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No. 29

Mineral exploration in the Harlech Dome, North Wales

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Mineral Reconnaissance Programme Reports

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SUMMARY

This report presents the results of an airborne geophysical (electromagnetic, magnetic and radiometric) survey of the eastern part of the Harlech Dome, North Wales, and the consequent geological, geochemical and geophysical investigations carried out on the ground and in the laboratory.

The report is divided into two parts. In Part 1 are the regional and general investigations including an account of the airborne geophysical surveys, an investigation into the causes of electromagnetic (EM) anomalies, Curie temperature determinations, the geochemistry and relationships to mineralisation of some igneous rocks in the Harlech Dome, a description of intrusion-breccias in the Harlech Dome, and fluid inclusion studies. In Part 2 are the details of 26 ground investigations carried out to explain the airborne geophysical anomalies. These investigations were of a reconnaissance nature aimed at detecting metal enrichments and explaining the causes of the anomalies rather than at delineating ore bodies.

The eastern side of the Harlech Dome contains a folded succession of Cambrian and Ordovician sedimentary, volcanic and intrusive rocks metamorphosed to a low grade. The area has long been a centre of mining activity containing the Dolgellau Gold-belt, in which quartz veins were mined for gold and silver with copper, lead and zinc sulphides, and the porphyry-style copper deposit at Coed-y-Brenin.

As reported in Part 1 the airborne magnetic and EM results showed a complex pattern of anomalies, whereas the aeroradiometric data showed little variation. Ground studies of aeromagnetic anomalies demonstrated that they were related either to magnetite present in some sandstones and igneous rocks, or, more importantly, to pyrrhotite enrichments in several lithologies. Mineralogical studies showed that whilst some enrichments in siltstones and mudstones were probably syngenetic in origin, others were possibly related to epigenetic concentrations produced during vein mineralisation. A study of the EM anomalies showed that many of them were related to relatively low concentrations (< 3%) of carbonaceous material or non-commercial quantities of sulphides in the dark mudstones of the Dolgellau Member and Clogau Formation. An interpretation of the radiometric data confirmed that the only indications of uraniferous enrichment occur in the black mudstones of the upper Cambrian Dolgellau Member.

The rock geochemistry study indicated that statistical treatment of rock analyses could be used to distinguish intrusions associated with porphyry-style mineralisation. It also showed that the porphyry-style mineralisation at Coed-y-Brenin was probably co-genetic with the end-Tremadoc magmatism which gave rise to both the volcanic pile on Rhobell Fawr and intermediate intrusions in the Cambrian, and therefore was quite distinct from the end-Silurian quartz-sulphide vein mineralisation. Intrusion breccias which are also linked to the Rhobell Fawr volcanism were recognised in the area for the first time. One of them contains the worked-out Glasdir copper deposit. The fluid inclusion study showed differences between quartz veins associated with the vein and disseminated styles of mineralisation, which may be useful in exploration.

The ground follow-up work reported in detail in Part 2 showed indications of mineralisation in many of the areas examined. Among these, the possibility of vein and stratabound lead and zinc mineralisation was found at Hengwrt Uchaf and Benglog. At Bryn Coch, Tyddyn Gwladys and Hafod Fraith possible associated but separate bodies or extensions to the proved porphyry-type copper deposit at Coed-y-Brenin were identified in addition to modest vein mineralisation.

In three areas, Mynydd Foel Uchaf, Hafod-y-fedw and Y-Gors, dispersed epigenetic sulphide mineralisation in bedrock, mainly pyrrhotite with sub-economic base-metal sulphides, were found. Similar metalliferous concentrations were tentatively identified in a number of other areas including Garth Gell where pilot studies were carried out on coincident EM and magnetic anomalies. At Mynydd Bach, Craiglaseithin and Dol Haidd there are indications of either new veins or extensions to known veins containing copper, lead and zinc as well as feeble disseminated copper mineralisation at the last two localities; again the metal concentrations are considered sub-economic. Ffridd Dol-y-moch and Waun Hir are both drift covered areas which may conceal mineralisation but exploration is hampered by contamination problems. At Nannau, slight copper enrichment was found in volcanic rocks which are believed to be cogenetic with the Coed-y-Brenin porphyry copper deposit.

Recommendations are made for further work at Glasdir, in the Coed-y-Brenin area, at Hengwrt Uchaf and Benglog, at Ffridd Dol-y-moch and Nannau and, pending the results of the drainage survey, on the nature and extent of the sulphide concentrations in the Clogau Formation.

Part 1: Regional and general investigations

INTRODUCTION

Scope of project

The Harlech Dome, in western Merioneth, North Wales, (Fig. 1) is well known as a geological structure, as part of the type area of the Cambrian in Great Britain and for its long history of mining activity. The Dolgellau Gold-belt, which also contains the Coed-y-Brenin porphyry copper deposit, lies on the southern and eastern sides of the dome, and manganese has been mined mostly on the western side.

This report is concerned with mineral exploration on the eastern and southern parts of the dome in an area defined to take in the Gold-belt, the Coed-y-Brenin porphyry copper deposit and the known occurrences of mineralised quartz veins north of the Gold-belt. Manganese does not come within the scope of this project.

Exploration began with an airborne geophysical survey (Fig. 2), the first stage of which was carried out in December 1972 and the second stage in June 1973. In May 1973 Phelps-Dodge Europa moved into the Harlech Dome to carry out a mineral reconnaissance survey based on stream geochemistry. In view of this, under the constraints of the Mineral Exploration programme, effort on this project was reduced to a ground investigation of the airborne geophysics results. The areas which were covered and the methods used in them are shown on Enclosure 1.

Limited geochemical investigations were carried out over selected airborne geophysical anomalies, where either the ground geophysics or the geology indicated the possibility of minerali-sation. All geochemical investigations were of a reconnaissance nature, aimed simply at detecting metal enrichments in the vicinity of geophysical anomalies. Geochemical methods are given in Appendix 1. When the mining company abandoned the area in 1975 and did not make the results of its survey available for inspection, the regional geochemical survey began. The present report deals with the airborne geophysics and its follow-up. The regional geochemistry, which is part of an on-going project, will be reported separately.

Physiography

Entirely within the Snowdonia National Park, this is a mountainous area, which although somewhat subdued compared with northern Snowdonia, still contains a number of peaks over 600 m (1968 ft) high. Several of them are in the Rhinogs, an impressive mountain range running from Maentwrog to Barmouth. Others include Arenig Fawr, Rhobell Fawr, Moel Llyfnant and Dduallt (Fig. 3).

There are two main river systems. In the north the Afon Prysor passes through the artificial lake at Trawsfynydd into the Traeth Bach near Portmadoc. The greater part of the area, however, is drained by the rivers Eden, Gain, Wen and Wnion which flow into the Mawddach, itself discharging into the sea at Barmouth. Only a small area in the north-east is drained by eastward-running rivers that flow into Bala Lake.

The hills are mostly covered with rough grass and heather and much of the land is used for sheep grazing. There are some small areas of oak forest and several areas of coniferous forest planted by both the Forestry Commission and private landowners.

Much of the land and nearly all the mineral rights are in private hands.

Previous work and sources

When the mineral exploration project began the only geological maps available covering the whole area were Old Series 1-inch Geological Survey sheets 75 SE and NE, and 59 NE, published in 1855. Parts had been remapped by Fearnsides (1905), Wells (1925), Cox and Wells (1921), Matley and Wilson (1946) and Lynas (1973).

In 1972 the IGS began mapping parts of the Harlech (135) 1:50,000 Geological Sheet which contains much of the exploration area. A year later B P Kokelaar and P N Dunkley of University College of Wales, Aberystwyth began mapping, under IGS supervision, areas around Rhobell Fawr and on the Aran mountains for PhD theses. All the mapping was completed by 1975.

The geological map (Enclosure 2) accompanying this report is a compilation from a number of these sources and it must be borne in mind that it may be subject to modification. The stratigraphic nomenclature used in the report has also been compiled from these sources and some unpublished work.

The Harlech Dome, being the type area for the Cambrian System, has attracted a considerable number of geologists, who have published on the area. Ramsay (1881) gives the most complete early account. In more recent times, in addition to the authors given above, Crimes (1970), Lynas (1973) and Ridgway (1975) have written about the geology of the area. Foster (1968) has considered the Pleistocene geology. Powell (1955) provided an account of the gravity and magnetic data on the area, which is also covered by Sheet 4 of the 1:250,000 Aeromagnetic Map of Great Britain (1964). Urquidi-Barrau (1973) refers to the area in his regional geochemical study of Wales and Ponsford (1955) reports on a radiometric survey of the area. There are many papers and articles on the mineral deposits, and many of them are given in the bibliography. The first comprehensive account of the Gold-belt is provided by Andrew (1910), but the only modern work of note is a PhD thesis by Gilbey (1969). Historical and descrip-tive accounts of the mines in the Gold-belt are provided by Hall (1975), Morrison (1975) and
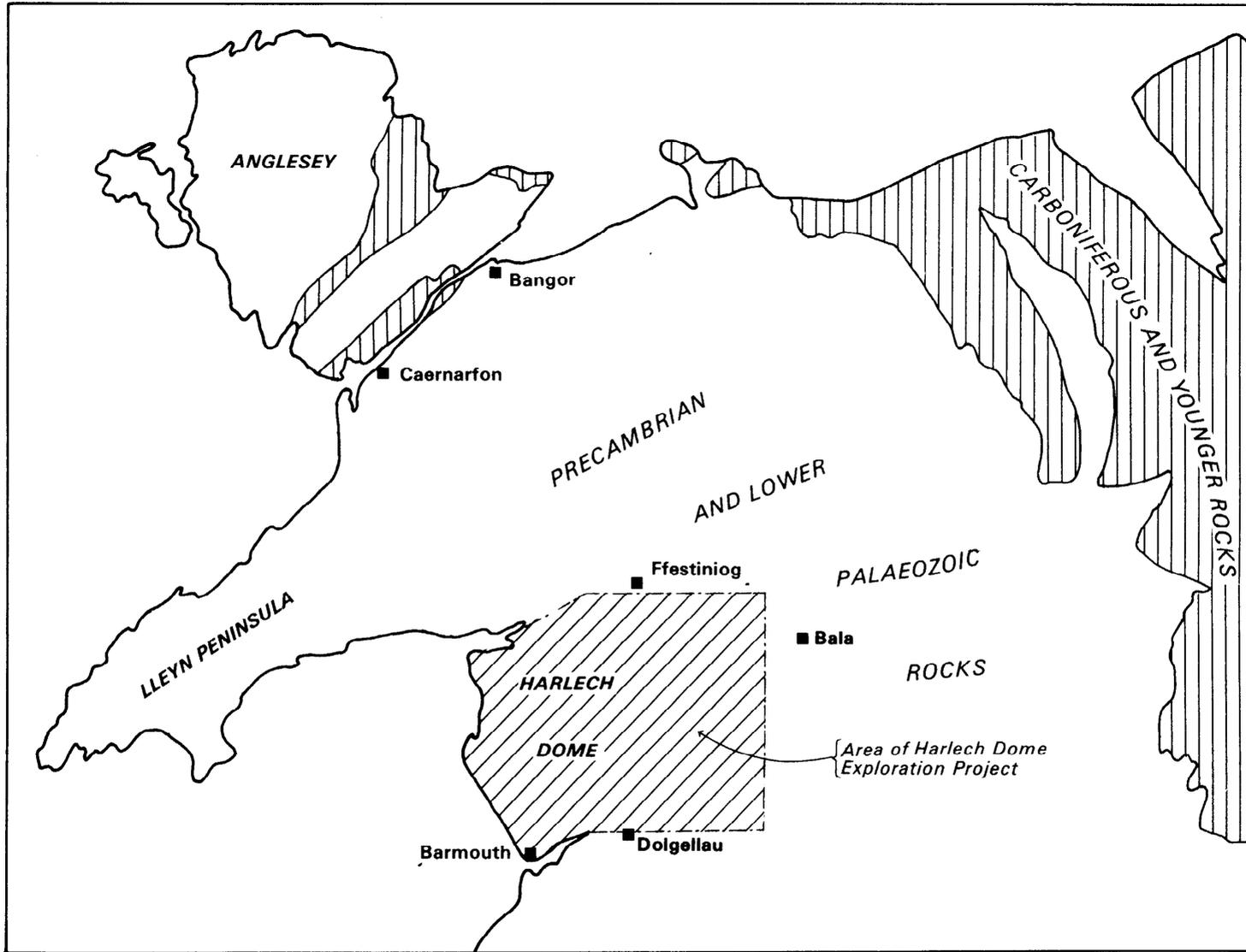
Fig.1 Location map showing area covered by Harlech Dome Exploration Project.
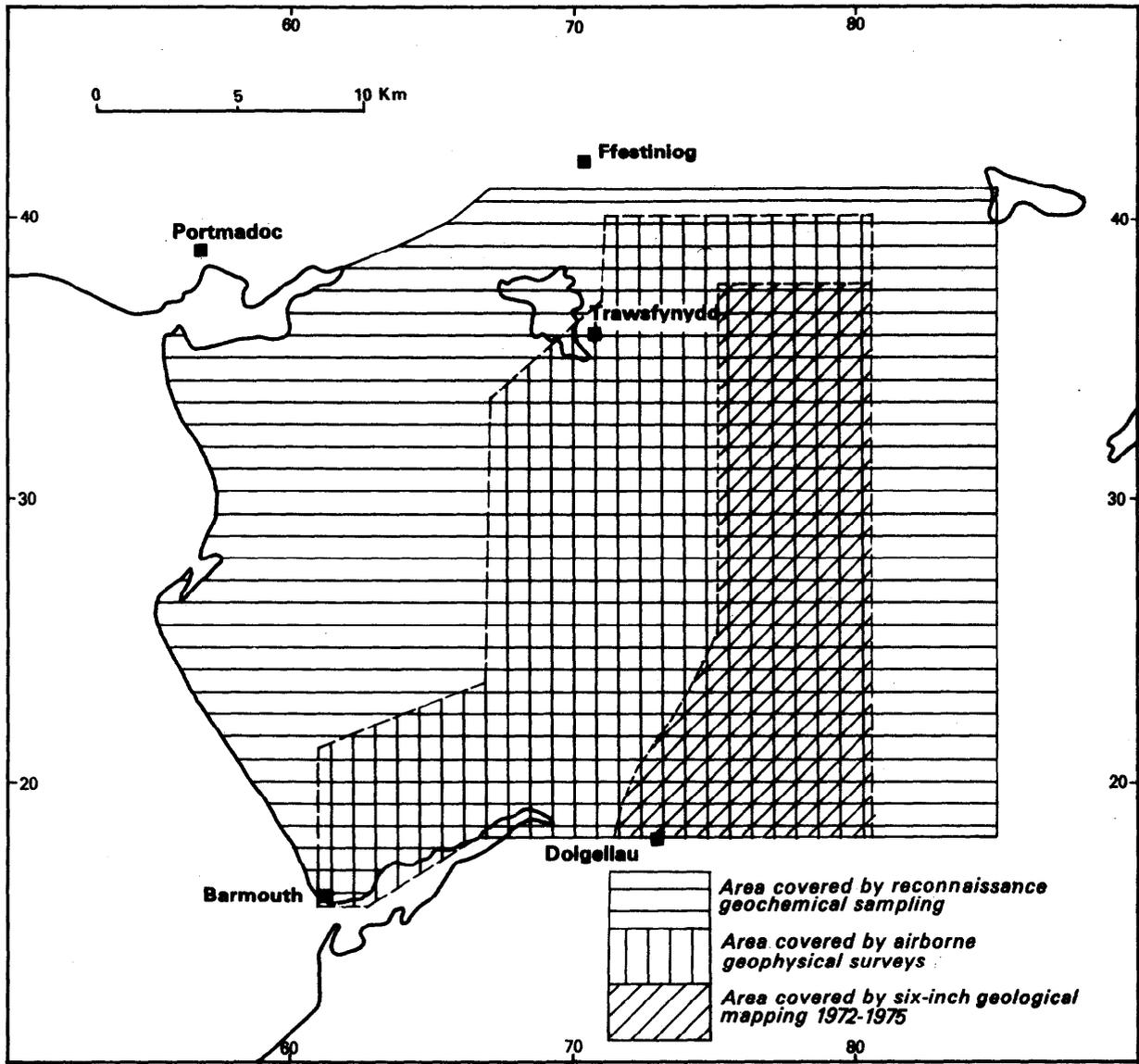
Fig.2 Areas covered by airborne geophysics, geochemical sampling and six-inch geological mapping.

