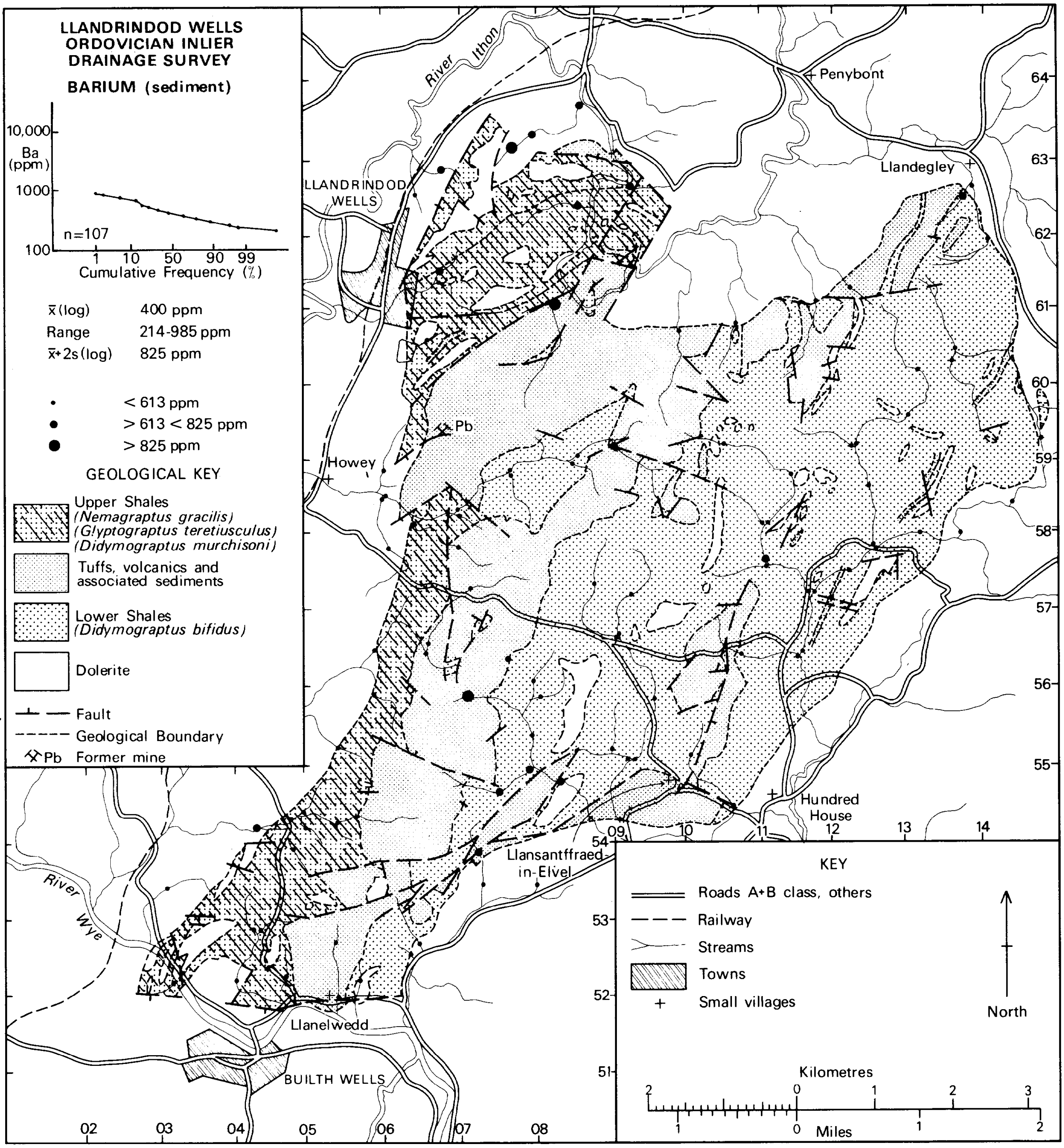

Figure 17 Distribution of barium in sieved stream sediment samples

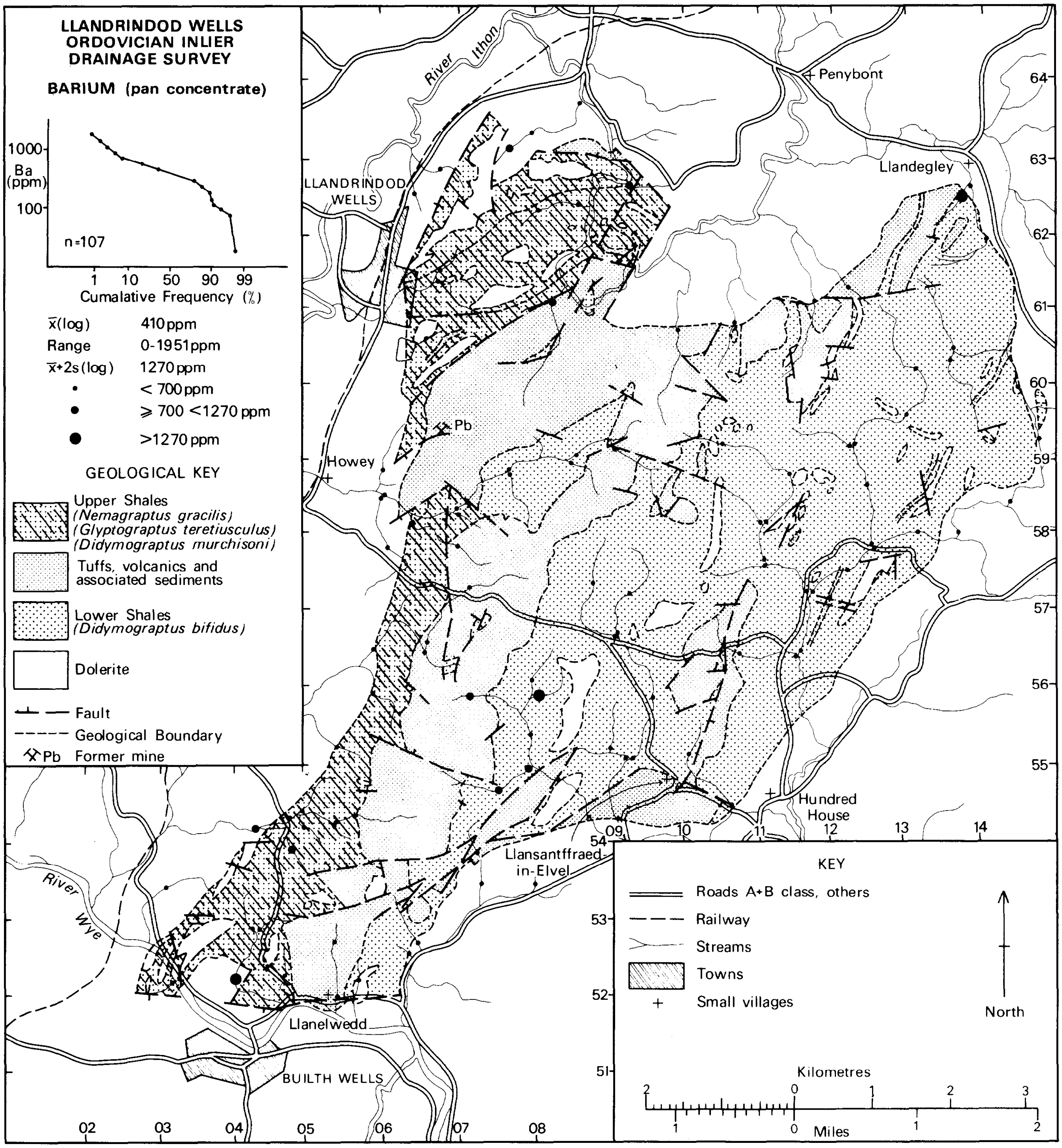

Figure 18 Distribution of barium in panned concentrate samples

unlikely that substantial amounts of baryte are present. Two of the most Ba-rich concentrates are not associated with anomalous levels in the corresponding sediment samples and could be derived from minor relatively coarse-grained baryte mineralisation.

Cerium (panned concentrate)

The cerium content of many of the concentrate samples is very high, as in other similar samples derived from sedimentary rocks of the Welsh Basin (e.g. Cooper and others, 1984). The cerium in these areas occurs as nodules of monazite or grain coatings which are thought to be of diagenetic origin (Cooper and others, 1983). In the Llandrindod Wells Ordovician inlier the maximum Ce levels are associated with the *Glyptograptus teretiusculus* zone of the Upper Shale sequence but the reason for this is unclear. In contrast the Ce levels of some samples derived entirely or largely from the volcanic rocks is relatively low.

Lead (sieved sediment)

The cumulative frequency plot of Pb shows a sharp break in slope and a high gradient anomalous population comprising 3 samples. Of these the one from near Howey is derived from the old lead workings and the one from south of Cwm-brith Bank [082 602], though contaminated with material of domestic origin, probably reflects mineralisation. The Pb in the sample from SW of Llansantffraed-in-Elvel [073 534] may be derived from a mineralisation source in view of the lack of an associated