The map legend reads:

Area covered by reconnaissance geochemical sampling

Area covered by airborne geophysical surveys

Area covered by six-inch geological mapping 1972-1975

Locations shown: Ffestiniog, Portmadoc, Trawsfynydd, Dolgellau, Barmouth
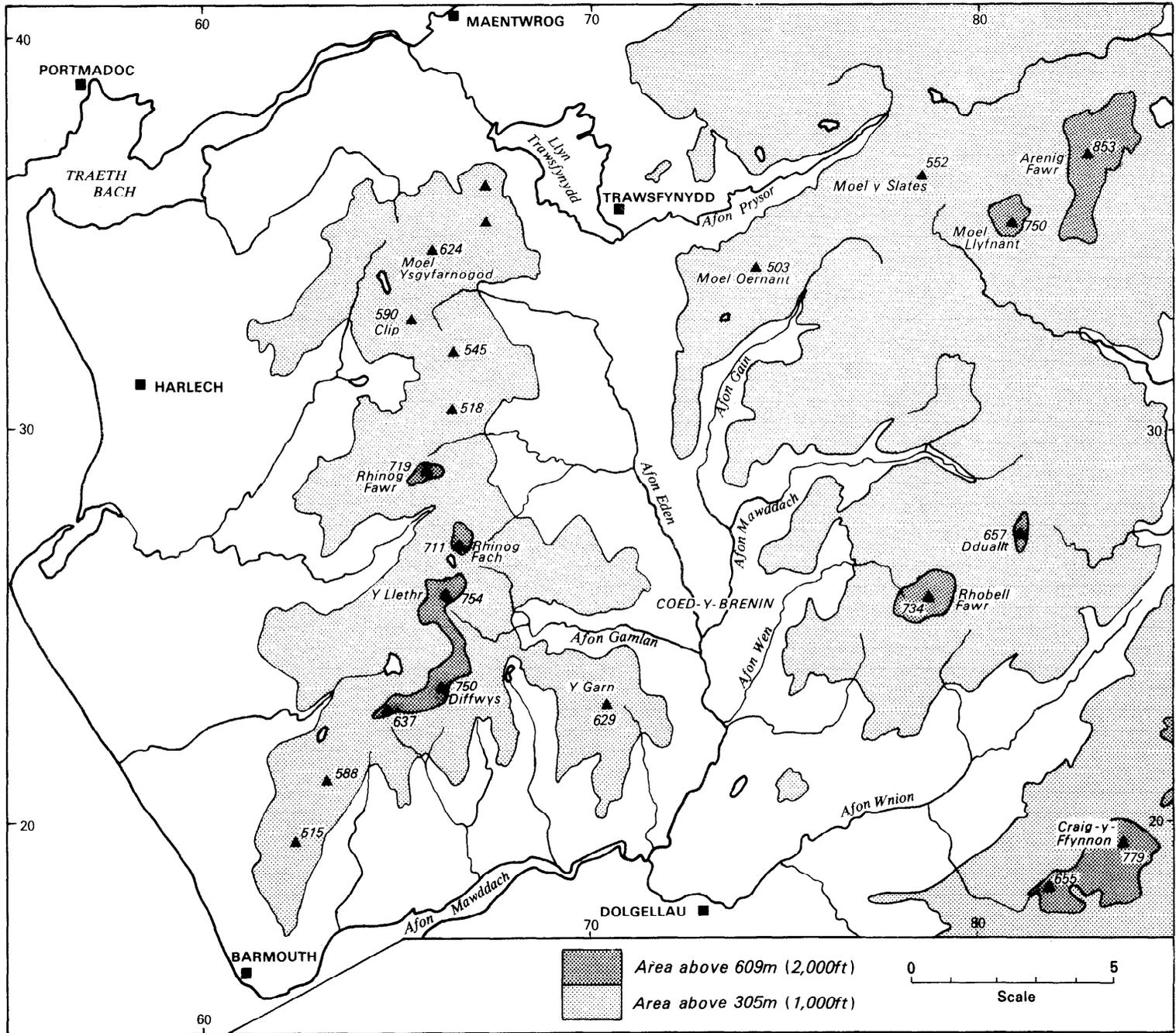
Fig.3 Main physical features of the Harlech Dome.

Foster-Smith (1977). Dewey and Smith (1922), Dewey and Eastwood (1925) and Archer (1959) also give accounts of geology and mining activities the Gold-belt. Rice and Sharp (1976) give an acccount of the Coed-y-Brenin porphyry copper deposit.

Exploration targets

From the known mineralisation and the geology of the area four possible exploration targets could be identified:

a) Porphyry-copper mineralisation of the type identified by Riofinex at Coed-y-Brenin (Rice and Sharp, 1976)
b) Vein mineralisation
c) Mineralisation in dark mudstone formations
d) Massive sulphide deposits associated with the Ordovician volcanic rocks

Availability of data

The data for the airborne geophysical surveys have been plotted on 1:10,560 scale O.S. sheets covering the area flown. Master transparencies are held in the major offices of IGS and may be copied on request. The geophysical data for the ground investigations are held in the office at Princes Gate, London. Only such data that are needed to support the conclusions are presented in the text.

For most of the areas examined the analytical data for the geochemical surveys are presented in various forms throughout the text; additional data may be obtained on request from the Keyworth Office of IGS.

Material taken from two internal reports prepared by the Mineralogy Unit (Easterbrook and Basham No. 210 and Easterbrook No. 214) and one by the Engineering Geology Unit (Forster No. 83) has been used extensively in this report.

GENERAL GEOLOGY

All the valleys and much of the high ground have a cover of boulder clay, in parts overlain by peat. Most hillsides have a thin cover of head and in some places scree is well developed. Alluvial deposits are extensive only in the lower Mawddach valley.

The solid geological succession is composed of sedimentary and igneous rocks of Cambrian and Ordovician age which were folded and metamorphosed in the Caledonian orogeny.

The rocks of Cambrian age have been divided into three groups (Table 1). The oldest, the Harlech Grits Group, consists of six formations which broadly reflect the alternation of sandstone and mudstone which characterises the group. The Dolwen Formation, the base of which is known only in the Bryn-teg Borehole (Allen and Jackson, 1978) consists of thick conglomeratic slide deposits at the base overlain by greywacke-type sandstone and siltstone. The principal arenaceous horizons above this, the Rhinog and Barmouth

formations, consist of thickly-bedded and coarse-grained sandstone, which shows many of the characteristics of turbidites (Crimes, 1970), with thin interbedded units of grey or green mudstone. In the remaining formations only the Llanbedr Formation, which consists of mudstone and silty mudstone from grey and green to purple in colour, is free of sandstone beds. The Hafotty Formation contains a thin bed of sedimentary manganese ore (Woodland, 1939; Mohr, 1959) interbedded with mudstone, and the Gamlan Formation contains in places a number of thick sandstone beds.

The Mawddach Group, which lies conformably on the Harlech Grits Group, differs from it in a number of ways, though it consists, again, of broad alternations of sandstone and mudstone. The mudstone, which comprises the Clogau, the upper part of the Maentwrog and the Cwmhesgen formations is grey or black; the sandstone is fine-grained and quartzose and individual beds rarely exceed 1 metre in thickness. In the lower part of the Maentwrog Formation the sandstone beds show some characteristics which Crimes (1970) attributed to distal turbidites, but in the Ffestiniog Flags Formation the sandstone beds are laminated, show current-ripple laminations, slump structures, sedimentary boudinage and disconnected ripples which appear to indicate deposition under shallow-water, unstable conditions, probably above wave base.

The Rhobell Volcanic Group is restricted in exposure to the south-eastern and southern part of the area. It consists of basaltic and relatively rare acidic volcanic rocks erupted in a mainly subaerial environment towards the end of the Cambrian Period (Kokelaar, 1977). The centre of eruption was probably to the west of Rhobell Fawr (Wells, 1925). The basal lavas and tuffs of this group unconformably overlie sedimentary rocks of the Cwmhesgen and Ffestiniog Flags formations.

Unconformably overlying both the Mawddach and Rhobell Volcanic groups is the Aran Volcanic Group. It consists of basic to acid lavas and tuffs, volcanic sediments, black mudstone and ironstone, representing an episode of essentially submarine volcanicity, spanning the Arenig to lower Caradoc epochs (Dunkley, 1978).

There are three main episodes of intrusive igneous activity. The earliest, which gave rise to sills, dykes and laccoliths of intermediate and basic composition is co-magmatic with the Rhobell volcanic episode. Many sills of this episode are folded with the rocks they intrude and they are present at all levels in the Cambrian succession. The larger intrusions, however, are almost entirely limited to the Maentwrog and higher formations. The greatest concentration of intrusions is immediately adjacent to Rhobell Fawr itself.

The second intrusive epidsode probably took place contemporaneously with the Ordovician volcanicity and is represented on the Migneint and around Arenig Fawr by many dome-like intrusions of quartz-latite porphyry found in the volcanic succession, whereas in the south-east there are some rhyolite domes. Dolerite sills are present throughout the lower part of the

Table 1. Stratigraphic nomenclature in the Harlech Dome.

	Group	Formation	Member
Ordovician	Aran Volcanic	(various)	
	Rhobell Volcanic		
Cambrian	Mawddach	Cwmhesgen	Dol-cyn-afon Dolgellau C
		Ffestiniog Flags	
		Maentwrog	Penrhos* C Vigra *
		Clogau C	
	Harlech Grits	Gamlan Barmouth Hafotty Rhinog Llanbedr Dolwen	

* These names were introduced as formational names by Matley and Wilson (1946) but have been found to be unreliable to map.

C indicates the presence of a conductive horizon.

Ordovician succession and possibly pre-date the acid intrusions.

Finally, a swarm of altered basic dykes crosses the Cambrian rocks and is apparently unaffected by any folding. Its age is unknown.

The main structural element in the area is the Dolwen Pericline of the Harlech Dome. Trending north it is flanked on the west by two broad structures, the south-plunging Caerdeon Syncline and, north of this, the north-plunging Moel Goedog Syncline. The Ordovician rocks are folded about axes parallel to the Dolwen Pericline. Whereas in the Migneint Lynas (1973) describes a conformable relationship in some places between the Arenig rocks and underlying Cwmhesgen Formation, elsewhere there are angular relationships between the Rhobell Volcanic Group and formations of the underlying Mawddach Group. This suggests that the pre-Ordovician phase of earth movements was probably locally confined and related to fault block movement. Cleavage is intermittently developed and, in places, the mudstone contains a penetrative slaty cleavage. Throughout the area the effects of low greenschist facies regional metamorphism are present.

There are three strong directions of faulting. In the south-eastern parts the NE-trending Bala Fault is accompanied by a cluster of lesser, parallel faults, and faults with trends subparallel to this are common in all parts of the area. Another main trend is NNE, shown by several faults named by Matley and Wilson in the north-western part of the Harlech Dome. Strong N to NNW faults include the Caerdeon-Bodlyn Fault which is axial to the Caerdeon Syncline and, on the eastern side of the Dome, the Trawsfynydd,

Craiglaseithin and Bryn Celynog faults.

History of mining

Historically, the Harlech Dome is one of the principal mining areas in Great Britain. Gold, lead, silver, copper and manganese have all been mined at least since the last quarter of the eighteenth century and, although none of the mines was very big, the total output of 130,000 oz gold for the area from 1850 onwards is the largest for any gold mining area of Great Britain (Hall, 1975; Morrison, 1975). Excluding manganese workings the locations of about 70 named old mines can be found in the area. Records of production are available for 26 of them. Many lie in a narrow area north and west of the Mawddach from Barmouth roughly to its confluence with the Afon Gain which Andrew (1910) called the Dolgellau Gold-belt. There are, however, a number of trials (Enclosure 3) and two important mines well outside this area. Full accounts of the historical development of this area, and descriptions of many of the mines have been written by Hall (1975) and Morrison (1975). The geological setting, mineralogy, wallrock alteration and metallogenesis have been studied by Gilbey (1969).

Broadly speaking, all the mines, except Glasdir and Turf, worked quartz veins for gold and Cu, Pb, Zn and Ag sulphides (Enclosure 4). Prior to 1844 when the first public announcement was made about the discovery of gold in the area, there were only a few mines operating, mostly working the veins for copper and lead/silver. From 1853 onwards, however, the prime target was gold and in two short periods, 1853-54 and in

the early 1860s practically every known vein in
the area was tried for gold, but it was not until
after 1888 that any really big production figures
were recorded, and these came from only two
mines, Clogau and Gwynfynydd. From 1888 until
1916 the Gold-belt saw its most fruitful years.
Both Hall (1975) and Morrison (1975) give the
known production figures for the whole period.
Since 1916 there has been very little serious
activity and minimal production of gold. The
Prince Edward and Marina mines operated until
mid 1930s and at that time Mr C.V. Sale tried to
reopen Gwynfynydd. After this the only recorded
production is from Graigwen between 1948 and
1953. Interest, however, never really died and
several mines have been looked at since then by
interested parties. At the time of writing an
attempt is being made to reopen Gwynfynydd.

Both before and after the discovery of gold,
copper was produced from mines in the Harlech
Dome. Some of it was won from veins, but the
biggest production came from two unique mines.
At Glasdir, which produced about 1300 tons of
copper between 1872 and closure in 1914, the ore
that was worked was chalcopyrite disseminated
through a breccia. At the beginning of the
mineral exploration project the significance of
this mine was not appreciated. It is now,
however, interpreted as a mineralised breccia
pipe and has been examined in some detail.

The other big copper producer was the Turf
Mine, where, in the early nineteenth century,
70 acres of peat (Dewey and Eastwood, 1925)
enriched in secondary copper minerals were
excavated, burned to concentrate the copper in
the ash and sent to Swansea for smelting. It was
realised at the time (Ramsay, 1881) that the
source of the copper was in the bedrock and a
great deal of energy was expended in search of
the "mother lode". It was not found, however,
until RTZ discovered the Coed-y-Brenin porphyry
copper deposit in the early 1970s (Rice and Sharp,
1976). This deposit has not been mined.

Besides Glasdir and Turf, several other mines
are known to have been worked for copper
minerals, and others were worked for lead, zinc
and silver. In all the gold-producing mines, the
gold is associated with sulphides. Production
figures for the other metals, however,
are almost absent from the records and the figures
of 267 tons lead, 492 oz silver and 107 tons zinc
recorded by Hunt (1848-1881) and in the Home
Office Mines and Quarries General Report from
1881 onwards can give no idea of the true
production.

Present conditions of the old mines

During the mineral exploration project many
of the old mines were visited both at surface and
underground. Apart from Gwynfynydd, where
conditions are good, many are flooded and roof
collapses have blocked the levels. A few main
adits have been bricked up or are blocked by
collapses, but in no mine is it not possible to
obtain access to some part of the worked lodes.
All the original buildings, tramways and leats
are in total ruin. Large tips, now partly

overgrown, exist only at Glasdir, Gwynfynydd,
Clogau and Vigra. The tip at Prince Edward
has partly been removed by CEGB to construct
a track used when erecting pylons.

Age of the mineralisation

Gilbey (1969), who was unaware of the exis-
tence of the Coed-y-Brenin porphyry copper
deposit, attributed all the mineralisation in the
district to hydrothermal activity in the late
Silurian period, at the end of the Caledonian
orogeny, though he made a distinction between
quartz veins in intrusions such as in the Cae
Mawr, Dol-y-clochydd and Maesmawr mines,
and all the other veins. The latter, he considered
to be part of a regional phase of hydrothermal
activity; the former the result of localised
reaction to regional metamorphism on the intru-
sions. Prior to Gilbey, Archer (1959) had
suggested that the mineralisation was post-
Carboniferous in age, but Gilbey had the advantage
of knowing that Moorbath (1962) had obtained
model lead ages with a mean of 430 m.y. on
minerals from the area. Later, Ineson and
Mitchell (1975) quoted ages ranging from $345^{+}_{-}8$
to $397^{+}_{-}5$ m.y. calculated by K/Ar method on
illite-chlorite-kaolinite mixtures from wallrock
samples from several mines in the area. Though
they were unable to provide an explanation for the
spread, the data did support the suggestion that
the mineralisation was late Silurian rather than
post-Carboniferous.

The first suggestion that there was, perhaps
mineralisation at two different ages, came from
Rea (1972) when he raised the possibility of the
Coed-y-Brenin mineralisation being related to
the late Tremadoc Rhobell volcanic episode and
thus distinct from the younger, end-Caledonian
phase. His evidence was largely circumstantial,
but largely as a result of work carried out during
this project Allen and others (1976) were able to
support his suggestion.

GEOPHYSICAL INVESTIGATIONS

INTRODUCTION TO AIRBORNE GEOPHYSICAL SURVEYS

General

An airborne geophysical survey was considered
a suitable method for a rapid preliminary investi-
gation of the mineralisation of the Harlech Dome
(Fig. 4). Bodies of conductive rock might be
revealed by electro-magnetic induction (EM)
surveys; information on structures and
distribution of magnetic rock-types may be gained
from aeromagnetic surveys. In addition it was
hoped to use the radiometric data to look for
uraniferous concentrations and aid the interpre-
tation of the EM results by delineating horizons
of dark mudstone.

The main objective in the appraisal of the
airborne EM results was to recognise anomalies
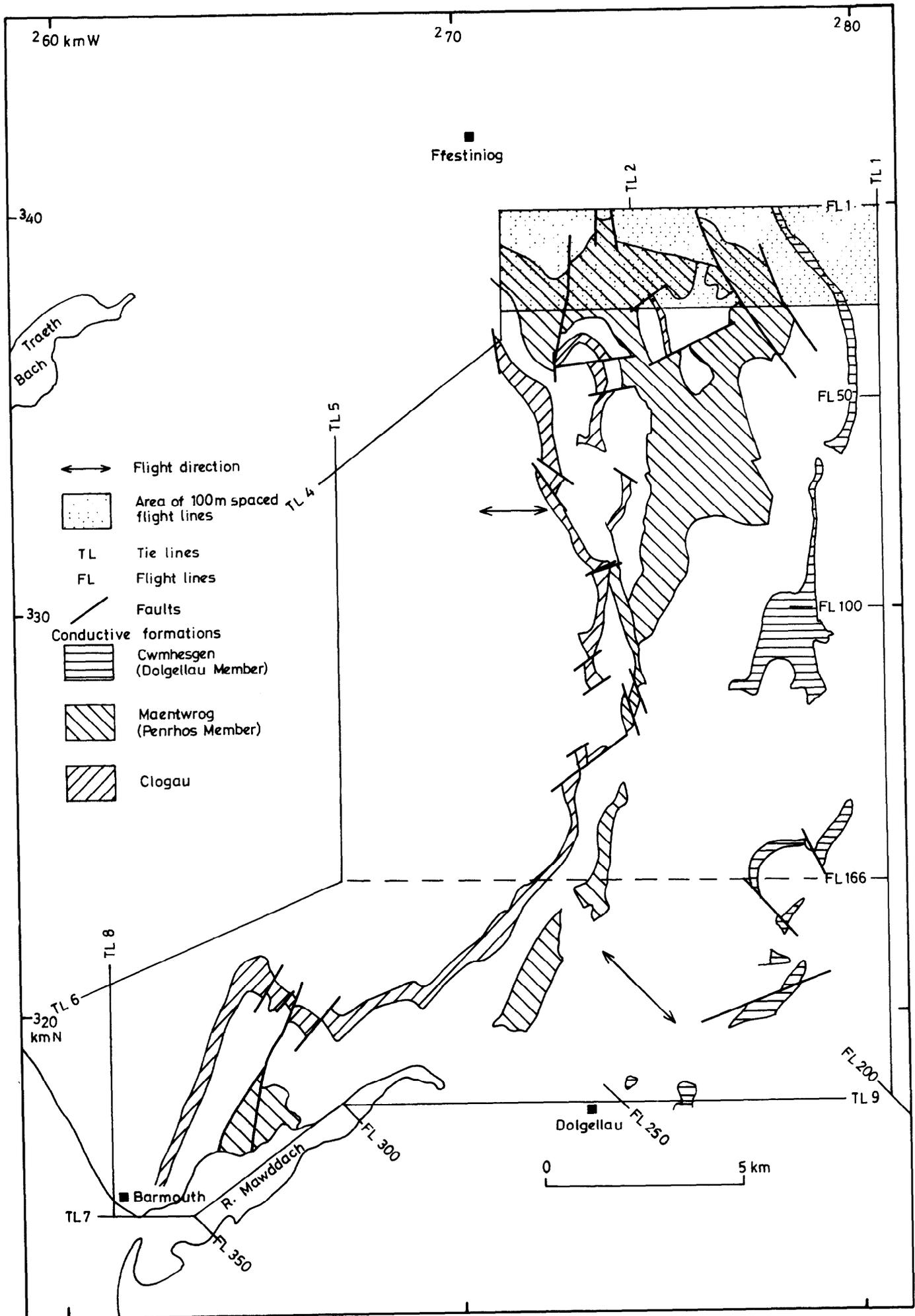
FIG.4.
OUTLINE MAP SHOWING AREA COVERED BY AIRBORNE GEOPHYSICAL SURVEYS AND APPROXIMATE
DISTRIBUTION OF CONDUCTIVE FORMATIONS

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associated with mineralisation and to distinguish them from the major response to conductive sedimentary horizons, man-made or artificial anomalies and those associated with conductive overburden. This was followed with a ground survey over likely targets.

The aeromagnetic survey was not only expected to indicate directly the presence of mineral deposits, especially where magnetic and EM anomalies coincided, but to be a guide to concealed structure and likely areas of minerali-sation. Artificial aeromagnetic anomalies are rare and can usually be identified easily by their close association with iron or steel objects. Less rigour is therefore required to determine whether the anomaly is of geological origin. It was, however, necessary to fix the position on the ground of airborne anomalies to eliminate the navigational shortcomings of the survey method.

The next two sections contain a brief descrip-tion of the results of the airborne surveys - a largely qualitative interpretation which provided the basis for subsequent ground geophysical surveys presented elsewhere in this report.

Survey procedure

The Harlech Dome area (Fig. 4) was included in the contract awarded to Hunting Geology and Geophysics Ltd for airborne surveys in 1972/3. The survey was made using a helicopter carrying magnetic, EM and radiometric equipment. A total of 1870 km of survey line was completed in the two periods December 7th to 17th, 1972, and June 4th to 26th, 1973.

The survey equipment and procedure differed slightly in these two periods; in 1972 a fluxgate magnetometer and EM equipment (measuring in-phase and out-of-phase components) operating at 1000 Hz were flown along flight lines 100 m apart with detectors at a nominal ground clearance of 100 ft (about 30 m). The survey was discontinued due to bad weather. In 1973 a proton magneto-meter (at a height of 150 ft (45 m)) and 1600 Hz EM equipment at 100 ft (30 m) were used; the spacing of the lines was increased to 200 m. These factors led to some differences in the appearance of the completed geophysical maps for the respective areas, the most obvious being that the magnetic data for 1972 (maps SH 73 NW, NE and SH 83 NW) show a more complex character due to the increased amount of data collected on the closer spaced flight lines and the smaller ground clearance of the magnetometer. The main change in the character of the EM maps appears to be due to the increased amount of data collected using a 100 m line spacing and not appreciably to the different frequencies.

The flight lines were orientated in an east to west direction in the northern part of the area (Fig. 4); south of National Grid Line 323.5 km N the orientation was changed to north-west in order to continue to produce intersections at right angles to the general strike of the strata.

General information on the survey procedure, instrumentation and data compilation is given by Burley and others (1977).

The geophysical data for the Harlech Dome area is presented on separate maps at a scale of 1:10,560 showing:

a)   contours of magnetic total intensity varia-tions above linear field for the British Isles at epoch 1955.5, which is given for any point by the equation:

$$T = 2.1728Y - 0.259X + 47033 \text{ nT}$$

where Y and X are respectively the National Grid northing and easting in km for that point.