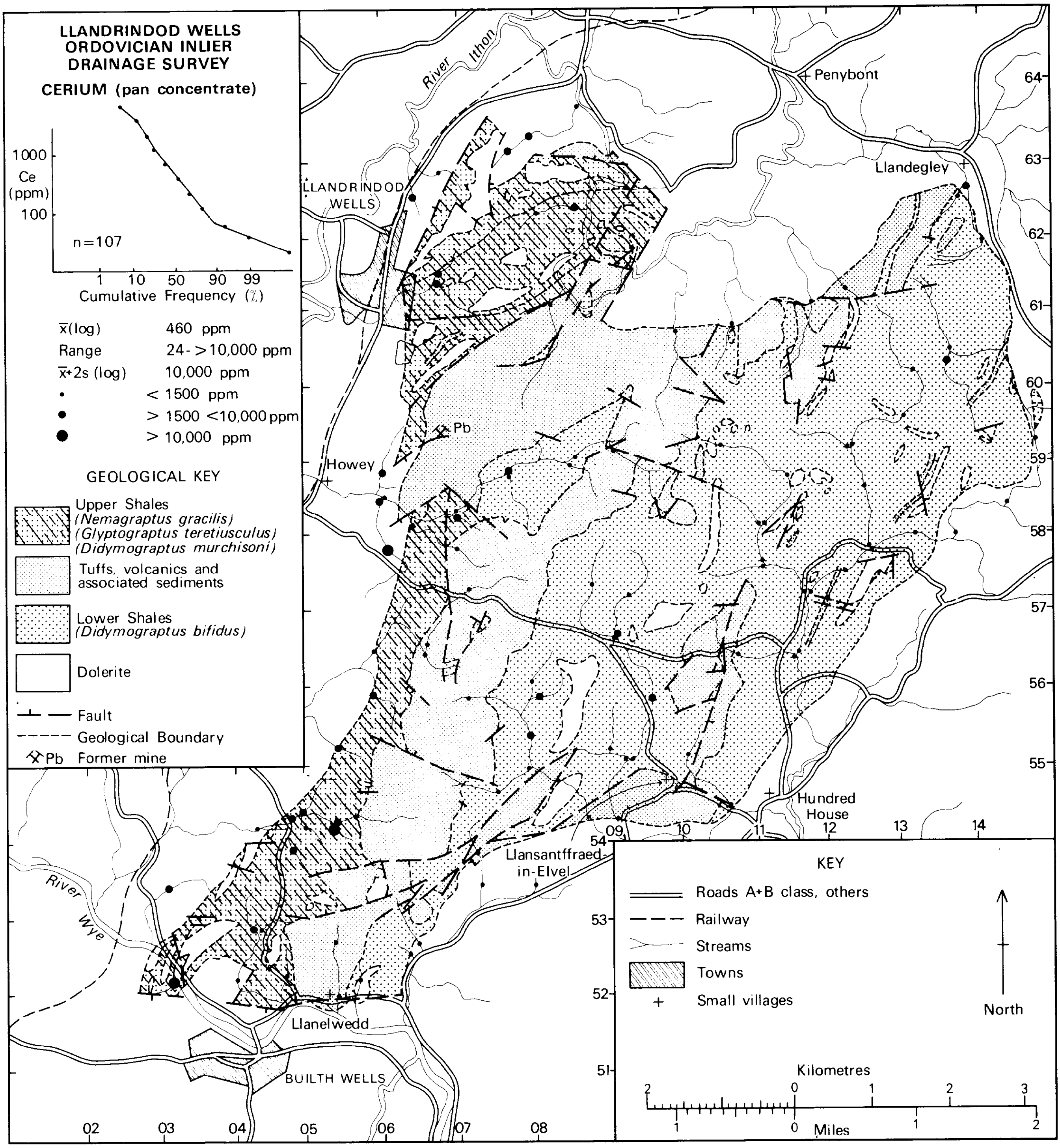

Figure 19 Distribution of cerium in panned concentrate samples

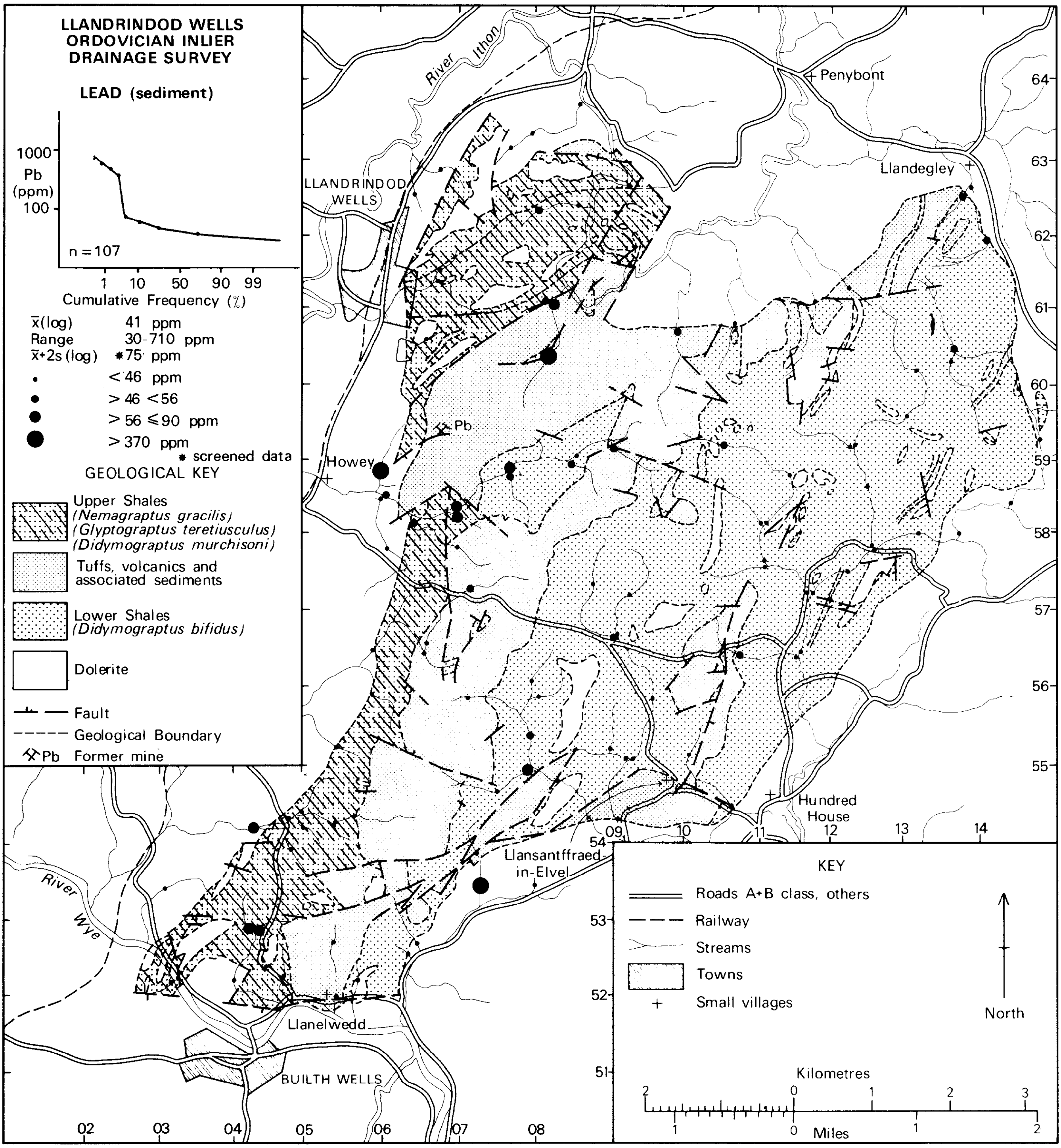

Figure 20 Distribution of lead in sieved stream sediment samples

high amplitude Sn anomaly, though mineralogical examination of the heavy mineral concentrate is required to confirm this. Slightly elevated levels of Pb are associated with several samples from the Howey Brook drainage basin and from north of Builth Wells but the sources of these are unclear.

Lead (panned concentrate)

The cumulative frequency plot of Pb in panned concentrate samples shows a very sharp increase in gradient at about 60 ppm which correlates with the appearance in the samples of a significant amount of a lead-rich phase. This corresponds to Pb minerals and to metallic contaminants which seem to be quite widespread in the vicinity of human habitation. In view of their relatively high Sn content several Pb anomalies from north of Builth Wells and also adjacent to roads in the centre of the area are likely to be derived from contamination. Anomalies likely to reflect mineralisation within the main tuff group are present south of Cwm-brith Bank [082 602] and east of Howey [091 594] and [111 594] and west of Llansantfffraed-in -Elvel.

Synthesis of reconnaissance drainage data

A synthesis of the highest amplitude metallic-element anomalies is shown in Figure 22. Several of the anomalous samples also contain elevated levels of Sn which represents a good contamination monitor in the absence of Sn mineralisation in the area. At some sites the

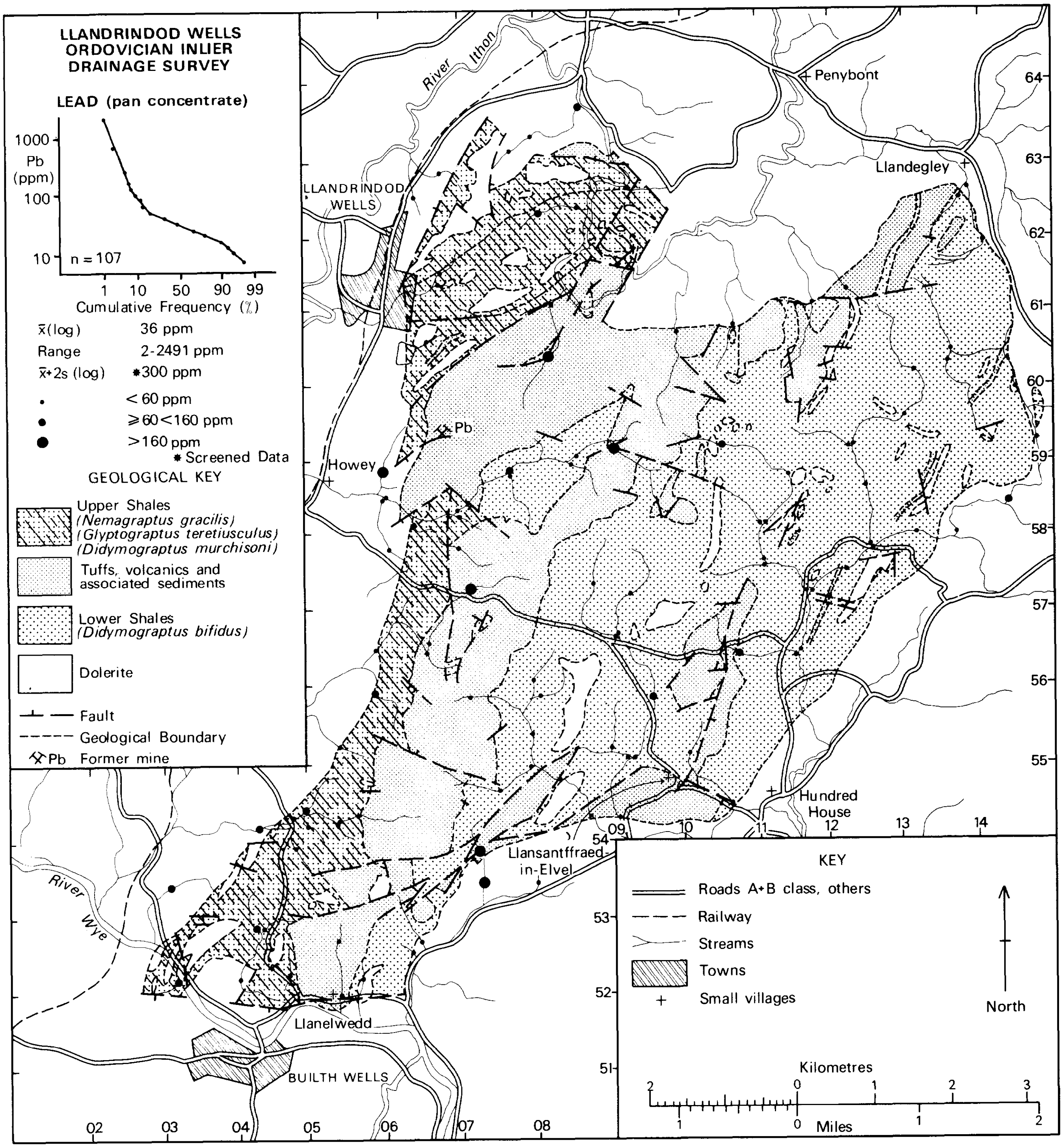

Figure 21 Distribution of lead in panned concentrate samples

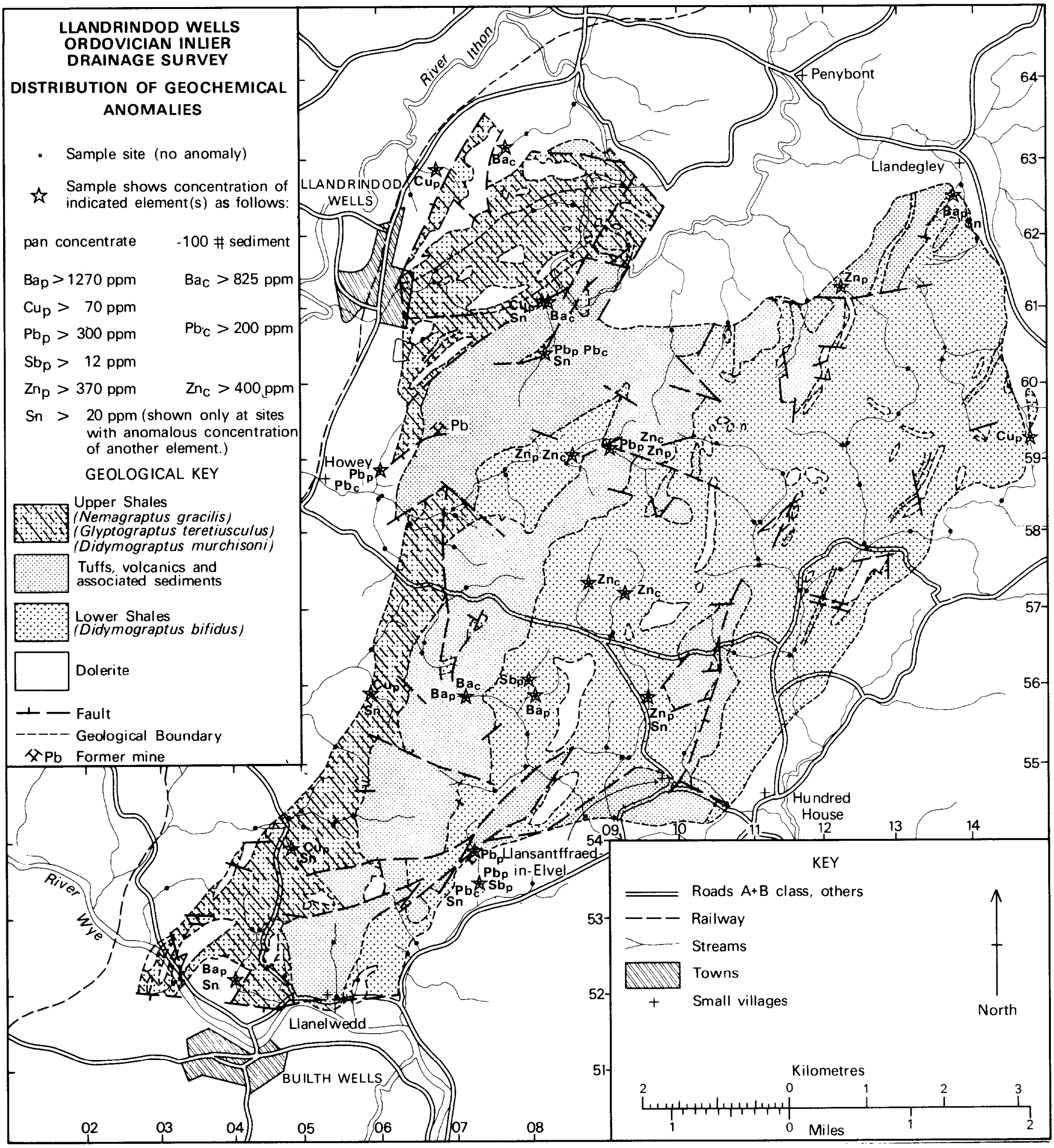

Figure 22 Synthesis of distribution of base metal anomalies in drainage samples

presence of both contaminants and natural heavy minerals is suspected and detailed mineralogical examination of the samples is required to confirm the presence of ore minerals. The most prominant anomalies of Pb and Zn appear to be associated with the outcrop of the volcanic unit, particularly in the north of the inlier. Elsewhere there are more isolated anomalous sites, some of which are clearly contaminated and environmental factors are responsible at least in part for the elevated Zn levels in the sieved sediment samples from the central Lower Shale area.

FOLLOW-UP DRAINAGE SAMPLING

Follow-up drainage sampling was carried out in 11 streams where the presence of anomalies derived from mineralisation was suspected, the location of which are shown in Figure 23. The sampling consisted of the collection of grab samples of stream sediment from natural sediment traps at 100 or 50 m intervals up the stream. A minus 85 BSI mesh (< 180 micron) fraction of these samples was obtained for chemical analysis. At the same time a sample of soil was collected from each bank at a depth of about 25 cm. The soil samples were dried, dissagregated and dry screened to give a minus 85 BSI mesh (< 180 micron) fraction for analysis.