Thus, for example, the value of the regional field at SH 7030 near the centre of the Harlech Dome is 48476 nT.

These maps are referred to the same datum and epoch as the Aeromagnetic Map of Great Britain (Geological Survey, 1965) and magnetic values for any point may be directly compared.

b)   contours of variations in the in-phase component of the secondary EM field, expressed as ppm of the primary field.

c)   plots of the ratio of the in-phase to the out-of-phase EM components.

These maps are available from the Applied Geophysics Unit of IGS.

The Harlech Dome survey was carried out over a topography which is often very rugged with rapid height variations between sea level and more than 700 m OD. There are many places where it was impossible to maintain the intended ground clearance and in these the geophysical data may be distorted by topographic effects. Rapid topo-graphic variations mean that in some places the sources of the geophysical anomalies did not remain at a constant distance from the detector and in extreme cases lay above the detector, with consequent distortion of the geophysical anomalies.

Deviations of more than 200 ft (61 m) from planned flight lines were reflown during the survey. However during the ground follow-up surveys certain discrepancies between the position of the airborne anomalies and those on the ground were proved. It is considered that most of these errors are in the airborne survey and could be caused by several factors which might not be recognised during compilation and plotting of the airborne data:

a)   Fiducial points may be inaccurate or infrequent in featureless moorland and forest areas.

b)   The variation of ground speed between fiducial points. Often the helicopter climbed or descended at different rates relative to the ground on adjacent flight lines; this can lead to the effect known as 'herring boning'. Differing ground clearances on adjacent lines affect the anomaly amplitudes which may emphasise the 'herring boning'.

c)   The effect of variable cross winds in mountainous country may cause errors in the assumption of a straight flight path between fiducials.

In general the positional errors were found to be less than 100 m with a very few up to 200 m, but clearly, where the flight-line spacing is nominally 200 m, there is likely to be considerable distortion of shape and size of the smaller anoma-lies.

AIRBORNE ELECTROMAGNETIC SURVEY

Introduction

The EM method detects the presence of good electrical conductors. These may be geological e.g. due to low resistivity zones in the bedrock or the drift, or they may be non-geological e.g. man-made conductors such as metal pipes, power lines or metal roofs, or interference from radio transmitters and power lines. In the Harlech Dome area the non-geological conductors are relatively uncommon and generally recognised on the records and from maps. There were some problems with radio interference in the north of the area, causing weak sinusoidal signals which were detected and reproduced on the maps.

Enclosure 6 is a reduced and simplified version of the maps produced by the contractor. It shows the major features described in the text. However, anomalies to which reference is made do not appear on the diagram if they are of smaller amplitude than would be represented by the contours.

At an early stage in the survey it was recognised that prominent, long, EM anomalies were due to certain stratigraphic horizons whereas smaller, less persistent anomalies, particularly in association with known minerali-sation or with magnetic anomalies, which might indicate magnetic minerals in sufficient quantities to be conductive were not always concordant with the geological strike. These were sometimes difficult to distinguish from conductive drift or from man-made sources without further detailed information.

Thus, it was important to carry out a series of ground surveys and laboratory investigations to identify and verify the cause of the anomalies, once a desk study of the maps, flight records and geological information had been carried out. A number of anomalies were investigated on the ground before detailed airborne EM maps had been compiled, with the result that initially too much work was carried out over the continuous anomalies due to the stratigraphic conductors.

EM anomalies associated with stratigraphic conductors

The most common anomalies in the Harlech Dome area are those associated with conductive stratigraphic horizons in the Cambrian and Ordovician rocks. The position of these anomalies, which can be easily recognised from Enclosure 6, coincide with the outcrop of the Clogau, Maentwrog and Cwmhesgen formations, which are all predominantly argillaceous (Enclosure 2). Table 1 shows the stratigraphy and identifies the conductive horizons. In all three of the formations it was realised that EM anomalies due to non-economic causes, e.g. carbonaceous material, might be overprinting and concealing anomalies related to economically worthwhile concentrations of sulphide minerals.

a) Clogau Formation

The strong EM anomalies related to the Clogau Formation, which consists of black mudstone with thin sulphide lenses, are more or less continuous in the south and the north of the area but there is a break in the central part, where only weak and discontinuous anomalies occur, although the formation continues throughout. It is interesting to note a similar effect in the magnetics.

Fig. 5 shows a profile across both the Clogau and Maentwrog Formation anomalies. There is a slight asymmetry on the Clogau anomaly, suggesting a south-easterly dip. Several other anomalies show a similar asymmetrical pattern, always indicating an easterly dip. Samples of rock from this formation, demonstrated in the field to be conductive, were collected for laboratory investigations which are reported in a later section (p. 26).

In a number of places the airborne anomaly was confirmed on the ground and demonstrated to coincide with the Clogau Formation. These investigations, (Enclosure 1), which are not reported in Part 2, are at Pig Idris (Centre point SH 730 319), Bryn Llefrith (SH 725 334), Hafod Wen (SH 728 356), Prysor (SH 742 355), Cae Hir (SH 658 200), Trawsfynydd (SH 719 350), Rhos Caerau (SH 655 200) and Dolgain (SH 733 300).

b) Maentwrog Formation

The upper part of the Maentwrog Formation, the Penrhos Shales of Matley and Wilson (1946), consists of grey and black, locally pyritous, mudstone which in the south of the area correlates with strong EM anomalies. Elsewhere the anomalies are much weaker and the cause not clearly stratigraphic in some cases. Several ground surveys and limited laboratory work were done to investigate these weak anomalies and are described later in Part 1 and under the appropriate section in Part 2.

c) Cwmhesgen Formation

An approximately continuous, roughly north-south zone of intense EM anomalies has been delineated along the eastern margin of the area covered by airborne survey as shown in Enclosure 6. This zone is correlated with the black mud-stones of the Dolgellau Member of the Cwmhesgen Formation.

A profile across the anomaly shows a single sharp, almost symmetrical peak (Fig. 6) which is typical for much of the zone. However, in some places (e.g. at SH 7928) the anomaly is a flat-topped, plateau-like feature. This probably results from saturation of the EM equipment by the very strong response, rather than being a characteristic of the real anomaly. The asymme-trical contour pattern suggests an easterly dip. This is not apparent in the rest of the zone, probably because the gradient of the anomaly was too steep for the response time of the airborne equipment.

Several dislocations of the anomaly are seen,
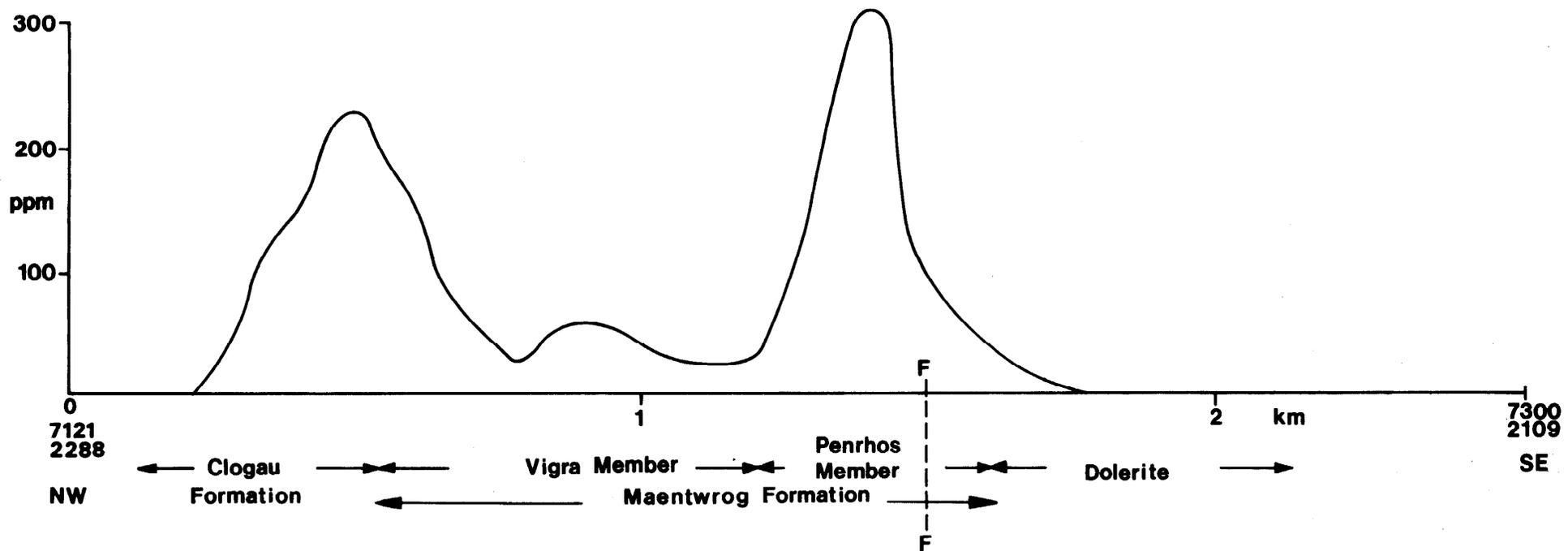
Fig 5. A profile showing airborne E M in-phase component anomaly across outcrops of the Clogau and Maentwrog formations. F = fault
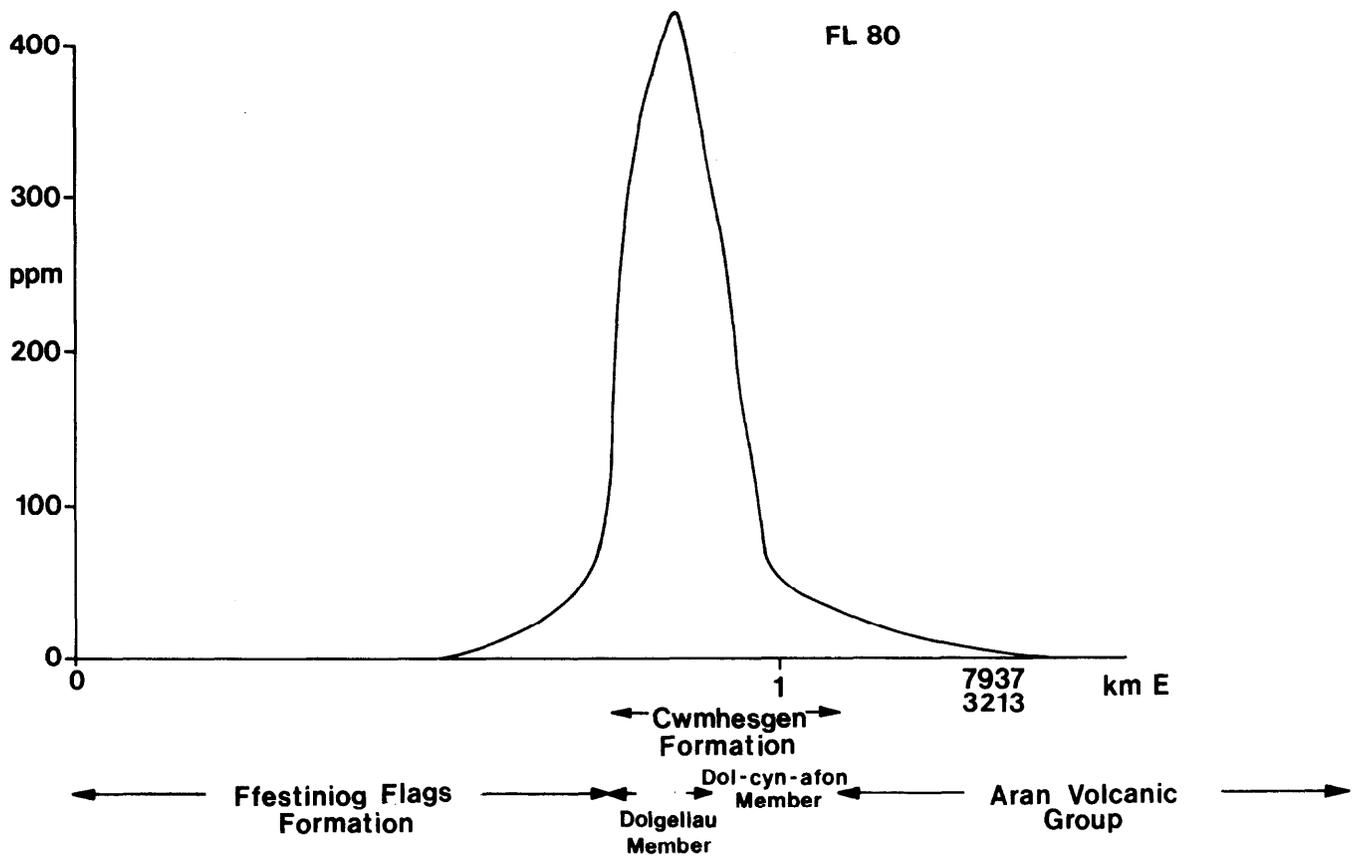
Fig.6   A profile showing the airborne EM in-phase anomaly across the outcrop of the Cwmhesgen Formation.

throwing the zone to the east or west by up to 0.5 km; these are the result of faults which have also been recognised, in most cases, by geological mapping.