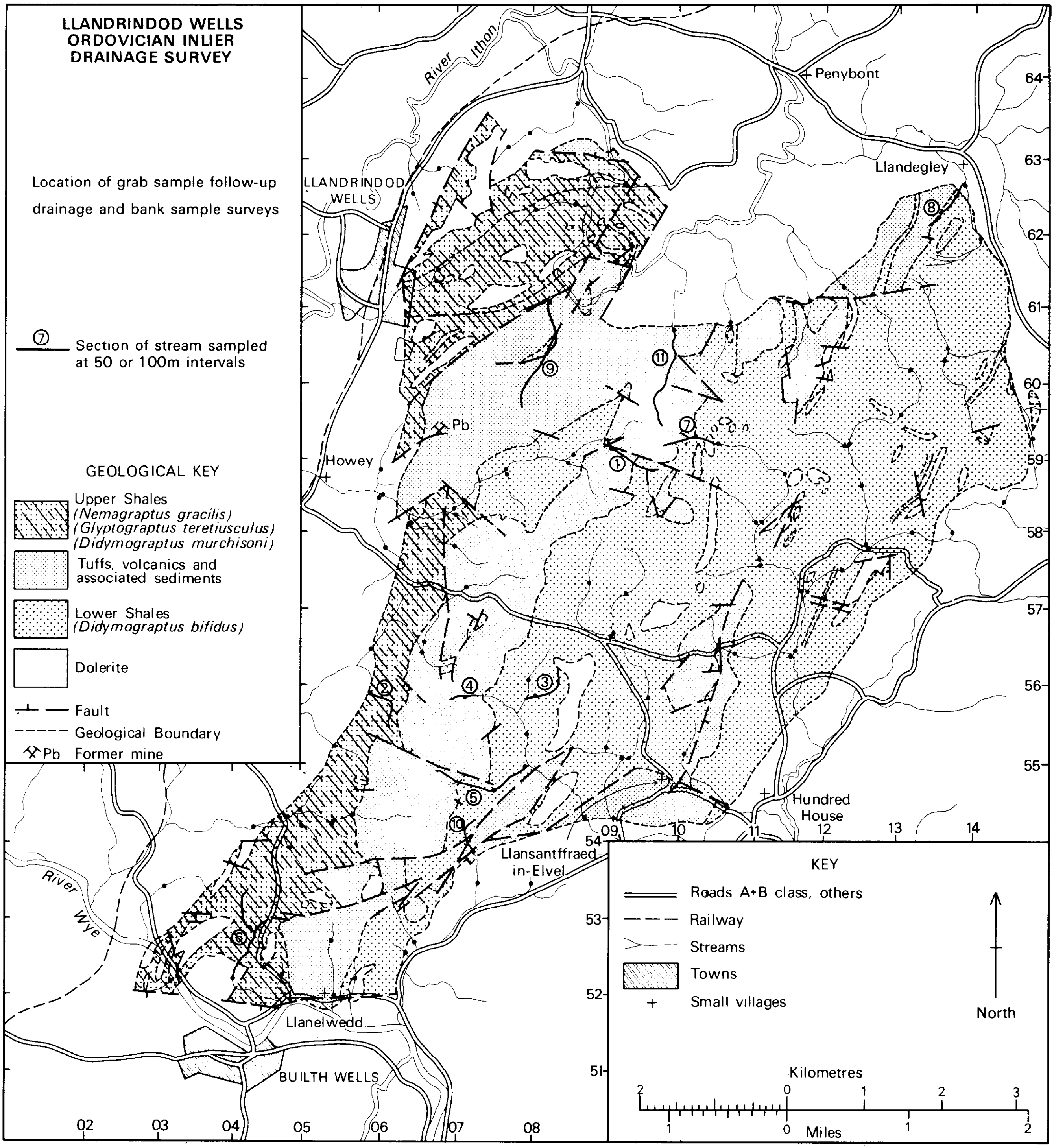

Figure 23 Location of follow-up grab sampling drainage surveys

A clear confirmation of elevation of Pb and/or Zn levels was obtained in 4 of the 11 streams sampled and the most anomalous sites are plotted for these in Figure 24. The highest amplitude and most persistent anomalies in the follow-up sampling occur in stream 1 which cuts across the outcrop of the volcanic unit. These are also confirmed in the lower part of the stream by anomalous levels of both Pb and Zn in the bank samples. Other sources are possibly indicated by the Zn and Pb anomalies further upstream. Sampling of stream 7 suggests that the source of the anomaly is likely to be further upstream within the outcrop of the same volcanic unit which is also probably the case in stream 8. The source of the anomaly in stream 3 is likely to be very local in view of the close correspondence between drainage and bank samples.

RECONNAISSANCE SOIL SAMPLING

The reconnaissance drainage data were supplemented by the chemical analysis of samples from 27 reconnaissance soil traverses, the locations of which are shown in Figures 27 to 29. All soil samples were collected in Kraft paper bags from material obtained by soil auger from between 30 and 60 cm, oven dried, dissaggregated where necessary and dry screened to give a minus 85 BSI mesh (180 micrometres) fraction. Two long orientation traverses (1 and 2) were sampled in the south of the area across most of the outcrop of the Ordovician rocks and 19 elements (Cu, Pb, Zn, Co, Ni, Ag, As,B, V, Cr, Mn, Fe, Zr, Sn, Ba, U, Sr, Zr and Mo) and loss on ignition (LOI) determined by AAS after nitric acid attack, OES and

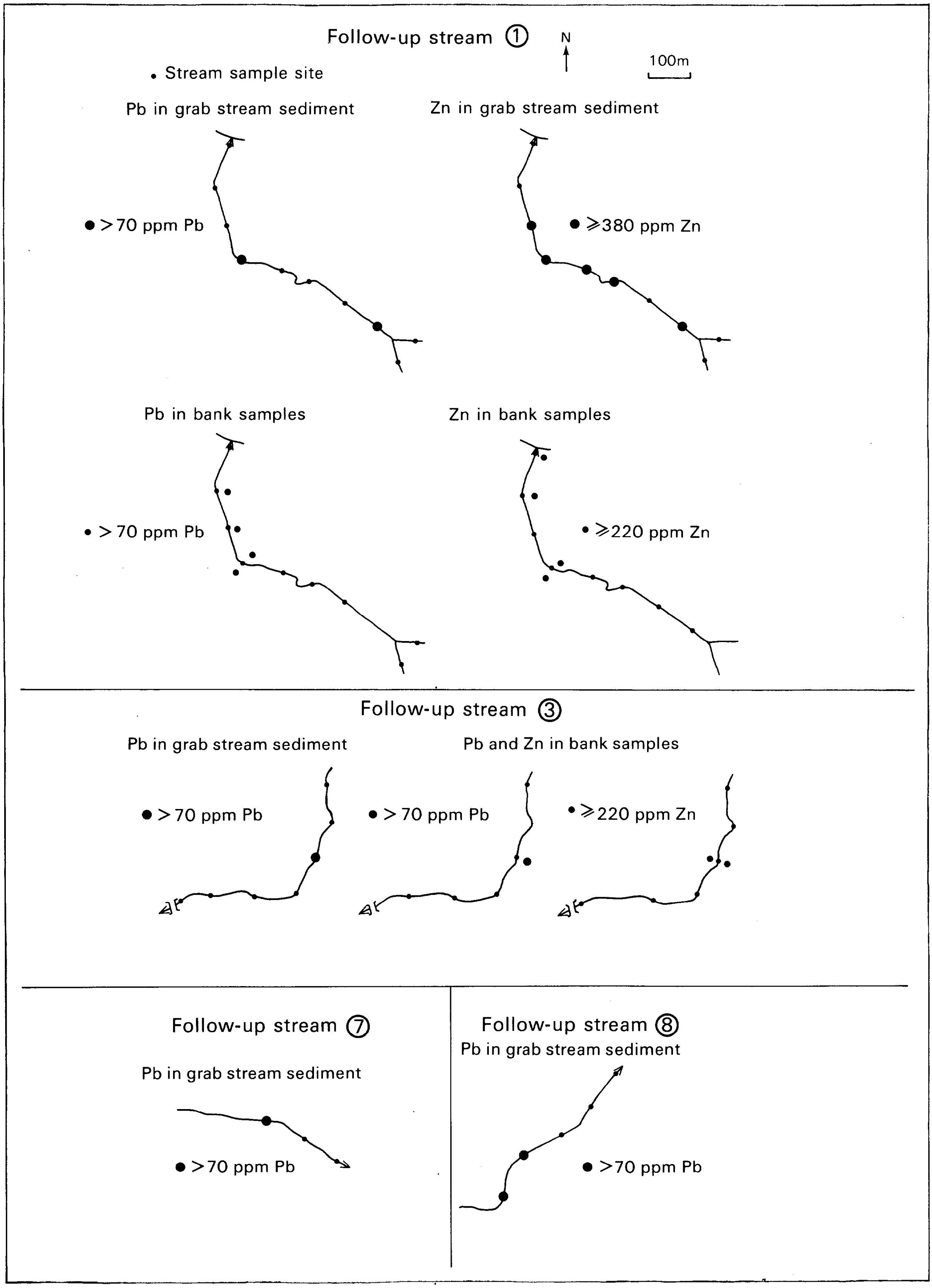

Figure 24 Distribution of Pb and Zn anomalies in follow-up drainage surveys

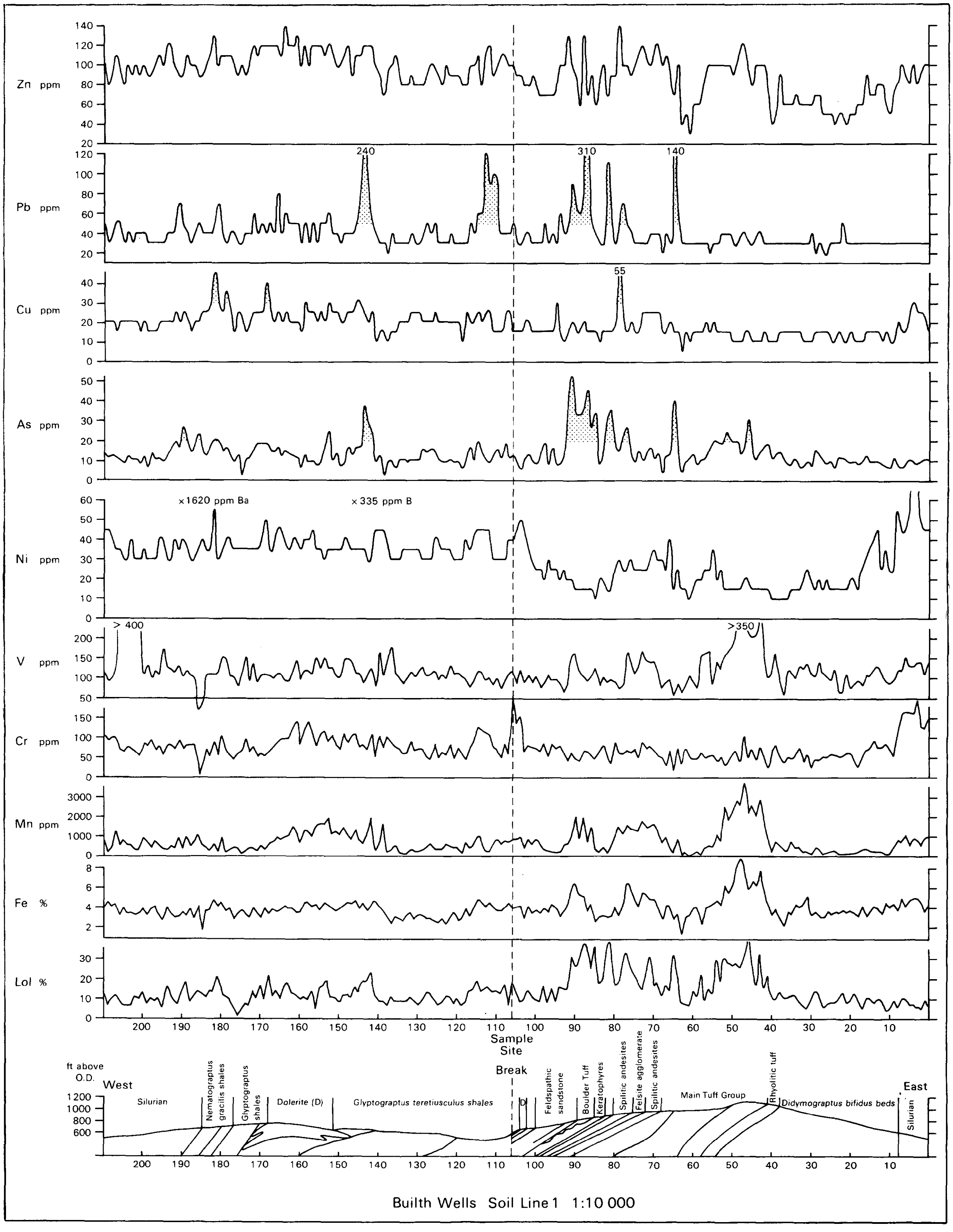

Figure 25 Plot of Zn, Pb, Cu, As, Ni, V, Cr, Mn, Fe and Loss on ignition (LOI) levels in reconaissance soil line 1

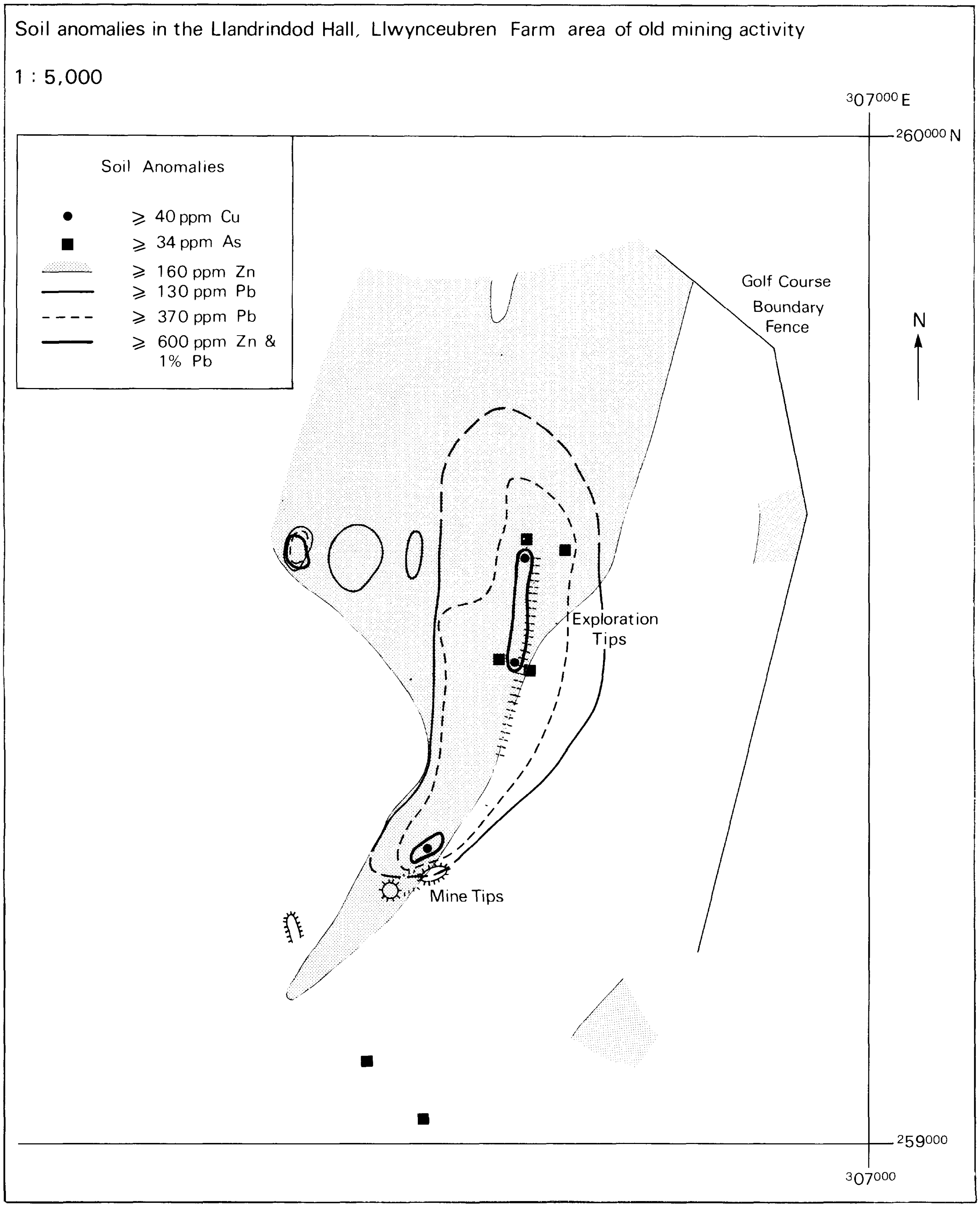

Figure 26 Distribution of Cu, As, Zn and Pb soil anomalies (Cu, As point, Zn, Pb contoured) around the area of old mining activity between Llandrindod Hall and Llwynceubren Farm

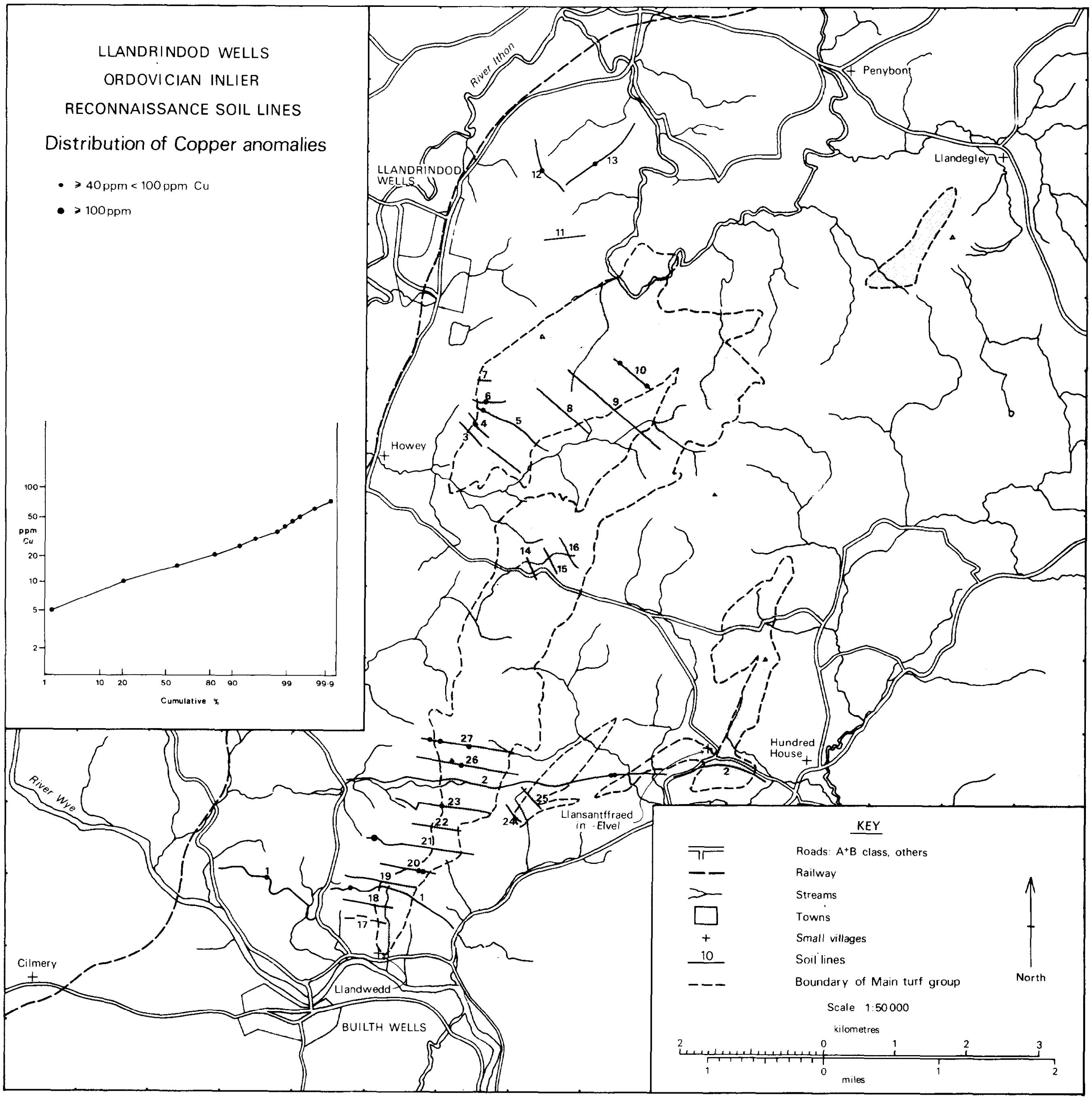

Figure 27 Distribution of Cu anomalies in reconnaissance soil lines

XRF, as shown in Table 1, in soil samples taken 20 m apart. A plot of elements with a significant range of contents viz. Zn, Pb, Cu, As, Ni, V, Cr, Mn, Fe and LOI values for line 1 is shown in figure 25 together with a geological section taken from the 1:25 000 geological map. The volcanic sequence is in general marked by low levels of Ni and higher levels of Mn, Fe and to some extent V than the sedimentary rocks. The plot shows some Pb and low amplitude As anomalies and a Cu anomaly to be associated with the sequence of andesites, felsitic agglomerates etc overlying the main tuff group. In addition there is also a low amplitude Pb and As anomaly associated with the top of the main tuff group and a broader area of relatively high Fe, Mn and V associated with the base of the unit. Isolated Pb and As anomalies are also associated with the *Glyptograptus teretiusculus* shales. Line 2 also shows an association of As and very low amplitude Pb anomalies with the volcanic belt but this is not plotted separately.

Samples from the lines other than 1 and 2 were analysed for a reduced list of elements. Lines 3 to 7 were analysed for Cu, Pb, Zn, Ag, Co and Ni after nitric acid leach by AAS at the Grays Inn Road laboratories of BGS. For lines 8 to 27 Cu, Pb, Zn, Ni, Mn and Fe were determined by AAS after a perchloric acid leach by Mather Research Limited of Rothbury, Northumbria. The majority of the lines cross all or part of the outcrop of the main tuff group roughly at right angles to the strike direction and spaced between 250 and 500 m apart. The lines in the SW part of the area also cross the spilitic andesites and other rock

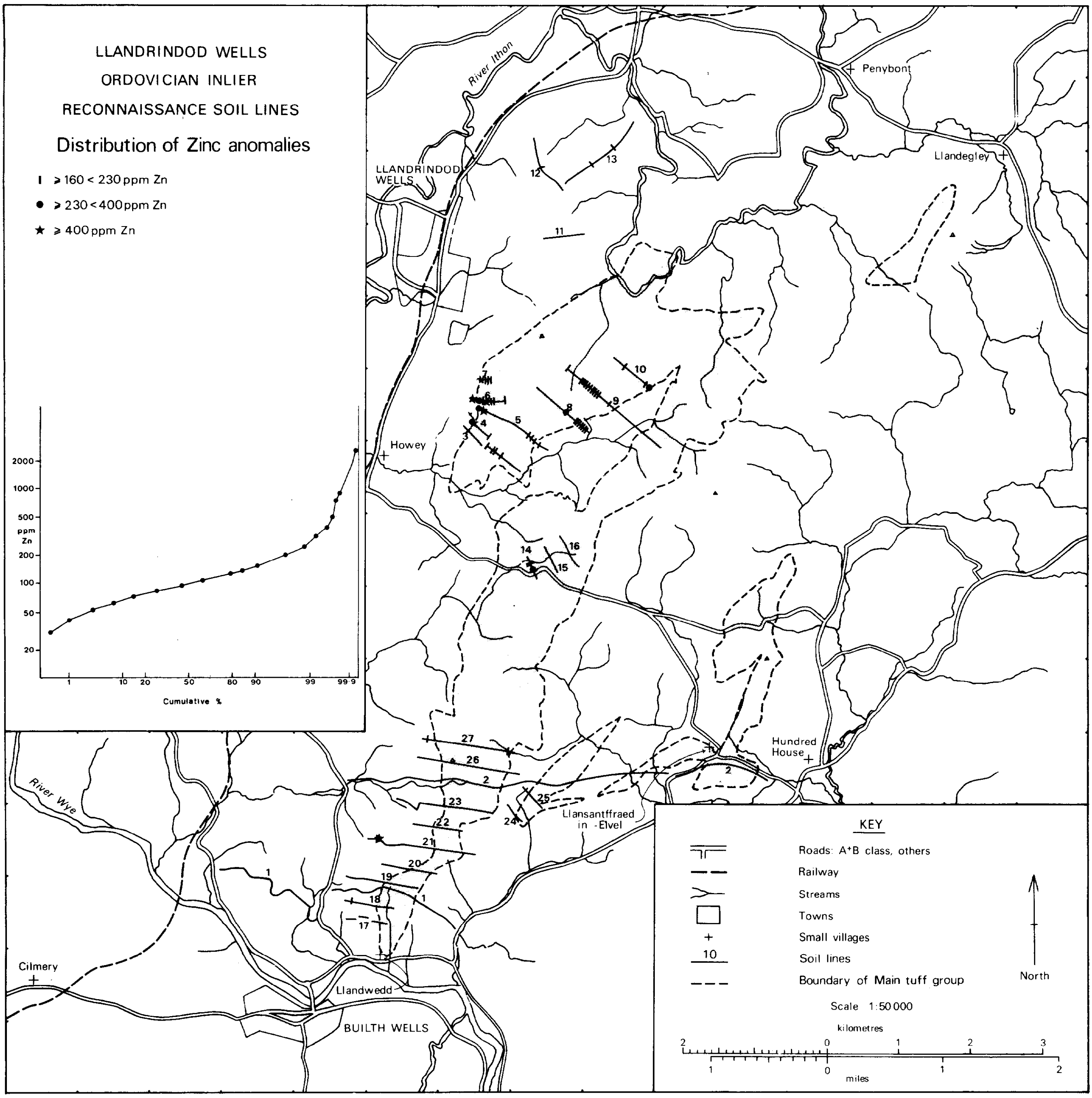

Figure 28 Distribution of Zn anomalies in reconnaissance soil lines

types overlying the main tuff group. Lines 3 to 7 crossed the area of old lead workings near Llwynceubren Farm in the west of the area while lines 11 to 13 cross doleritic intrusions in the *Nematograptus gracilis* shales and in the *Glyptograptus teretiusculus* shales in the NW of the inlier of Ordovician rocks.

Soils are poorly developed on the volcanic rocks forming the higher ground of most of the Ordovician inlier. They typically have a light open texture with a thin (5–10 cm) dark brown humic horizon overlying a paler medium brown or buff silty soil containing rock fragments. Soil thicknesses vary from 15 cm to 1 m and were probably developed on a shattered periglacial surface. The ease of working of these soils can be demonstrated by the abundance of mole hills even on the highest ground. Heavier soils are developed on the lower ground of the inlier over shale horizons and glacial till.

The location of Cu, As, Pb and Zn anomalies in the area of the old lead workings near Llwynceubren Farm is shown in Figure 26. The location of the traverses and the cumulative frequency plots of the complete soil data set are shown in Figures 27 to 29. The large amplitude Pb anomalies, the levels of which were set empirically, are located adjacent to the old excavations as are the highest Zn anomalies and the low amplitude Cu anomalies. There is also a halo of lower amplitude Pb anomalies around the workings and further Pb anomalies and one relatively high Zn anomaly between 120 and 240 m to the west of the northernmost excavation. Zn levels are much lower in the most anomalous soils than the corresponding

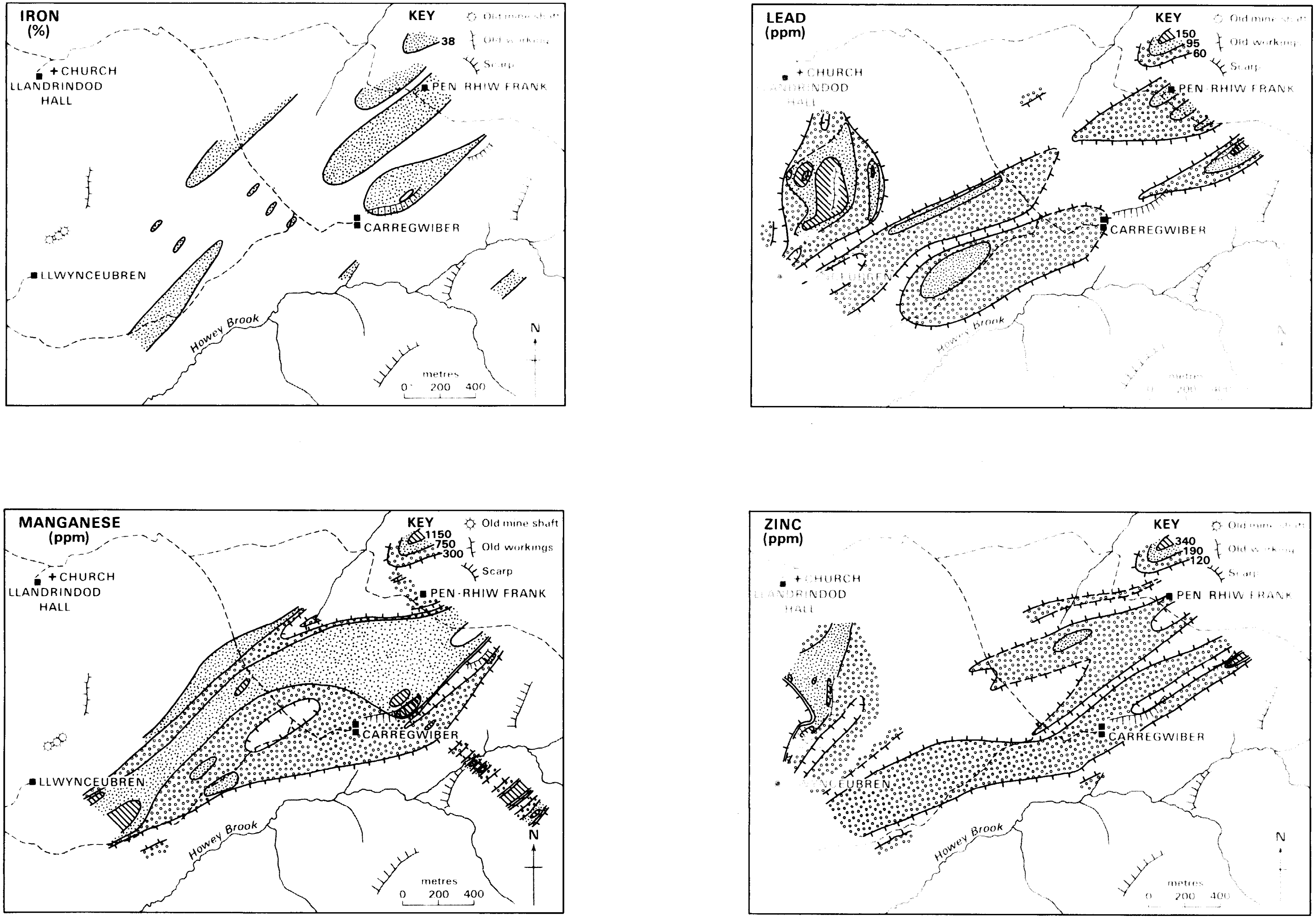

Figure 30 Distribution of Fe, Mn, Pb and Zn anomalies (contoured) over northern part of main tuff group