Several areas were investigated on the ground to identify the cause of the anomaly. Where the anomalies were found to coincide exactly with the Dolgellau Member they are not reported in Part 2. These are Blaenau (Centre point SH 785 225), Ffridd-y-Castell (SH 785 245), Torrent Walk (SH 756 186), Y Trinant (SH 798 375) and Feidiog (SH 790 318). Rock samples were collected from several areas, including Ogof Ddu near Criccieth which is outside the area of this investigation, for laboratory examinations which are reported later in Part 1.

Artificial EM anomalies

This section covers those anomalies shown on the maps which, when investigated on the ground, using Slingram equipment, could be demonstrated either to be caused by man-made conductors, or to be due to EM (radio) interference or not to exist at all.

a) Man-made conductors

These include such metallic objects as cables, pipes, metal roofings, cars etc. One such anomaly was investigated at Pont-y-Sel (see Part 2) in the south-east of the area. The ground survey shows that the airborne in-phase anomaly of about 200 ppm was due to the combination of a major power line and a water pipe. The airborne effect of such features is usually fairly weak compared to geological anomalies because the object is usually small compared to geological structures and there is a consequent rapid decrease in EM response with increasing distance. Conversely, the effect of artificial conductors on ground equipment is often very considerable. Other sites where the airborne EM anomaly was shown to be caused by man-made conductors were Brithdir (SH 773 188), Nant Gefail (SH 765 397) and Farchynys (SH 662 183).

b) Radio interference

There is a radio transmitting station in the north of the area in grid square SH 70 39. This caused a weak sinusoidal response in the airborne EM equipment on the northern flight lines which probably results from the EM 'bird' towed beneath the helicopter swinging about its heading on flight lines orientated roughly towards the transmitter. These sinusoidal variations have been contoured and effectively mask any geological anomalies in the area. Anomalies followed up on the ground which were probably due to radio interference were Dol Haidd (see Part 2), Glanllafar (SH 730 373) and Roman Fort (SH 710 389).

Power lines when under load also emit EM radiation and this can interfere with the equipment, causing spurious anomalies. These can often be recognised by a characteristic anomaly shape; e.g. their position along straight lines or roads can be diagnostic as can be seen for example at

SH 716 279. In most cases they do not appear on the maps because their amplitudes are less than the 25 ppm contour interval and so may be recognised only by inspection of the flight records.

c) Spurious anomalies

Much work was expended on following up airborne anomalies which were not detected on the ground. Such anomalies are often characterised by a strong negative out-of-phase component, and positive in-phase components; these features cannot be explained by the simple theory of secondary EM radiation from conducting bodies and are unlike power lines, which show the opposite effect of positive out-of-phase and negative in-phase components. However, other anomalies which were not found on the ground did not show this feature. In many cases the cause was probably an instrumental malfunction of the airborne equipment due to flexing of the towed bird. In other cases it appears that the wrong zero datum was used for a short length of record during data reduction, probably a result of instrumental drift. It is also possible that small anomalies could have been missed on the ground because of navigational erros in the airborne survey and, less likely, during the ground survey. Such 'lost' anomalies are listed as follows:

Area name	Centre point
Bwlch yr Ysgol	SH 649 190
Coed y Brenin	SH 719 268
Craig Aberserw	SH 700 272
Craig Penmaen	SH 726 296
Ffridd Fechan	SH 615 176
Goetre	SH 642 184
Gwartheg (includes Crawcwellt)	SH 689 325
Mynydd Bach (peak)	SH 745 310
Nant Bod Fuddau	SH 732 344
Nant Lligwys	SH 753 340
Pant Mawr	SH 717 365
Rhinog	SH 680 274

There is a major anomaly on the airborne EM map in the south of the area over the tidal parts of the Mawddach valley. The anomaly is caused by the high conductivity of salt water which covers a broad area during high tides and saturates the underlying alluvial deposits.

Conclusions

Strong, continuous EM anomalies are associated with dark mudstone in the Clogau, Maentwrog and Cwmhesgen formations and though they are most likely to be caused by some intrinsic quality of no economic importance within the formations there is a possibility that they might conceal bands of economically worthwhile sulphides. Other anomalies are clearly associated with artificial conductors, radio transmitters and salt water. There remain, however, a number of small anomalies for which the available geological evidence offers no explanation and these had to be examined in detail on the ground.

AEROMAGNETIC SURVEY

Introduction

An aeromagnetic map of part of North Wales
(Fig. 7) compiled from data recorded in 1960 at
a flight height of 300 m above mean ground level,
(Geological Survey, 1965) shows the area to be
strongly anomalous. Although the anomalies
appear to be generally related to the main surface
geological features of the area, the lack of
resolution makes it impossible to provide exact
explanations and interpretations. It is clear,
however, that the magnetic anomalies are asso-
ciated with the outcrop of the Cambrian sedimentary
rocks in the Harlech Dome. However, to the
north, where strong anomalies occur over
Snowdonia, they are apparently associated with
Ordovician igneous rocks. The Padarn Ridge,
which brings Cambrian sediments to the surface,
also shows magnetic anomalies.

On a broad scale the anomalies over the
Harlech Dome are aligned north to south, parallel
with the dominant strike direction of the Cambrian
sedimentary rocks. There is a less strongly
developed north-east trend. East to west profiles
across the dome typically show two major
magnetic peaks, the one to the east usually having
the larger amplitude. The anomaly values
decrease gradually away from the eastern margin
of the dome but to the west they decrease rapidly
along the line of the Mochras Fault, then rise
gradually towards the Lleyn.

A profile along National Grid line 325 km N
has been interpreted in Fig. 8 as a homogeneous
inductively magnetised body about 12 km wide,
coming near the surface in one place and extending
to a depth of 10 km. The depth to the magnetic
body west of the Mochras Fault is not considered
particularly reliable because the magnetic field
is influenced by anomalies to the north. It must
be presumed that this postulated body is a
representation of all magnetic material in the
area, with a susceptibility of $2.9 + 10^{-2}$ SI Units,
rather than a single homogeneously magnetised
body with these specific dimensions. Most of the
anomalies, when inspected on the lower level
magnetic survey or by ground survey, show a
more complex pattern and are caused by many
smaller bodies, magnetised in different directions
with different intensities.

This is illustrated on the maps produced from
the 1972/3 survey, represented in simplified form
on Enclosure 7. The general agreement between
the two surveys and between the geological strike
(Enclosure 2) and magnetic trends can be seen.

A number of different zones of distinct
magnetic character may be identified and the zones
are used in the following sections to describe the
aeromagnetic map.

Description of the aeromagnetic results

Zone 1

In the south-west part of the area there is a
zone north of Barmouth associated with the

outcrop of part of the Harlech Grits Group, from
the Rhinog Formation upwards. It is characterised
by anomalies with a wavelength of about 1 km.
There is a slight increase in intensity to the west
over the Rhinog Formation, a feature also seen
on the 1960 aeromagnetic survey (Fig. 7) at
SH 6118 which shows an anomaly co-incident with
this horizon. It is possible that the diminishing
anomaly strength to the east as shown in Fig. 9
is due either to increasing depth of burial of the
Rhinog Formation, or to decreasing magnetisation
in the higher formations.

Zone 2

This is a zone of intense anomalies in the
south of the area, closely associated with the
outcrop of the Clogau and Maentwrog formation
and strong EM anomalies. In general the trends
of individual anomalies are parallel to the
geological strike.

The eastern margin is very sharply marked,
as can be seen in Fig. 10 which shows a profile
crossing the Clogau Formation and Penrhos
Member of the Maentwrog Formation eastwards
onto a large dolerite intrusion which was later
shown to be non-magnetic. In this area of Clogau
and Maentwrog formations is a high concentration
of small sills of intermediate composition; these
are possible causes of the anomalies. However,
further detailed ground work showed a high
concentration of pyrrhotite in fractures throughout
the shaly horizons and this is also likely to cause
anomalies.

Assessments of individual areas and anomalies
are reported in Part 2 in the sections on Garth
Gell, Hafod-y-Fedw, and Mynydd Foel Uchaf.

Zone 3

This is a poorly defined zone of irregular
anomalies which is roughly comparable with the
lower part of the Rhinog Formation, south and
east of the Dolwen Pericline. There are some
minor intrusions shown on the geological map
around SH 7025 but detrital magnetite has been
found elsewhere in the Rhinog Formation which
may cause the anomalies. The trend of individual
anomalies shown on Enclosure 7 is between north
and north-east, which is oblique to the north-west
striking minor intrusions and the strike of the
bedding which might contain magnetite. However,
it is probable that the complex anomaly pattern
has not allowed for accurate contouring. Details
of an individual anomaly at Ffridd Bryn Coch are
given in Part 2.

Zone 4

Zone 4 surrounds the more magnetically active
Zones 3, 10 and 11 in the west of the survey area.
It is generally magnetically fairly quiet, but there
are isolated strong anomalies, which have ampli-
tudes of up to 100 nT and irregular trends. EM
anomalies in this zone associated with the Clogau
Formation tend to be discontinuous.

In the southern part, the zone covers the
outcrop from the Llanbedr Formation up to the