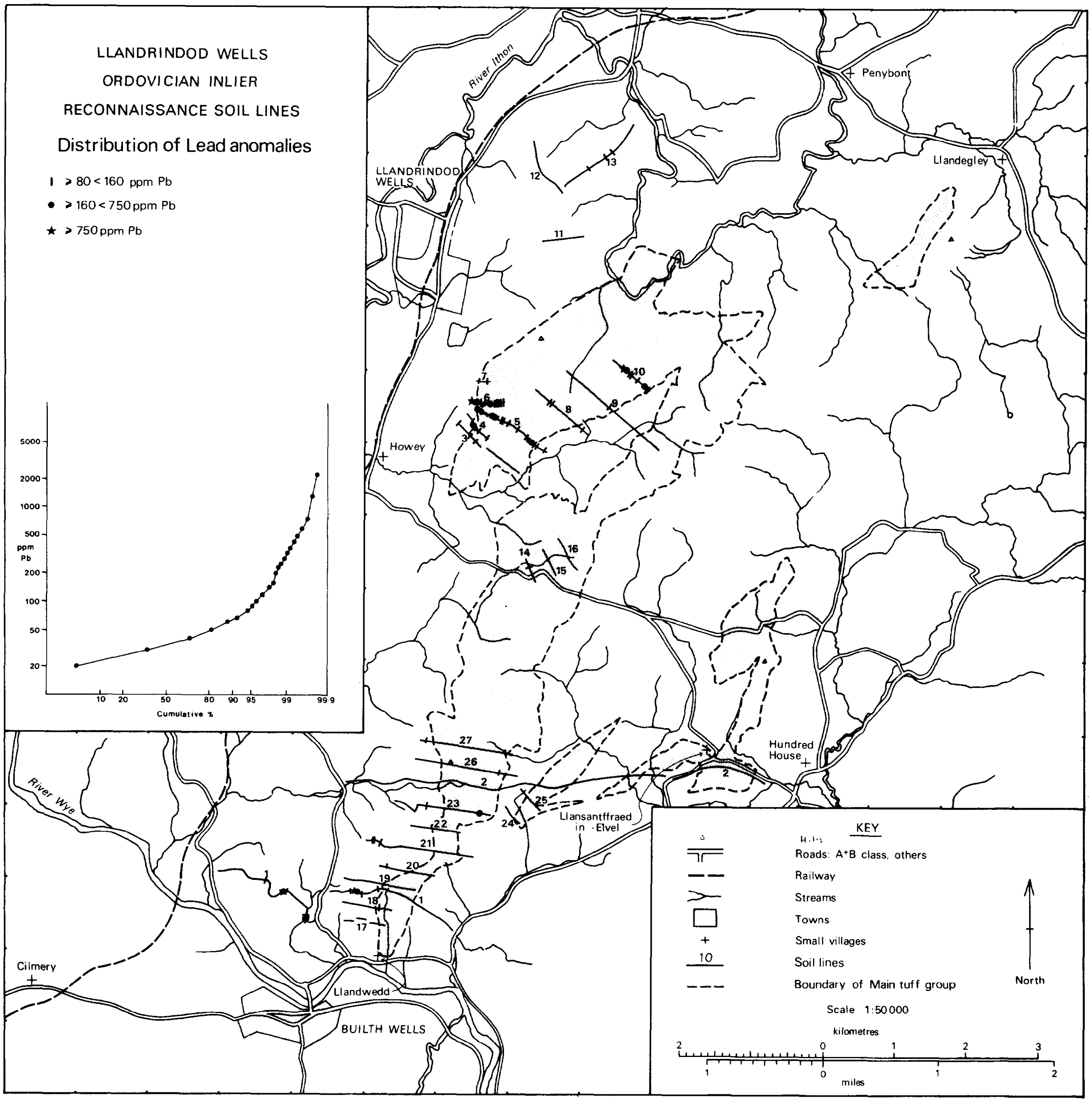

Figure 29 Distribution of Pb anomalies in reconnaissance soil lines

amounts of Pb but a wider zone of anomalous Zn in soil is associated with the mineralisation, especially in the north of the area sampled. Low amplitude Zn anomalies are the only features on the lines sampled beyond the limits of the known mineralisation and the lack of Pb anomalies suggests that the vein Pb mineralisation does not extend beyond the limits of the workings.

The location of Cu, Zn and Pb anomalies on the reconnaissance soil lines are shown in Figures 27 to 29. Class intervals of anomalous levels were established from the points of rapid gradient change on the cumulative frequency plots of the whole soil data set. Copper anomalies are relatively few, low amplitude and scattered except for those associated with the old mining area between Llandrindod Hall and Llwynceubren Farm described above.

A loose group of low amplitude anomalies are present towards the western margin of the main tuff group to the north of Builth Wells. The relatively high amplitude Cu anomaly near the west end of line 21 [051 535] is associated with a zone of high Zn and Pb in soils. The location of the anomalous zone suggests that it may be related to the roughly east-west trending Wern To fault shown on the published geological map and which cuts the sequence of volcanic rocks in the vicinity.

There are relatively few Zn anomalies outside the northern outcrop of the main tuff group which are discussed below. Most of the anomalies in the southern part of the area are isolated and scattered except for those around Wern To mentioned above. There are coincident Zn and Pb anomalies at each end of line 27 and in the middle of

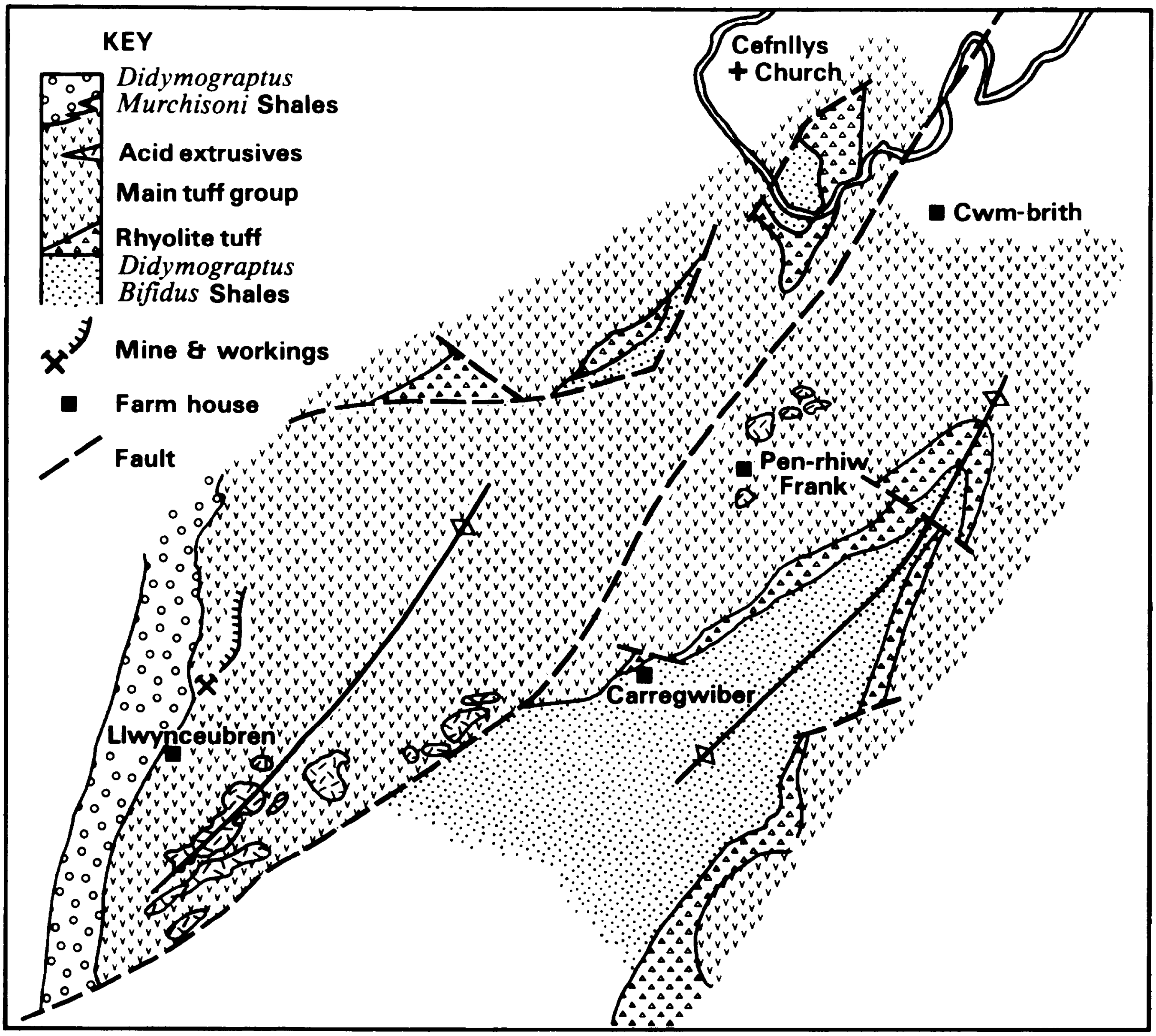

Figure 31 Geology of northern part of main tuff group

line 14 but Pb is not associated with the higher amplitude Zn anomaly towards the south end of line 14.

The higher amplitude Pb anomalies are also largely confined to the northern part of the area. There is a loose grouping of low amplitude anomalies to the west of the outcrop of the main tuff group in the south of the area. Though no anomalous zone can clearly be defined there is a suggestion of an association of the anomalies with the mapped outcrop of the coarse feldspathic sandstones shown on the 1:25 000 geological map.

Contoured plots of Zn, Pb, Fe and Mn in soils from the northern outcrop of the main tuff group are shown in Figure 30 and the mapped geological boundaries of the unit in Figure 31. Apart from the anomalies associated with the area of old mining activity at the west end of the outcrop there are broadly coincident diffuse Zn and Pb anomalies which follow the strike of the belt. Areas of relative enrichment in Fe and Mn are also associated with the belt but a detailed correlation between these elements and Zn or Pb is not apparent. The highest Zn and Pb anomalies occur to the southeast of Pen Rhiw Frank with levels reaching up to 2000 ppm Pb.

DETAILED SOIL SAMPLING

Further detailed work was carried out around Pen Rhiw Frank in order to provide a better picture of the distribution of anomalous Zn and Pb in soil and also because of the observation during the reconnaissance sampling that significant amounts of weathered pyrite occur in tuffs and lavas in the vicinity. The additional soil sampling comprised 4 lines at 200 and 400 m on either side of the original line 10 along which samples were taken at 25 m intervals. Contoured distributions of anomalous Zn and Pb in the area are shown in Figure 32. The contour patterns are complex but when considered in the light of the detailed photogeological interpretation of the area described below they can be seen to represent anomalous zones which broadly follow the local strike of the rocks. The anomalous zones are marked by samples containing Pb levels generally between 200 and 300 ppm but with more isolated samples containing in excess of 1500 ppm Pb. Most of the area is also marked by low amplitude anomalous levels of Zn but the few samples containing more than 200 ppm Zn do not correlate with the lead anomalies.