16
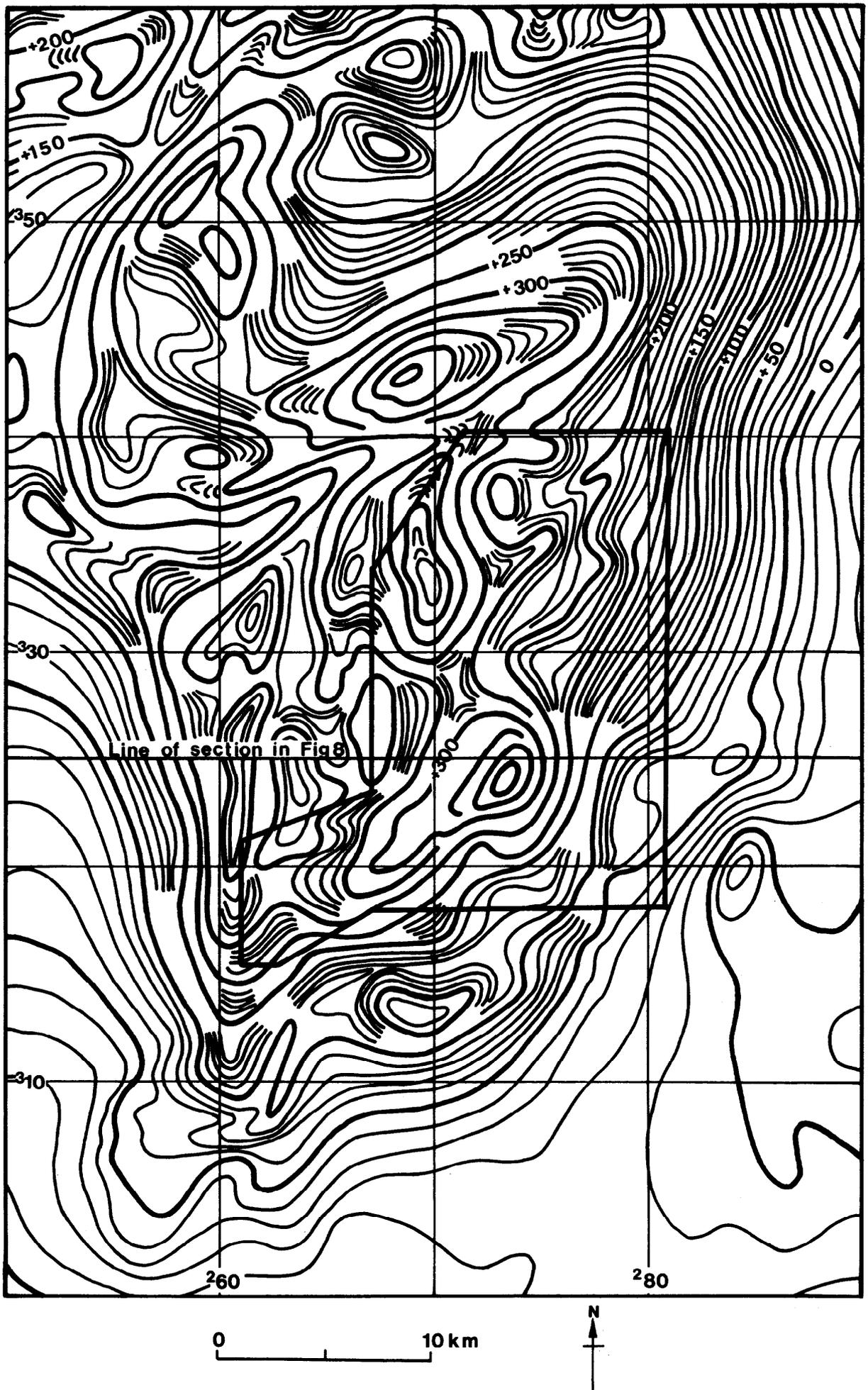
Fig. 7 Taken from the Aeromagnetic Map of Great Britain showing area
covered by the low-level airborne survey.
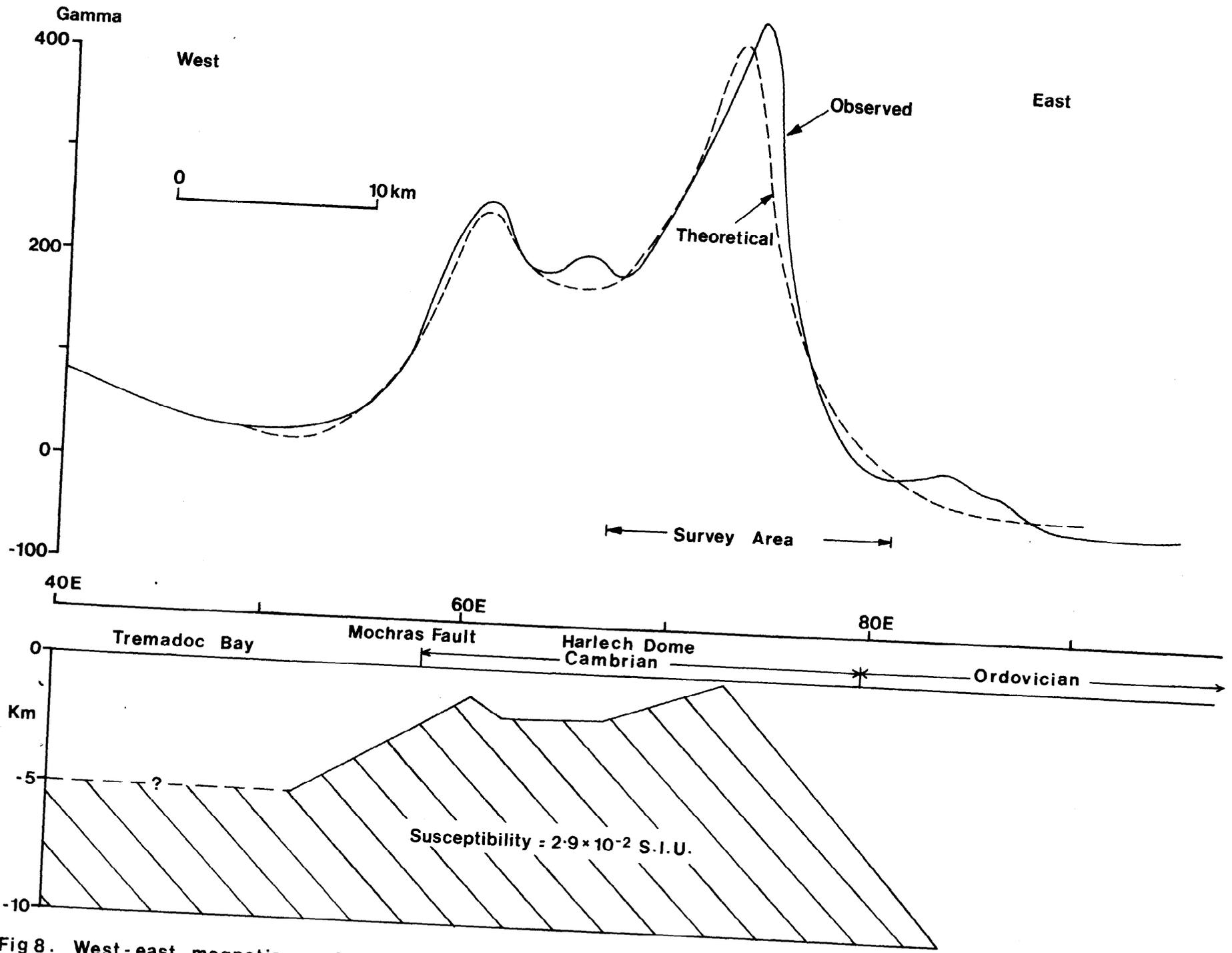
Fig 8. West-east magnetic profile across Harlech Dome, with a possible interpretation model showing theoretical anomaly curve for the model.
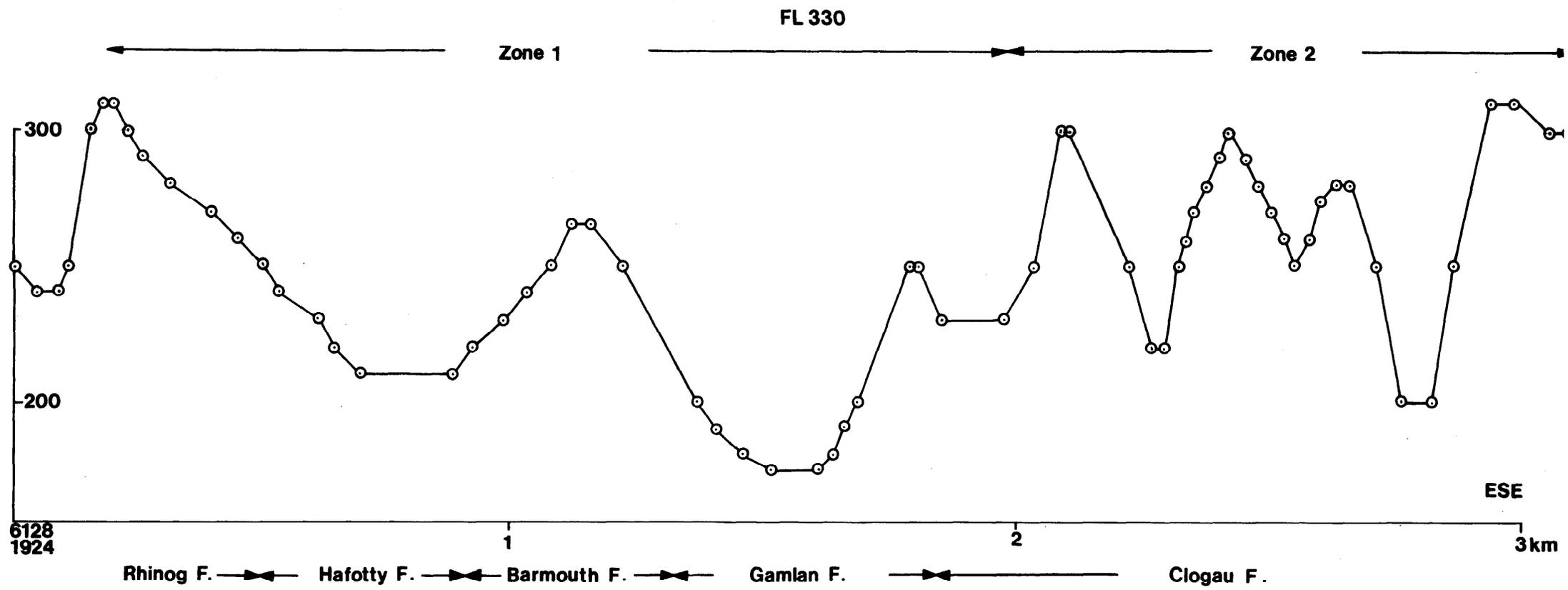
Fig. 9.   Magnetic Anomalies in Zones 1 and 2   (shown   as Profile 1 on Enclosure 7)

FL 234
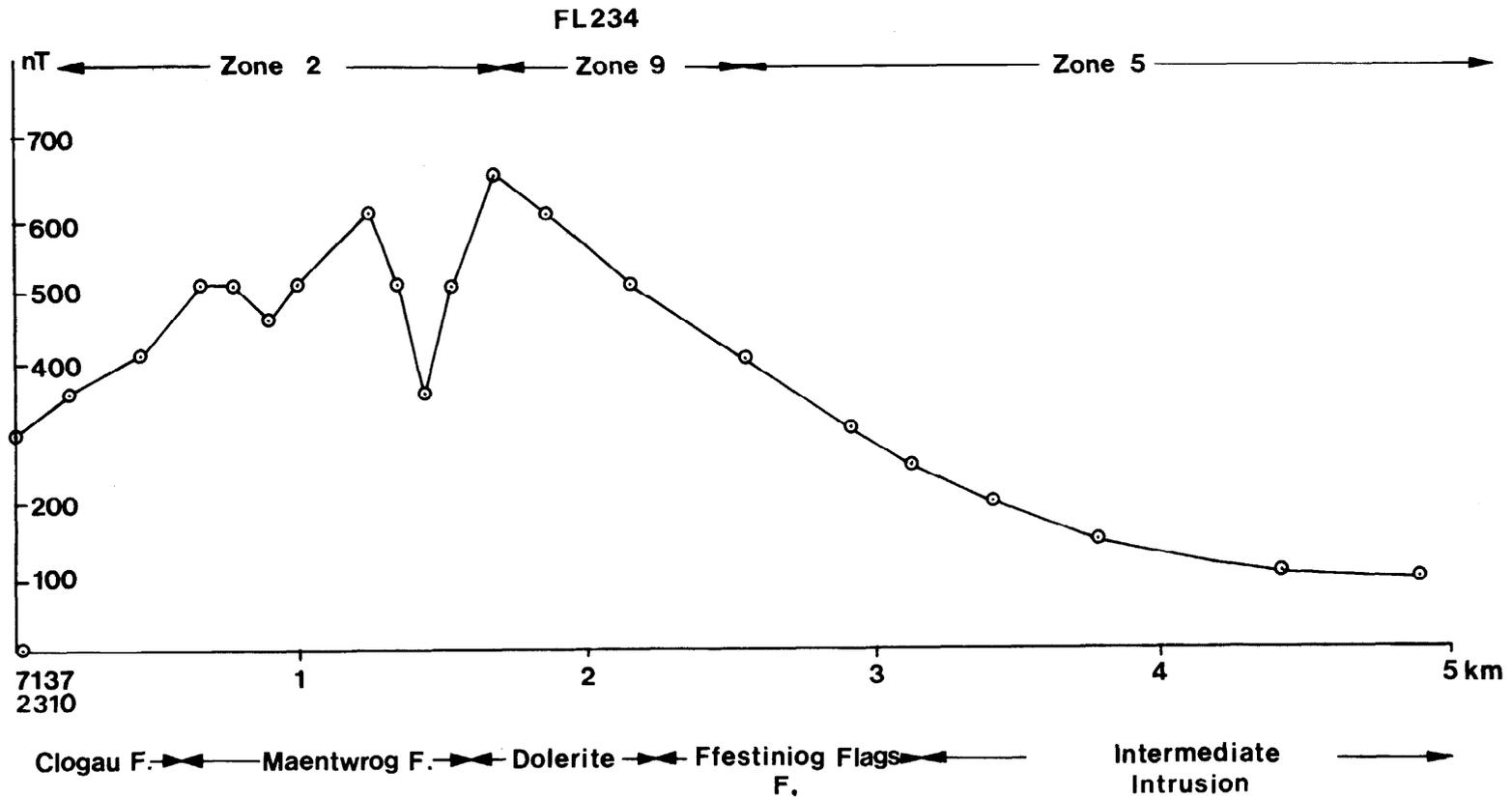
Fig.10. Magnetic Anomalies in Zones 2,5 and 9 (shown as Profile 2 on Enclosure 7)

Gamlan Formation, but excludes the magnetic Rhinog Formation within Zone 3. In this part some of the anomalies may be due to buried Rhinog Formation. The few minor intrusions which occur do not correlate with individual anomalies. To the north the zone includes outcrop of the Maentwrog Formation to the east of Zone 10 and Ffestiniog Flags Formation to the north of Zone 10, both of which include large areas of intermediate intrusions. On the east of Zone 11, speculative occurrences of Clogau Formation under drift do not coincide with magnetic anomalies.

The most notable anomaly in the zone is at SH 7434 on Moel Oernant (c.f. Fig. 7), which has a well defined north-east trend. There is no obvious cause for the feature, which occurs over the otherwise non-magnetic Vigra Flags Member of the Maentwrog Formation.

Zone 5

This extensive zone is magnetically inactive. The contours show a gradual decrease of values to the east, which is interpreted as representing the effect of magnetic rocks of the Harlech Dome dipping away eastwards at depth. The marked contrast is illustrated in profile 2 (Fig. 10). Most of the zone is over the outcrop of the Ffestiniog Flags and Cwmhesgen formations with a small part over Rhobell Volcanic Group. However, the Penrhos Member of the Maentwrog Formation also outcrops without causing an anomaly. This is different from its behaviour in Zone 2, where it is associated with strong anomalies. This may indicate that the mudstones themselves are not the magnetic rock but act as host rock to the magnetic material.

An anomaly at SH 7834 is due to the dolerite intrusion at Foel Boeth reported in Part 2. A single, rather unusual anomaly with a north-west trend is seen at SH 7623: this particular trend is not found elsewhere in the dome. Its possible significance is discussed in the report on the Llanfachreth area in Part 2. A weak anomaly at Cors-y-garnedd (SH 7723) is due to a dolerite intrusion and is not reported here.

Zone 6

This is a zone of irregular, intense magnetic anomalies adjoining the quiet Zones 5 and 7 in the south-eastern corner. There are 2 main anomalies shown in Fig. 11, which have a north-east trend parallel with the strike of the Cwmhesgen Formation and dolerite sills. It is unlikely that the mudstones of the Cwmhesgen Formation contain magnetic material and the anomalies are probably due to the intrusions of dolerite. Reports on the ground follow up of parts of this zone are given in Part 2 under Gorwyr, Ty Glas and Pont-y-Sel.

Zone 7

Zone 7 is an area of irregular, weak, generally elongated anomalies with trends parallel to the volcanic rocks of Rhobell Fawr. This is not apparent on Enclosure 7 since the amplitudes of the anomalies are too low to appear, but are seen on the large scale maps. The absence of strong magnetic anomalies over this extensive area of intermediate and basic volcanic rock is possibly explained by the destruction of primary magnetite during low grade metamorphism. The anomalies followed up on the ground are described in the report on the Nannau area in Part 2.

Zone 8

Zone 8 is a narrow belt of anomalies with an overall trend parallel with the local north-northwest strike and co-incident with part of the Penrhos Shales Member of the Maentwrog Formation. There is an abrupt termination to the south where the Maentwrog Formation is much faulted and abuts against a series of intermediate minor intrusions. Profile 5 in Fig. 12 shows the negative asymmetric shape of the anomaly. Qualitative interpretation of the anomaly suggests the possibility of an easterly dipping, reversely magnetised body.

Zone 9

This north-south zone contains the strongest magnetic anomalies in the surveyed area, with the field decreasing smoothly to the east into Zone 5. To the west the strength also decreases although near-surface anomalies with short wavelength tend to disguise this. Zone 9 is clearly defined by the marked peak on Figs. 7 and 8, taken from the 1960 aeromagnetic survey, and on Fig. 10. The smooth eastern flank appears to correlate with the eastern edge of the Maentwrog Formation outcrop and covers a series of apparently non-magnetic dolerites and intermediate rocks as well as the Ffestiniog Flags Formation.

It is probable that the origin of these near-surface anomalies is the same as in Zone 2, even though the anomaly pattern is more complex in the latter. This is probably because the direction of dip and strike are different in the two zones, resulting in different outcrop width and orientation of the magnetic bodies to the magnetising vector. In addition there are fewer minor intrusions in Zone 9. There are EM anomalies associated with the outcrop of the Clogau Formation in this zone, but this is less marked than in Zone 2.

Zone 10

This irregularly shaped zone contains many small anomalies the appearance of which are modified by the closer spacing of the flight lines (100 m). They occur over the same horizons as Zone 2 (Clogau and Maentwrog Formations) and the shape of the zone conforms to the sinusoidal outcrop pattern of these folded horizons. The southern margin of the anomalous zone is sharply defined at the top of the Gamlan Formation in the core of an anticline. Many of the anomalies are negative in sign, as in Zone 8.
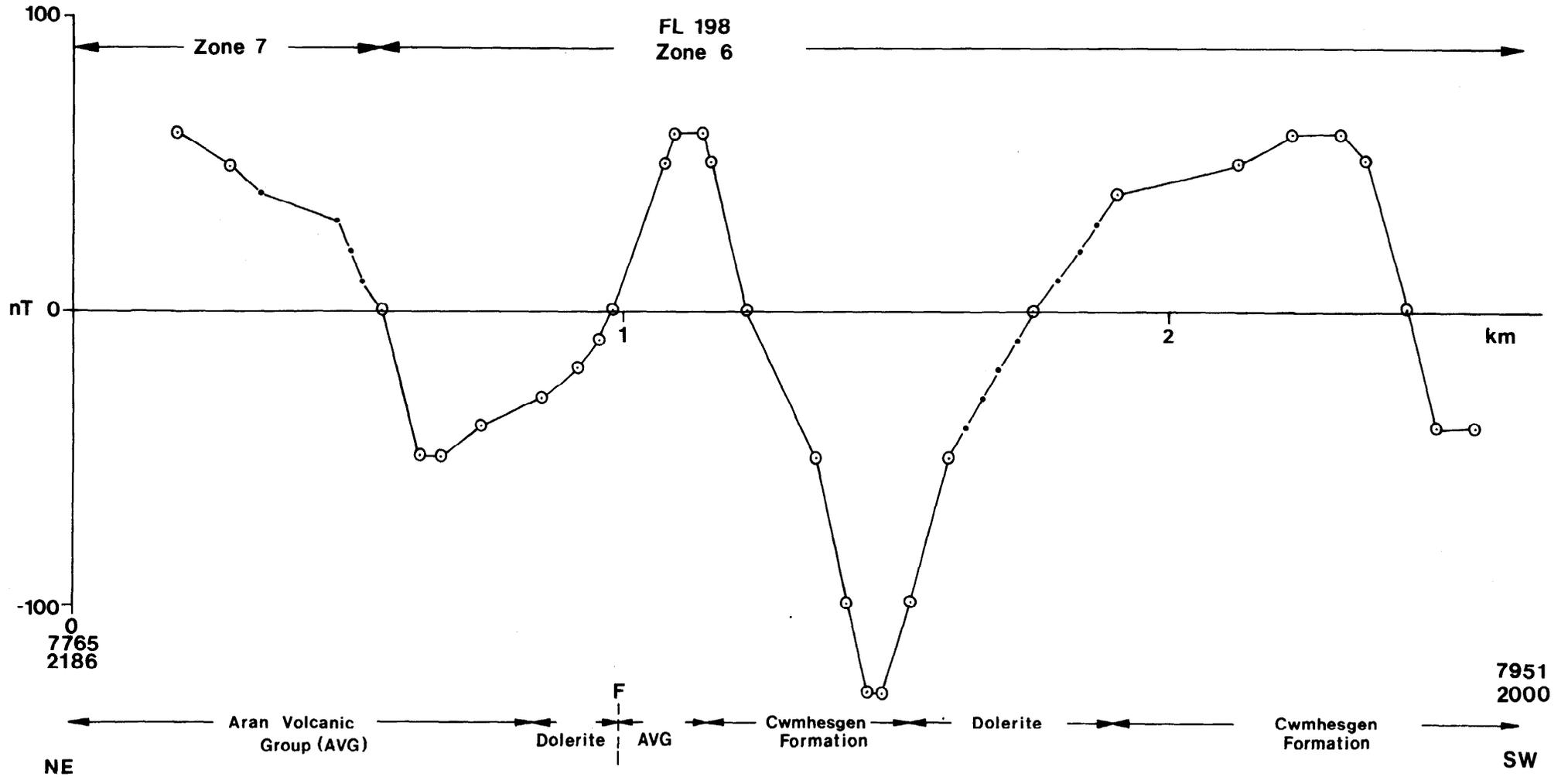
Fig. 11. Magnetic Anomalies in Zones 6 and 7 (see Profile 3 on Enclosure 7)
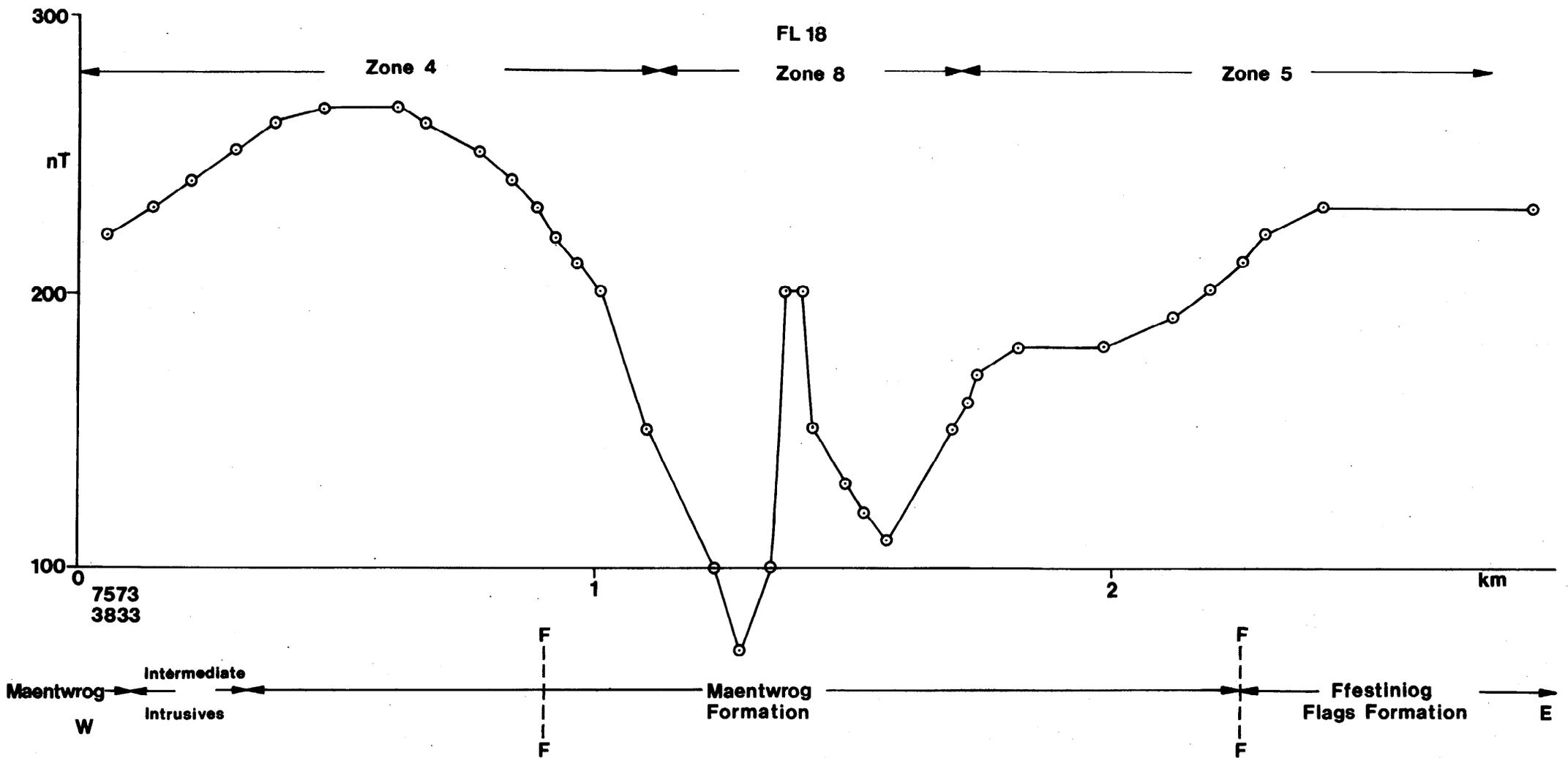
Fig. 12. Magnetic Anomalies in Zones 4, 5 and 8 (shown as Profile 4 on Enclosure 7)

W   FL 64   Profile 5   E

nT

100

0

6927
3368

7168
3371

0   1 km

nT

100

W   FL 106   Profile 6   E

0

6785
2946

7161
2945

0   1 km
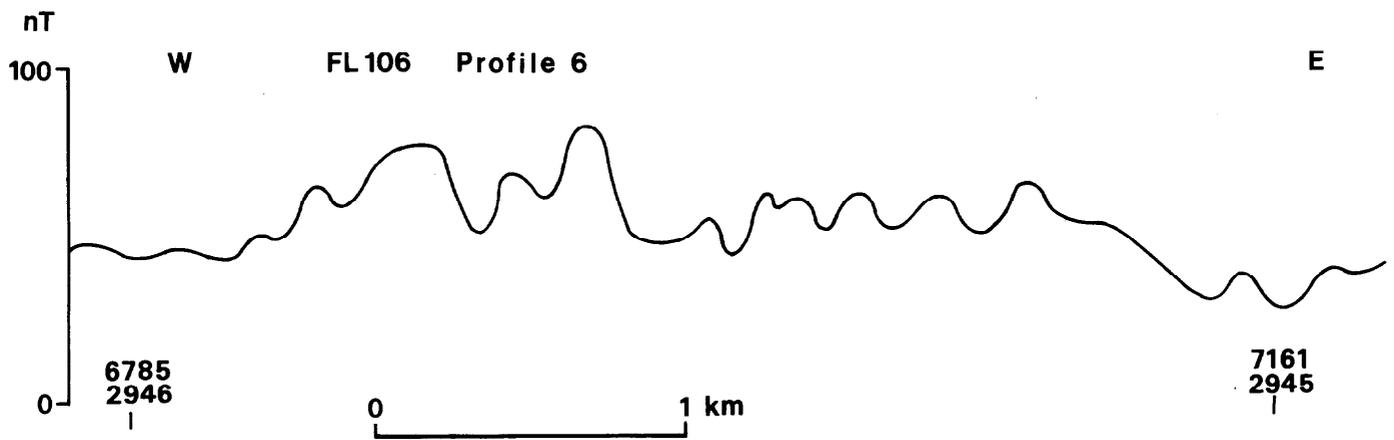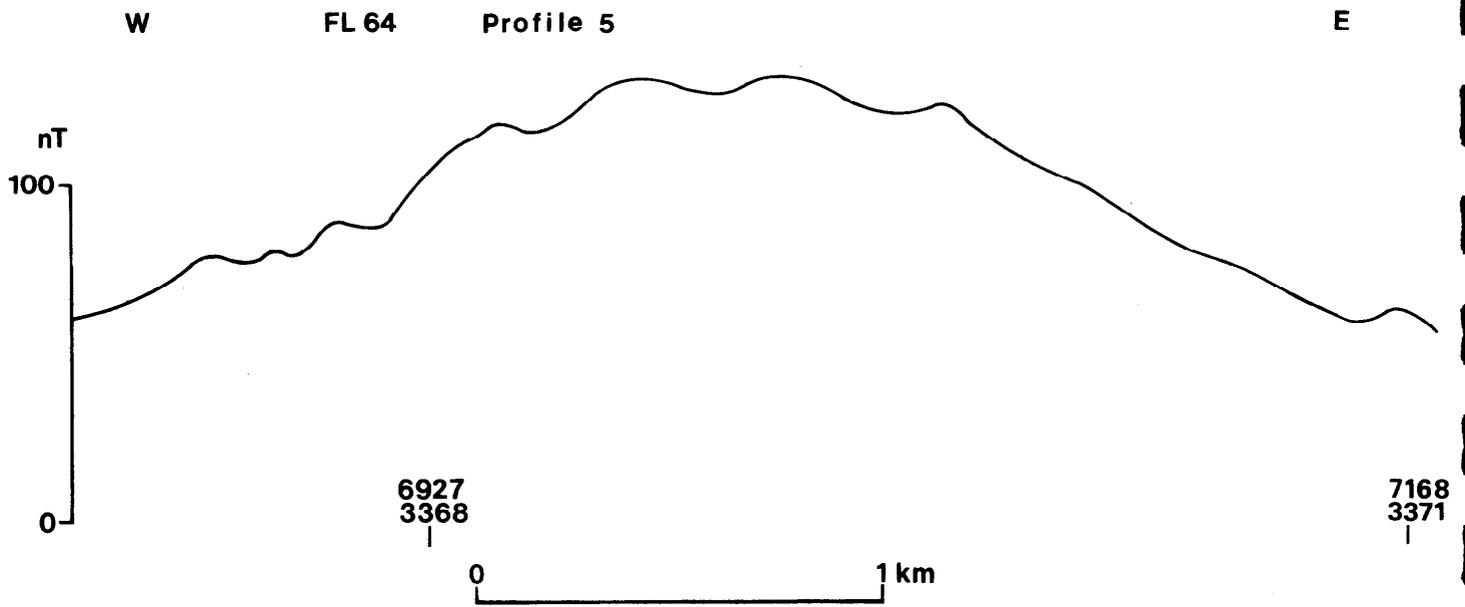
Fig 13.   Profiles 5 and 6 (Enclosure 7) across Zone 11 showing distinct total field magnetic anomaly types in the north and south.