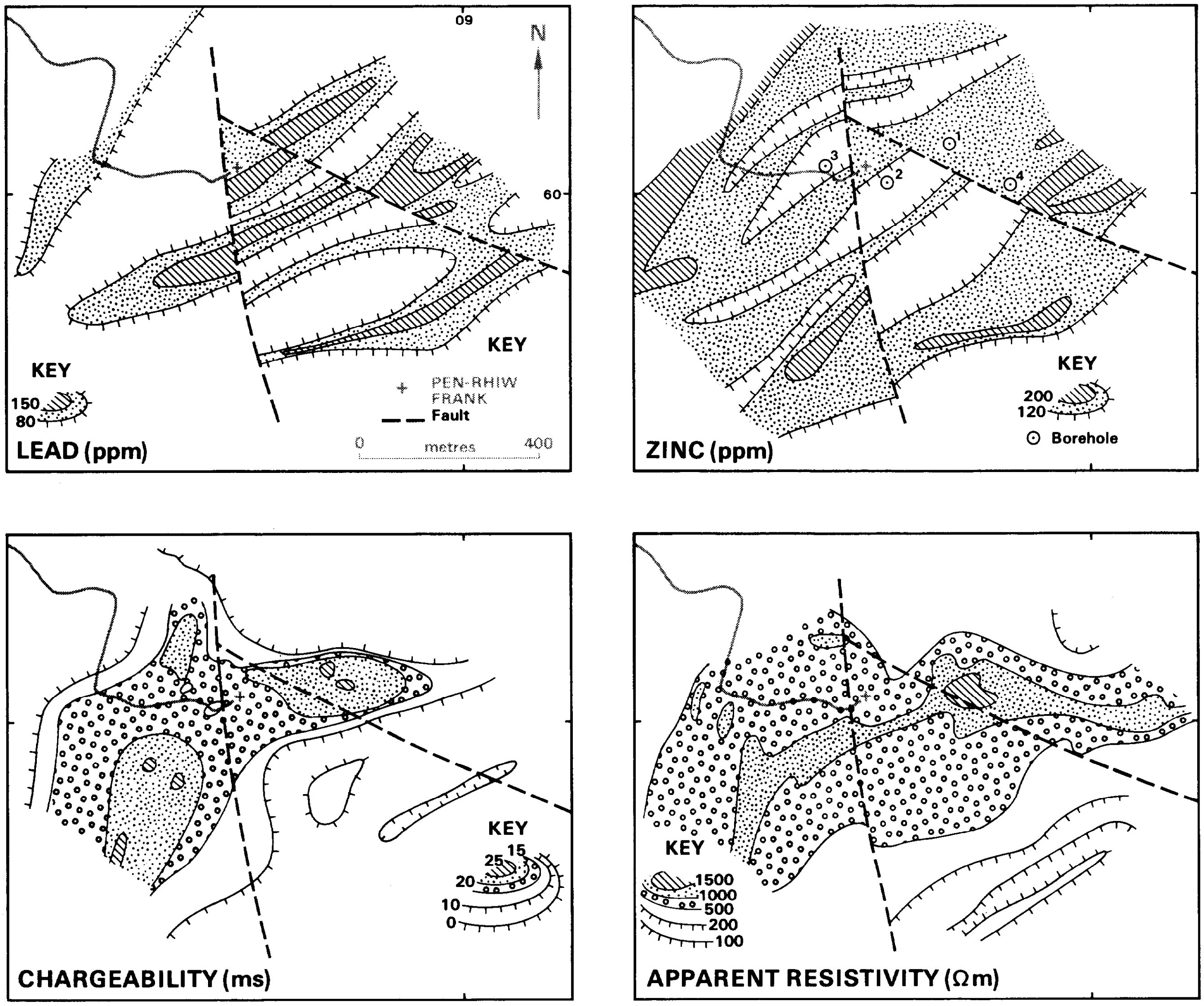

Figure 32 Contoured plots of chargeability and apparent resistivity together with Pb and Zn in soil around Pen Rhiw Frank. Borehole locations also shown

Pits were dug down to about 50 cm at a few of the sites containing the highest Pb levels and the profiles sampled at three or more depths. Chemical analysis of these samples for Pb, Zn, Mn and As did not reveal any evidence of downward enrichment in the elements, the levels being similar to those of the hand auger samples.

DETAILED GEOLOGY

To augment the geological information on the published 1:25 000 map of the Llandindod Wells Ordovician Inlier a photogeological interpretation of the area immediately around Pen Rhiw Frank was prepared using aerial photographs at 1:6600 scale. The existence of three units in the area was indicated. These were a) a well-bedded gently dipping sequence, b) a steeper-dipping unit which forms crags on valley sides and c) hummocky ground which shows no obvious orientation of features. In the field the above were found to correspond with the following lithological units: a) acid lavas interbedded with tuffs, b) pale grey well-indurated tuffs and c) acid lavas. A geological map containing information obtained from the air photographs together with information taken from the published geological map is shown in Figure 33.

The outcrop surface of the acid lavas is commonly rusty and ochrous and when broken the rock is usually pale grey or buff. Rounded dark blue areas, 2–3 mm in diameter, represent either remnants of less altered rock or micro-xenoliths. Vesicles are frequent and usually contain quartz or secondary iron oxides or a combination of both. Samples with cuspate voids probably represent flow-top material. The groundmass of the rock is aphanitic and contains 1–2 mm long feldspar microphenocrysts. Cut surfaces show the groundmass to have a speckled appearance. The pale buff speckles (< 0.1 mm diameter) probably represent devitrification products such as sericite. Pyrite occurs as a fine dissemination in the matrix, in aggregates up to 2 mm in diameter and also as vesicle fillings. Oxidation of the pyrite has produced a network of goethite throughout the rock and accounts for the general ochrous outcrop surface.

In the tuff sequence poor exposure makes individual beds difficult to identify. Outcrops are typically smooth and either buff or ochrous in colour and when hammered the rock often shatters into granules. Cut surfaces show that most of the exposed rock is pumiceous lapilli tuff with a buff devitrified matrix containing feldspar microphenocrysts up to 1 mm in length. Vesicles are filled with quartz or a mixture of quartz and pyrite and there are also large pyrite crystals, up to 1.5 cm in diameter which cut across the fabric of the rock. Lithic clasts of lava, usually vesicular, also occur. 25 m west of Pen Rhiw Frank a hard dark grey tuff is exposed in an old excavation. It consists of pale blue-grey siliceous clasts, 1 – 2 mm in diameter each with a rim of fine pyrite. The clasts appear aligned and some are flattened with a long axis of up to 5 mm, indicating incipient welding. Pyrite occurs within the clasts, usually with a spheroidal form.

Structure

The sequence forms the northwestern limb of a NE-plunging anticline, the axis of which runs along Howey Brook and dips are broadly towards the north. The rocks near to the eroded anticlinal axis show steeper dips than those further down the limbs, presumably due to stress release as the core of the anticline in argillaceous rocks was eroded. The photogeological interpretation reveals that the area around Pen Rhiw Frank is cut by a north-trending fault and the eastern block defined by this fault is divided by a northwest-trending fault. Within the western block dips are generally within 10 degrees east of north. The northeastern block shows well defined and consistent photogeological dips 15 degrees west of north. Poor exposure in the southeastern block allows few dips to be measured except in the case of the broadly northerly-dipping basal tuff.

GEOPHYSICAL SURVEYS

Geophysical surveys were carried out in the area around Pen Rhiw Frank on lines generally either 175 or 200 m apart. IP/resistivity, VLF, SP and magnetic techniques were employed. All IP/resistivity results were collected with a dipole-dipole array of unit length 25 m and a separation of 50 m (N = 3) and this implies a nominal depth of penetration of 50 m below surface.

Apparent resistivities are given in ohm-metres but due to an instrument calibration error the true values are 1.66 times greater. Apparent resistivity values have been 'filtered' using a running mean procedure to smooth out variations caused by 'thin' resistive horizons. In this context 'thin' means a width comparable to the dipole length (25 m). The results are plotted in contour form in Figures 32 and 34. Values range from 60 ohm-metres to 2000 ohm-metres and a recognisable zone of high resistivity is discernible.

Background chargeabilities are very low, in the range 0 to 10 msecs but values rise to 25 – 30 msecs generally coincident with zones of high resistivity. The values in contour form are superimposed on the apparent resistivity map in Figure 34. The highest chargeability value of 29 msecs occurs at 250 m SE on line 200NE.

Separate VLF base and traverse lines were surveyed because no suitable transmitting station exists for the traverse direction used for the IP surveys which was orientated nearly at right angles to the presumed strike of the rocks. The station used was NAA (16.8 kHz) and the signal strength and null definition was only moderately good. Cultural noise from fences etc was removed from the results by eye. Only one recognisable cross-over was apparent, on the eastern lines, and the position of this is plotted in Figure 34. The clearest cross-overs, on lines 350E and 490E suggest a conductive structure. Though this might represent mineralisation it is more likely to reflect a fault. Though this cross-over does not coincide with the fault deduced from the photogeological interpretation it is parallel to this and marks the edge of the zone of high resistivity.

SP surveys were carried out on lines 00, 200NE and 200SE but no anomalies were found. Similarly the total variation in magnetic field was less than 20 nT and accordingly the results have not been plotted.

DRILLING

The association of chargeability maxima with the highest levels of lead in soil within a sequence of acid lavas and tuffs containing significant amounts of visible pyrite in very limited exposure was considered suitable for further investigation by drilling. Four holes were drilled to test the source of the geochemical soil anomalies and to investigate any association between this and the observed geophysical anomalies. The location of the holes is given in Figures 32 and 33.

In the siting of boreholes a regional dip of 30 degrees to the N was assumed from surface mapping. Borehole 1 was sited to test the continuation at depth of the lead anomaly 100 m SE across stike and to test the possible association of this anomaly with apparent resistivity and chargeability maxima, relatively displaced to the NW (i.e. towards the borehole site). Borehole 2 was also sited to intersect the source of soil lead anomalies across strike within the same fault block assuming them to be statabound. Borehole 3 was sited in the westerly fault block to intersect surface lead anomalies and a zone of relatively high chargeability down dip 200 m to the north. Borehole 4 was sited to help in interpeting the sequence of volcanic rocks intersected in borehole 1.

The rock types encountered within the boreholes consist of acid/intermediate lavas and tuff. Tuffs were greatly predominant but a black vesicular lava occurred between 5.55 and 6.0 m in borehole 1 and lava of the type termed 'keratophyre' on the published 1:25 000 map, is predominant in the upper 20 m of borehole 2 and the upper 15 m of borehole 3. These 'keratophyres' when fresh are pale grey homogeneous rocks with iron oxide-coated open voids (cuspate or oval) or vesicles (usually quartz filled). The open cuspate voids may represent cindery flow-top material. Dark grey cuspate patches (0.5 – 2.0 mm) and mottling of pale grey within grey green probably represents crystals or quartzose patches within a microcrystalline groundmass of sericitised feldspars showing weak flow alignment enclosing rare microphenocrysts exhibiting albite twinning. Fine pyrite is disseminated throughout the groundmass and larger grains with broken edges enclose the groundmass, possibly indicating disintegration during flow. Pyrite crystals up to 2 cm across also occur in veins.

In general the upper part of the tuff sequence intersected in the boreholes consists predominantly of pumiceous-lithic-lapilli tuffs containing horizons of possibly reworked water-lain tuffs and probably corresponds to the main tuff group recognised on the BGS 1:25 000 special geological sheet of the area. The lower part of the sequence comprises pumiceous lapilli tuff, a well-lithified unit possibly equivalent to the basal rhyolitic tuff unit of the 1:25 000 map though compositionally it is not rhyolitic but andesitic.

The upper part of the tuff sequence contains a variety of textural varieties ranging from tuff containing fragments (0.5 – 2.0 mm) in a dark grey matrix to pumiceous-lithic-lapilli tuff with clasts (up to 5 mm)

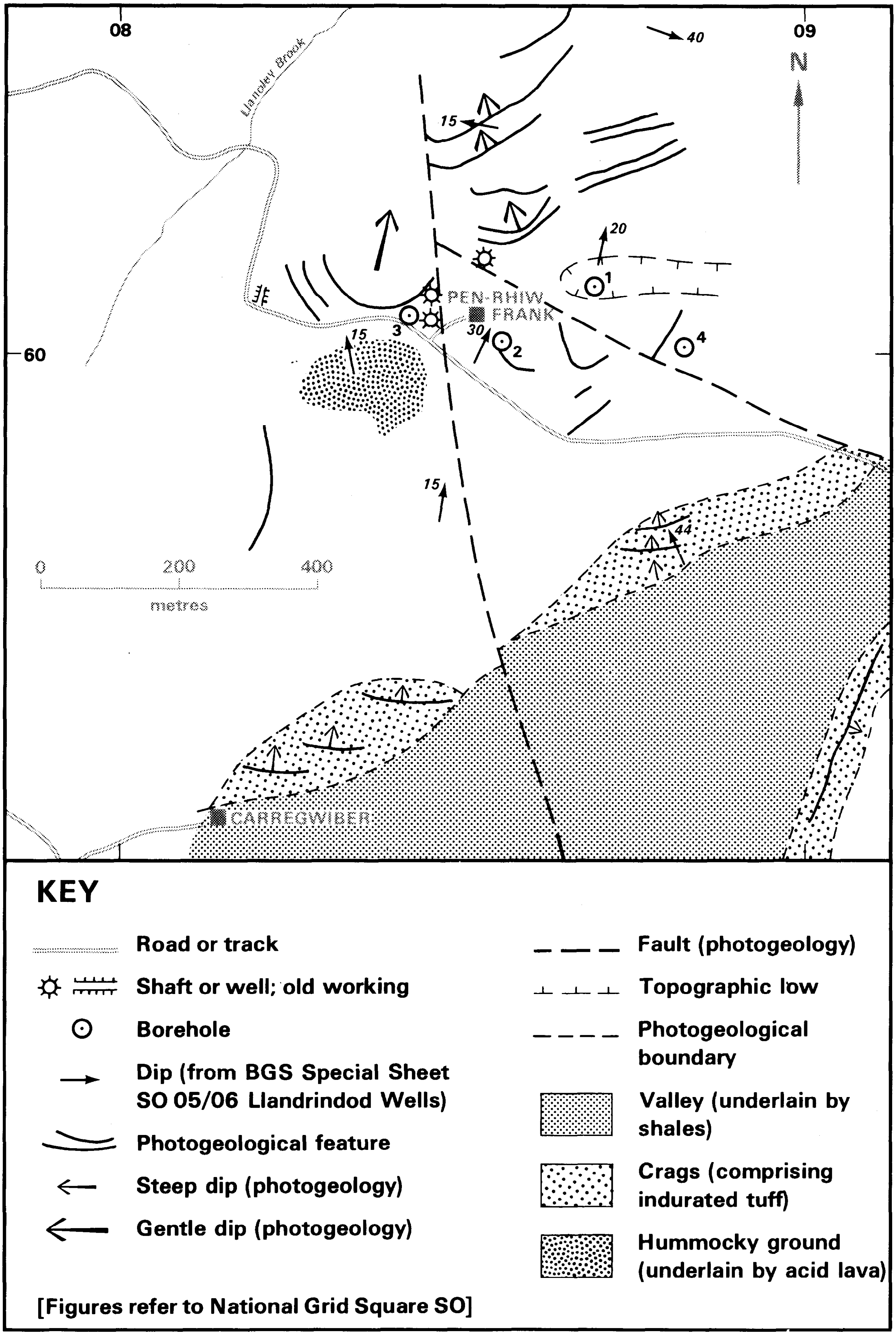

Figure 33 Photogeological map of area around Pen Rhiw Frank with borehole locations

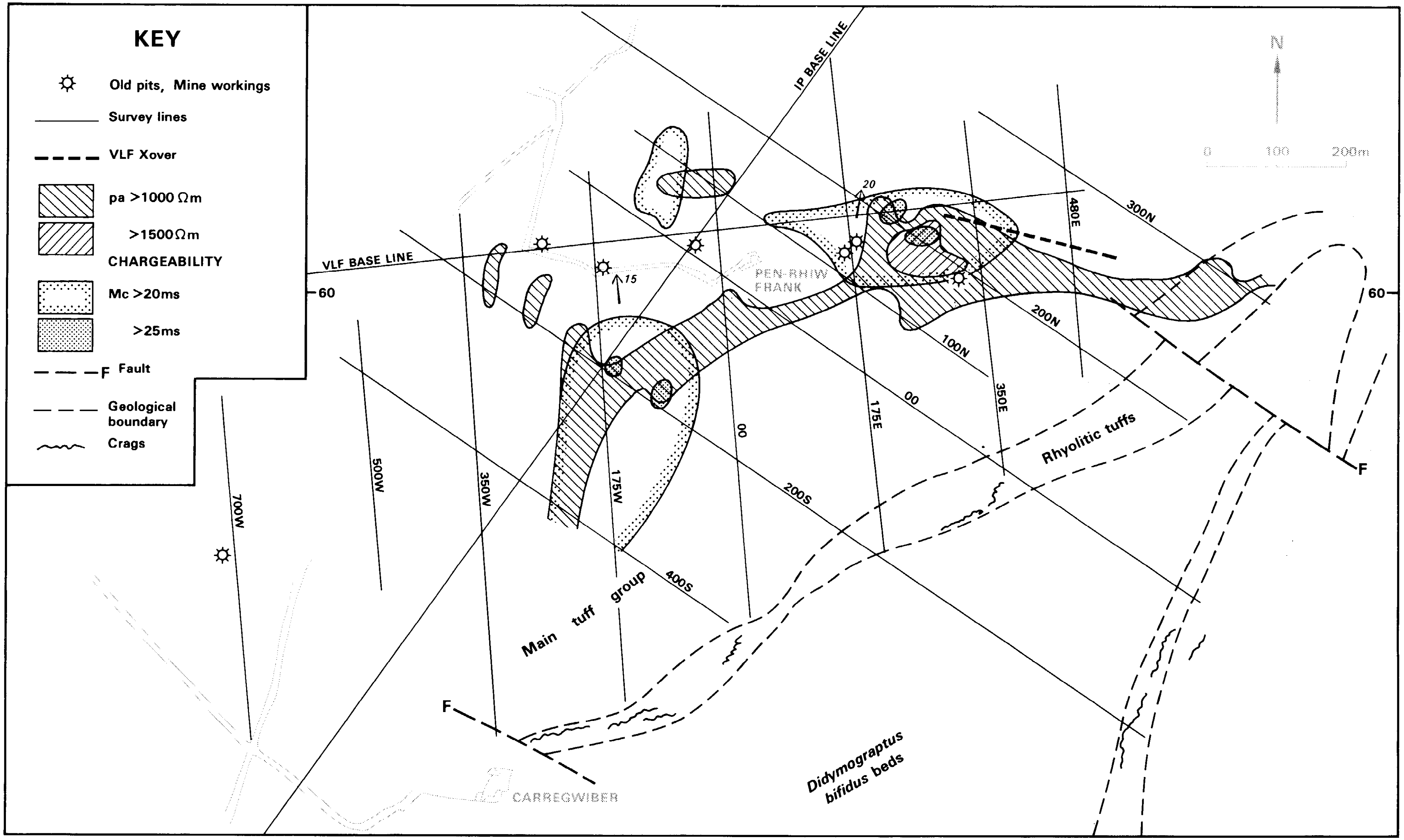

Figure 34 Compilation of results of geophysical surveys over northern part of outcrop of main tuff group

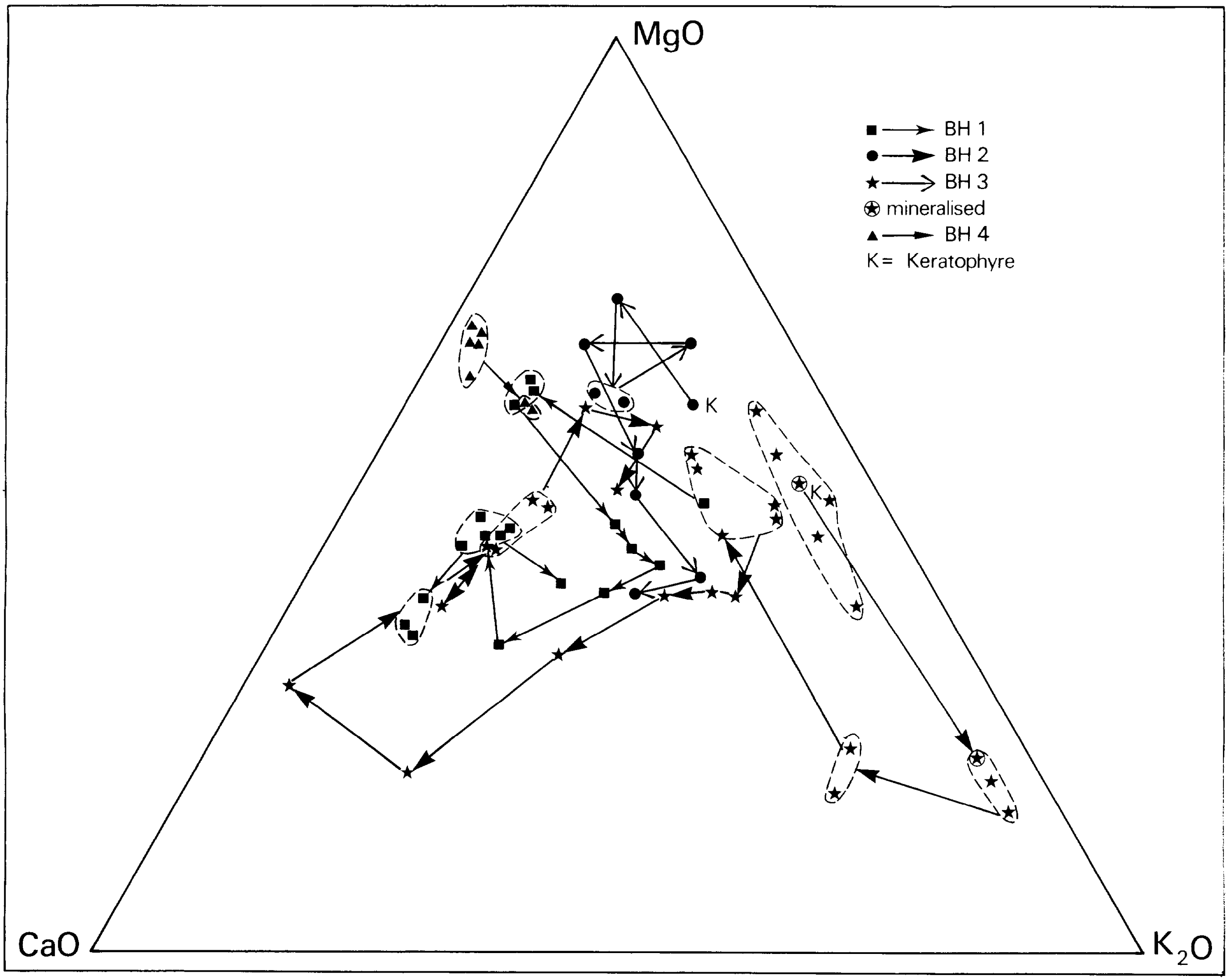

Figure 35 Triangular CaO-MgO-K_2O plot of borehole samples in sequence down each hole

mainly of white or grey purple rhyolite or pumice (1 – 10 mm) in a devitrified dark grey of chloritic greenish grey matrix. Thin sections demonstrate that lapilli and groundmass are both devitrified to sericite and secondary iron minerals. Groundmass material is predominantly subrounded ash fragments containing feldspar microliths while polycrystalline quartz also occurs. Pyrite is widespread in some parts of the core and two generations can be recognised. Within clasts pyrite usually shows good crystal form while that found in the groundmass cuts across the fabric of the rock and is clearly secondary in origin. In one specimen pyrite is concentrated in rims to clasts. Over much of the sequence pyrite is altered to secondary iron oxides and the rock is fissured and permeable to such an extent that during drilling operations for most of the time there was no return of water.

The pumiceous-lapilli tuff forming the lower part of the sequence intersected in the boreholes contains subangular clasts (0.5 – 15.0 mm) of pale grey pumiceous and subangular to cuspate dark grey pumiceous and microlithic clasts in a light grey matrix. Thin sections show that both lapilli and matrix are devitrified. Pyrite occurs as anastomosing growths sometimes associated with 0.5 – 2.0 mm wide calcite veinlets and thin sections show that it is always rimmed by and intergrown with calcite. Patches and veinlets of calcite are common throughout the rock and probably account for the well-developed lithification. Vesicles in the pale lapilli are filled with calcite and vesicles in both dark and pale lapilli show no signs of collapse.

The core from all boreholes was split and samples taken for chemical analysis at intervals based on lithology and differences in the degree of alteration of the pyrite and variation in rock matrix. In some parts of the core the matrix appeared to have been hydrothermally altered and these sections were split and a quarter of the entire length taken for analysis. Other sections were selectively sampled with a minimum of 20 cm to represent each metre of core. The core showing little evidence of mineralisation was sampled in 5 m sections.

Each sample was passed through a jaw crusher and a 100 g split was ground to minus 300 BSI mesh (< 53 micrometres) using a Tema mill with tungsten carbide pot. Portions of the ground sample were taken for determination of Pb, Zn, Co and Ni by AAS after nitric-perchloric acid attack and of Cu, Mo, Mn, Fe, Sr, Sb and Zr by XRF at the BGS laboratories in Grays Inn Road. Additional determinations of MgO, SiO_2, S, K_2O, CaO, As and Rb were carried out by XRF at Midland Earth Science Associates and 11 of the most mineralised and pyrite-rich samples were analysed for Au at Caleb Brett Laboratories Limited, St Helens, Merseyside.

The ranges of the elements determined in each of the boreholes is given in Table 4.

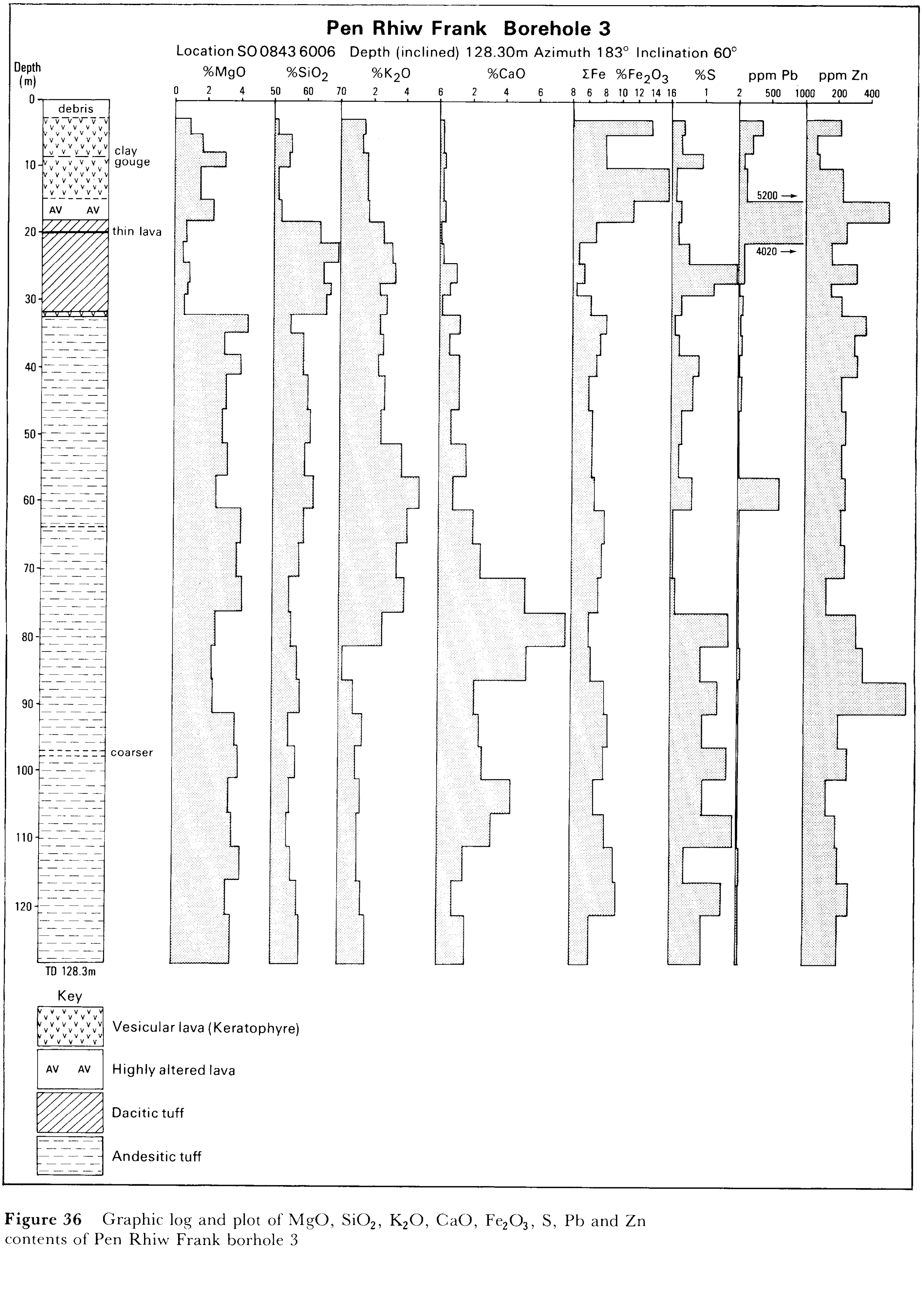

Figure 36 Graphic log and plot of MgO, SiO_2, K_2O, CaO, Fe_2O_3, S, Pb and Zn contents of Pen Rhiw Frank borhole 3

Table 4 Range of elements in boreholes

	Borehole 1	Borehole 2	Borehole 3	Borehole 4
MgO%	2.45– 4.81	2.60– 5.42	0.62– 4.50	3.51– 4.95
SiO_2%	48.72–61.33	54.90–60.73	51.60–69.96	53.74–58.53
S%	0.15– 0.97	0.28– 1.46	0.10– 2.00	0.04– 0.48
K_2O%	0.47– 2.49	0.80– 2.88	0.35– 4.87	0.19– 1.05
CaO%	1.22– 5.37	0.56– 2.49	0.19– 7.72	1.56– 2.17
Mn ppm	690–1360	380–1520	200–1480	730–1210
Fe_2O_3%	6.30– 9.69	6.81– 8.59	4.72–15.84	7.58– 8.67
Co ppm	15– 35	15– 50	10– 30	20– 30
Ni ppm	25– 60	20– 80	20– 55	20– 30
Cu ppm	11– 28	14– 26	12– 43	10– 16
Zn ppm	87– 259	105– 135	9– 613	117– 172
As ppm	<1– 17	<1– 20	<1– 12	<1– 7
Rb ppm	9– 48	18– 56	8– 98	2– 20
Sr ppm	50– 110	50– 90	50– 140	30– 50
Zr ppm	260– 330	290– 330	220– 360	320– 350
Mo ppm	<1– 1	<1– 3	<– 7	<1– 2
Sb ppm	<1– 6	<1– 11	<1– 9	<1– 6
Pb ppm	8– 129	7– 30	11–5200	8– 28
Au ppb			<10	

A comparison of MgO, K_2O and CaO levels in each sample from the various boreholes is given in the form of a triangular plot in Figure 35. This shows a great deal of similarity between samples from the lower parts of boreholes 1, 2 and 3 which suggests that the same sequence is intersected in these boreholes. In contrast there is a considerable variation in the samples from the upper part of these boreholes. This can be accounted for if there is significant heterogeneity in the upper part of the volcanic sequence both in terms of original chemistry and characteristics superimposed on this as a result of hydrothermal alteration and mineralisation. The overall composition of the majority of the tuffaceous rocks appears to be andesitic although further chemical data on the more immobile elements is required for a more detailed classification. The graphic log of borehole 3 in Figure 38 shows that significant variation in K and Ca levels occur throughout the sequence but as no detailed petrographic studies of the core have been carried out the origin of this is not clear. The association of the highest level of K with the lead-rich sample from 56–61 m in borehole 3 suggests that some potassium enrichment may accompany the base-metal mineralisation. Chemically the most distinct unit occurs in borehole 3 between 18.3 and 31.8 m. This unit is significantly higher in Si and lower in Mg, Ca, Mn and Fe than the other rocks and is probably dacitic in overall composition.

MINERALISATION

In the borehole sections significant mineralisation is confined to a 6.4 m section (5.8 m estimated true thickness) of borehole 3 below an inclined depth of 14.9 m. Contents of Pb, Zn and S together with Mg, Si, K, Ca, Fe and K are displayed together with a graphic log in Figure 36. Though the mineralisation within the anomalous zone consists almost entirely of lead, levels of Zn are also mildly anomalous over some of the section. The lead is present in secondary minerals within a highly altered and soft clay-rich section but in view of the presence of a small amount of galena within much less altered siliceous clasts at 25.36 and 26.50 m it is probable that the lead was originally present as galena in the main zone. Such galena would have been converted into secondary minerals as result of oxidative alteration in a near surface weathering environment and possibly also within a previous episode of alteration. Additional minor lead mineralisation is possibly associated with minor fault structures and brecciation between 56 and 61 m down the hole. It is difficult to assertain whether Zn as sphalerite was originally associated with the lead mineralisation as it would tend to be leached under the conditions that lead to the crystallisation of lead secondary minerals. Zn levels are also mildly anomalous in borehole 3 between 86 and 91 m where vesicles are conspicuous though no sphalerite has been identified in this section. The composition of the 'keratophyre' lava horizon overlying the mineralised zone is anomalous with high levels of iron chiefly in the form of limonite of probable hydrothermal origin in some sections

Pyrite is conspicuous within much of the core and levels of sulphur reach more than 2 per cent over 5 m. No correlation between pyrite abundance and proximity to the base metal mineralisation can be established from the core. In fact there is a greater abundance of sulphur in the lowest part of borehole 3 and also the top of borehole 2, apparently at two different parts of the sequence, but the significance of this is not apparent. Eleven samples from borehole 3, including some relatively rich in pyrite, have been analysed for gold by Caleb Brett Laboratories Ltd and all were found to contain less than the detection limit of 10 ppb. The low levels of As and Sb throughout the core, with maxima of 20 and 11 ppm respectively, and similarly low levels in the drainage samples and soil samples analysed also suggest that it is probably unlikely that precious metal- bearing volcanogenic mineralisation of significance is present within the area investigated.

Assessment of the controls of the mineralisation is very difficult in view of the high degree of alteration and poor recovery of the main mineralised section. The site of mineralisation is at the interface between a localised dacitic tuff unit which is chemically distinct from the rest of the volcanic sequence and a lava horizon which is probably of local extent. The chemistry of the mineralised sections is more consistent with the alteration of prexisiting volcanic rock than the introduction of material as

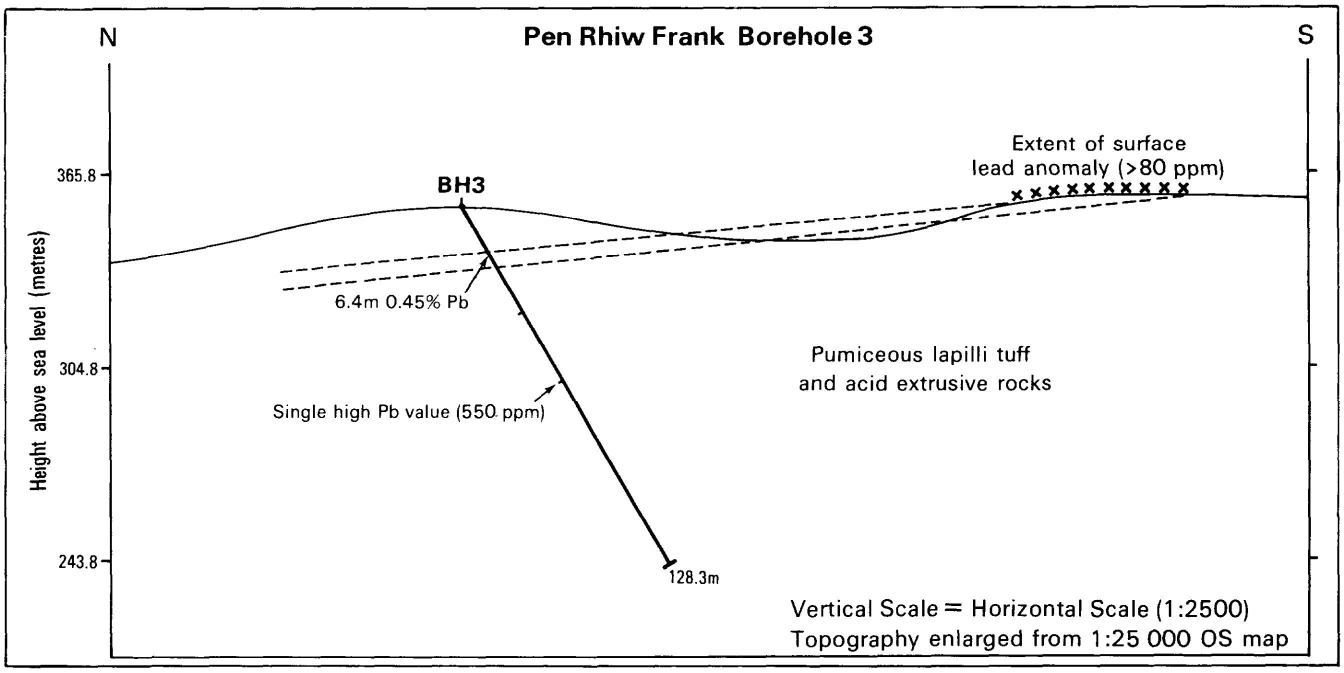

Figure 37 Section to show interpretation of relationship between surface soil anomalies and Pen Rhiw Frank borehole 3

chemical sediment of exhalative origin. Since mildly anomalous levels of lead occur over most of the intersected thickness of the lava, which is also marked by sections highly anomalous in iron, it is likely that the base-metal mineralisation is tied to the emplacement of lava. Further difficulties of interpretation arise because of the association of the mineralisation with rocks which because of almost flat dip occupy topographically the highest part of the area investigated. The drill holes suggest that the dips of strata around Pen Rhiw Frank are around 5 degrees to the north, which is significantly less than that portrayed on the published 1:25 000 geological map (Earp, 1977). In consequence none of the holes were sited at suitable locations to intersect the stratabound mineralisation, which was the source of surface anomalies, at sufficient depth to be below the zone of surface weathering. A possible relationship between surface anomalies and the mineralisation intersected in borehole 3 is shown in Figure 37. A further consequence of the relatively flat strata is that a minor stratabound enrichment in lead could give rise to an extensive overburden anomaly of the type observed in the Pen Rhiw Frank area.

Of fundamental importance in an assessment of the significance of mineralisation within the Llandrindod Wells Ordovician inlier is the accurate modelling of the environment of volcanism. In particular it is important to establish whether the volcanism took place within a submarine or subaerial environment. In general the volcanic rocks can be seen to be situated within a sequence of marine rocks which though not generally deposited in a shallow water environment were close to the eastern margin of the Welsh Basin. Though volcanism must have started within a submarine environment it is possible that a volcanic island was rapidly formed which continued to grow as volcanism continued. Furnes (1978) in a detailed study of the volcanic rocks of the area failed to find conclusive proof of either environment but concluded that the evidence observable suggested that the lavas were subaerially erupted and reached a similar conclusion for the bulk of the tuffs. Bevins (1985) mentions the existence of local pillowed flows and hyaloclastites and uses this together with the nature of the associated volcaniclastic sediments both above and below the lavas to suggest that for much of the time lava emplacement was in a submarine environment. The underlying tuffs which were intersected in the present survey are not considered by Bevins (1985) however. Within a subaerial environment it is likely that mineralisation tied to a particularly eruptive phase would be diffuse and irregular in distribution unless concentrated by a particular well-developed linear or arcuate structure. Within a marine environment concentration of brines to give stratiform mineralisation is possible though not always present, given the need for exhalative solutions of appropriate density and composition and a suitable environment for accumulation. Further work on the nature of the volcanic rocks and their environment of deposition is required to establish whether sufficient concentrations of base-metal sulphide of potential economic significance are at all likely within the area.

CONCLUSION

Evidence of base metal mineralisation of probable stratabound type has been found in association with a lava-tuff interface but the high intensity of alteration of the material has prevented an adequate assessment of its nature and controls. Nevertheless it appears that the mineralisation is associated with an intermediate lava horizon that was probably errupted in a subaerial environment. The mineralisation appears to be of limited aerial extent and therefore of minor significance. The volcanic association of the mineralisation suggests that there is a possibility that base metal mineralisation of greater significance could occur on the flanks of the volcanic centre within a marine environment where basins which could trap metal-rich brines might exist. However it is probable that this environment of equivalent age to the mineralised material is not exposed in the area, being covered by younger rocks. Mineralisation could also be associated with the waning stages of volcanism in the area, in rocks younger than the main tuff group but there is no direct evidence of this from either the drainage or overburden data.

ACKNOWLEDGEMENTS

The British Geological Survey is indebted to landowners within the survey area for their co-operation in permitting access to collect geochemical samples, to undertake geophysical surveys and to carry out a programme of drilling. Dr D. Cooper is thanked for valuable comments on the contents of the report. Diagrams were prepared by staff of the Keyworth Drawing Office under the supervision of Mr R. J. Parnaby.

REFERENCES

BEVINS R. E. 1985. Pumpellyite-dominated metadomain alteration at Builth Wells, Wales-evidence for a fossil submarine hydrothermal system? *Min. Mag.*, 49, 451–456.

— KOKELAAR B. P. and DUNKLEY P. N. 1984. Petrology and geochemistry of lower to middle Ordovician igneous rocks in Wales: a volcanic arc to marginal basin transition. *Proc. Geol. Assoc.*, 95, 337–347.

EARP J. R. 1977. Llandrindod Wells Ordovician inlier, 1:25 000 Geological Map. Classic areas of British Geology. IGS/BGS.

ELLES G. L. 1939. The stratigraphy and faunal succession of the Ordovician rocks of the Builth Llandrindod inlier, Radnorshire. *Q. J. Geol. Soc. London*, 95, 383–445.

FRANCES E. H. and HOWELLS M. F. 1973. Transgressive welded ash-flow tuffs among the Ordovician sediments of N.E. Snowdonia, N Wales. *J. Geol. Soc. London*, 129, 621–641.

FURNES H. 1978. A comparative study of Caledonian volcanics in Wales and west Norway. D. Phil thesis Univ. Oxford (unpublished).

HALL G. W. 1971. Metal mines of Southern Wales. G. W. Hall, Westbury.

JONES O. T. and PUGH W. J. 1941. The Ordovician rocks of the Builth district. A preliminary account. *Geol. Mag.*, 78, 185–191.

— — 1946. The complex intrusion of Welfield, near Builth Wells, Radnorshire. *Q. J. Geol. Soc. London*, 102, 157–188.

— — 1948. a) A multilayered dolerite complex of laccolithic form near Llandrindod Wells, Radnorshire. b) The form and distribution of dolerite masses in the Builth-Llandrindod inlier, Radnorshire. *Q. J. Geol. Soc. London*, 104, 43–98.

— — 1949. An early Ordovician shoreline in Radnorshire, near Builth Wells. *Q. J. Geol Soc. London*, 105, 65–99.

KOKELAAR B. P., HOWELLS M. F., BEVINS R. E., ROACH R. A. and DUNKLEY P. N. 1984. The Ordovician marginal basin of Wales. In Marginal Basin Geology: Volcanic and associated sedimentary and tectonic processes in modern and ancient marginal basins. *Spec. Publ. Geol. Soc. London*, 16, 245–269.

LEPELTIER C. 1969. A simplified statistical treatment of geochemical data by graphical representation. *Econ. Geol.*, 64, 538–550.

NICHOLS G. D. 1958. Autometasomatism in the Lower Spilites of the Builth Volcanic Series. *Q. J. Geol. Soc. London*, 114, 137–162.

SPARKS R. S., SIGURDSSON H. and CAREY S. N. 1980. The entrance of pyroclastic flows into the sea. II. Theoretical considerations on subaqueous emplacement and welding. *J. Volcan. Geoth. Res. Amsterdam*, 7, 97–105.

WOODCOCK N. H. 1984. Early Palaeozoic sedimentation and tectonics in Wales. *Proc. Geol. Assoc.*, 95, 323–335.