Zone 11

This oval zone corresponds closely with the Dolwen Formation at the centre of the Dolwen Pericline. In general the anomalies in the south are sharper, with higher frequency than those in the north of the zone (see Fig. 13 where two east-west profiles are shown). This could result from either the source rock being progressively more deeply buried to the north or, as appears more likely, two separate sources - a shallow origin for the southern anomalies and a deeper one in the north. Geophysical studies on the Bryn-teg Borehole (Smith, in Allen and Jackson, 1978), drilled on the crest of the pericline, showed that the probable causes of the high frequency anomalies are several thin, strongly magnetic horizons containing magnetite within the Dolwen Formation. At a depth of 282 m the borehole entered a volcanic succession which also contains magnetic minerals, but in addition it was necessary to postulate a magnetic core to the pericline at a depth of 1 km to explain the broader anomalies similar to those on FL64 (Fig. 13). The high level aeromagnetic survey of 1960 shows a broad high correlating with that of the present survey, but the shallow features are not represented, which is consistent with the interpretation made by Smith (in Allen and Jackson, 1978).

Conclusions

Magnetic anomalies appear to have three main causes: a) detrital magnetite contained in the Harlech Grits Group, in particular in the Dolwen and Rhinog formations; b) the Clogau and Maentwrog formations, apparently where they also show EM anomalies; c) dolerite intrusions in the south-east of the survey area.

Within the Clogau Formation there appears to be a correlation between the conductive and magnetic characteristics, notably in the south of the survey area, corresponding to the Dolgellau Gold-belt, and in the north. In both areas there are many minor intrusions and widespread mineralisation. This suggests a possible correlation between the conductive and magnetic properties, the minor intrusions and the mineralisation.

AERORADIOMETRIC SURVEY

Introduction

The radiometry of the Harlech Dome has previously been briefly examined by Ponsford (1955) and Ball (pers. comm.) who found weak syngenetic uranium concentrations in the black shales of the Dolgellau Member. However, because the Harlech Dome is a difficult area to cover by ground survey it was decided to include gamma spectrometry in the airborne survey, both to search for uraniferous concentrations and to assist in the interpretation of other airborne data.

Radiometric data were collected using a four channel gamma spectrometer, and two six inch diameter, 4 inch thick thallium activated sodium iodide crystal detectors (combined crystal volume 226 cubic inches). The spectrometer and recorder channel settings employed are shown in Table 2 (Burley and others, 1978).

Table 2. Airborne gamma spectrometry, instrument settings

Channel		Energy band (MeV)	Recorder range (counts/s)
1	Total count	1.00-2.90	0-6,000
2	Potassium	1.31-1.61	0-100
3	Uranium	1.61-2.20	0-60
4	Thorium	2.20-2.90	0-30

Results

Examination of the traces from all four spectrometer channels showed that no distinct peaks were present and that all variation was of limited magnitude and on a broad scale. The total variation recorded in the total count channel was about 1,000 counts/s. compared with a full scale deflection on the chart recorder of 6,000 counts/s. This compressed the trace into a small section of the chart which hampered contouring of the results. Another interpretation problem was caused by a discrepancy between readings made in the autumn of 1972 and the following spring. This was the result of changes (including drift) in the instrumentation, detectors and survey procedures between the two periods. Consequently, the autumn results, which covered a relatively small part of the area in the north, had to be multiplied by a constant (1.5) to bring them into line with the spring results. This, together with the small width of trace, introduced considerable errors into the results, and therefore only a roughly contoured, total-count map uncorrected for height variation, was produced from the data (Enclosure 5).

Ground control took the form of an examination of conveniently exposed sections of the various lithologies found in the area with an AERE 1597A ratemeter. The results of this work, which are not comprehensive, are shown in Table 3. It was concluded from the ground control work, and a comparison of the aeroradiometric map with geological and topographical maps, that all the radiometric variation recorded could be related to one or more of the following factors:

(a) Lithological variation. High readings at outcrop (> 25 μR/h) are recorded on rocks of the Dolgellau Member. An aeroradiometric high attributable to the Dolgellau Member is seen at Cwmhesgen (SH 785 295), where the highest airborne counts were recorded, and the peak is probably enhanced by solid angle effects. Other elongate areas of high values in the east of the area, such as around SH 795 245, SH 786 226 and SH 780 217 follow outcrops of the same rocks.

Aeroradiometric peaks also coincide with outcrops of the Clogau Formation and the lower part of the Maentwrog Formation. These are probably the product of the natural radioactivity in the formations and some other enhancing factor, such as prominent exposure (e.g. SH 625 161). The lack of high values on the airborne map associated with the Llanbedr Formation is attributed to its poor exposure.

Low values are recorded over dolerites and the Rhobell Volcanic Group. For example, a large aeroradiometric low centred on SH 780 270 is central to elongate highs produced by the Dolgellau Member and roughly follows the northern part of the Rhobell Volcanic Group. The low values are enhanced by extensive peat cover.

In general, the Harlech Grits Group, with the exception of the Llanbedr Formation, gives lower radiometric values than the overlying Mawddach Group because of the dominance of argillaceous rocks in the latter. However, the range of radiometric values is similar throughout the Cambrian (Table 3) because formations consisting mainly of grits also contain some silty beds, on which higher readings are recorded. This, coupled with the radiometric values of intrusive rocks falling in the same range as the grit-shale alternations, partly accounts for the subdued aeroradiometric pattern. The association of radiometric features related to broad alternations of sandstone and mudstone is seen north of Barmouth where 'ridges' of high aeroradiometric values coincide with the outcrop of the Hafotty and Gamlan formations, whilst intervening lows are located over outcrops of the dominantly arenaceous Rhinog and Barmouth formations.

The coincidence of high aeroradiometric values with dark shale is useful in helping to identify airborne EM anomalies generated by stratigraphic conductors in the Dolgellau Member and Clogau Formation. Several examples of combined EM and aeroradiometric highs over the Dolgellau Member are found in the east of the area, such as around SH 780 217 and SH 790 310, and over the Clogau Formation at SH 648 211 and around SH 720 345.

(b) Solid angle effects. These effects are seen most strongly in scree-lined valleys and close to escarpments. Examples include high values on the south east slopes of Diffwys, around SH 650 228, high values following the Prysor valley around SH 768 372 and high values over the Wnion valley east-north-east of Dolgellau. In the latter case the effect is accentuated and complicated by outcrops of the Dolgellau Member.

(c) Height Variations. Aeroradiometric variations caused by height changes have been difficult to pinpoint, probably because either they coincide with other effects such as solid angle and vegetation or they are relatively small with respect to the contour interval.

(d) Drift and Vegetation Cover. Wooded areas can reduce aeroradiometric levels and this is probably the cause of the low values recorded over the Clogau Formation north of Barmouth. Peat cover is widespread and its dampening effect is one of the main reasons for the relatively featureless aeroradiometric results and the relatively poor correlation of geology and aeroradiometry

over much of the area. For example, areas of low readings centred on SH 775 316 and SH 795 360 over the Ffestiniog Flags Formation are believed to be largely the result of peat cover, and the lack of high values over the Llanbedr Formation in the centre of the Dome is attributed to the same effect. Estuarine sands in the Mawddach estuary also produce aeroradiometric lows.

(e) Lakes. These produce low features on the aeroradiometric map, for example Llyn Trawsfynydd (SH 700 360) and Llyn-y-garn (SH 762 377).

(f) 'Noise' and calibration effects. There is an apparent concentration of high aeroradiometric values in the north of the surveyed area, to the east of Trawsfynydd, which may be related to difficulties in matching spring and autumn results.

Radiometry of the Coed-y-Brenin copper deposit

It has been shown in some areas that radiometry can be used to detect porphyry-style copper deposits (Davis and Guilbert, 1973). An increase in total radioactivity may be found over these deposits, related to the potassic alteration zone. No such increase was visible on the airborne results over the Coed-y-Brenin deposit, confirming the findings of Rice and Sharp (1976) who did not identify a zone of potassic alteration in this deposit. Though ground control, carried out using an AERE γ-spectrometer, suggested slight increases (2-3μ R/h) in radioactivity over altered lithologies associated with the mineralisation, the individual channel data indicated that uranium series elements, possibly retained on clays, were as responsible for the increase in total radiation as any potash increase. Because the variations in radioactivity are less than the normal range of variation recorded in the host rocks they are of little practical use in identifying this deposit.

Conclusions

1. The aeroradiometric results in conjunction with ground control work support the conclusion of earlier surveys that the only rocks in the Harlech Dome to show appreciable uranium enrichment are dark mudstones of the Dolgellau Member. The Llanbedr Formation, Clogau Formation and lower part of the Maentwrog Formation yield the next highest radiometric values but these levels are normal for argillaceous rocks.

2. The relatively high radiometric values associated with dark mudstones in the Dolgellau Member and Clogau Formation are useful in helping to identify airborne EM anomalies likely to be caused by stratigraphic conductors.

3. No significant increase in radiometric values was associated with alteration accompanying the Coed-y-Brenin porphyry-style copper deposit.

4. In addition to the lack of uraniferous rocks and the similar range of radiometric values recorded in many formations, the relatively featureless results of the aeroradiometric survey can be attributed to the dampening effect of widespread peat cover and limitations in the data.

Table 3. Radiometric readings on outcrop in the Harlech Dome

GEOLOGICAL DIVISION	NORMAL RANGE TOTAL γ, $\mu R/h$	COMMENTS
Intrusives		
Dolerites	3-6	Altered dolerites reach 8 $\mu R/h$
Intermediate rocks	5-11	Highest values on small stringers and dykes
Acid rocks	10-17	Only rocks in the Arenig area were measured
Sedimentary and Extrusive Rocks		
Rhobell Volcanic Group	3-5	
Dol-cyn-afon Member	12-15	Only measured at one locality
Dolgellau Member	12-50	
Ffestiniog Flags Formation	11-19	
Upper Maentwrog Formation	11-18	
Lower Maentwrog Formation	12-20	23 $\mu R/h$ recorded at one locality
Clogau Formation	12-22	
Gamlan Formation	10-18	
Barmouth Formation	7-12	16 $\mu R/h$ recorded on silty horizon at one locality
Hafotty Formation	8-15	Manganese-bearing shales 12 $\mu R/h$
Rhinog Formation	7-14	
Llanbedr Formation	12-20	Higher values (25 $\mu R/h$) recorded in slate quarry at Llanbedr but enhanced by solid angle effects
Dolwen Formation	7-15	20 $\mu R/h$ recorded on a silty horizon at one locality

INVESTIGATIONS INTO THE CAUSES OF ELECTROMAGNETIC ANOMALIES IN CAMBRIAN SEDIMENTARY ROCKS FROM THE HARLECH DOME

Introduction

Strong EM anomalies were recorded in the airborne survey over the Dolgellau Member of the Cwmhesgen Formation, the Clogau Formation, parts of the Maentwrog Formation and over black mudstone horizons in the Ordovician volcanic succession. In order to assess the significance of these anomalies and establish whether or not they are indicative of sulphide mineralisation field investigations were supplemented by detailed laboratory studies on a number of rock samples.

Initially twenty two samples were collected from the vicinity of either strongly defined airborne EM anomalies or ground-verified anomalies. Attempts to relate the bulk mineralogical composition and geochemistry to their propensity to give EM anomalies were inconclusive, though there was a suggestion that the carbon content in the Dolgellau Member was of more significance than the sulphide content, whereas in the Clogau Formation the ore minerals were possibly more important.

It was considered that the sampling method was inadequate to identify the causative rock type and that a more stringent method of selection should be applied. Thus, in the second phase of the investigation a further nine samples were collected; three on the same basis as the first

batch, but six located more precisely in the field using EM slingram equipment. Reports on the work carried out on these samples are contained in Mineralogy Unit Report No. 210 and Engineering Geology Unit Report No. 83.

One of the carefully located samples was from the Maentwrog Formation and is discussed in the Hafod-y-fedw report (p. 113). The other five are the subject of the present report; two were from the Dolgellau Member and three from the Clogau Formation. Because of poor outcrop in the vicinity of proved EM anomalies over the Ordovician succession and most parts of the Maentwrog Formation neither of these could be considered for detailed investigations.

Method of selection of samples for determinations of physical properties

a) Dolgellau Member

A complete section through the Dolgellau Member is known at Ogof Ddu near Criccieth, where the stratigraphy is identical to that in the Harlech Dome and where exact identification of the conducting horizons was possible. An EM traverse was measured along the top of the cliffs to locate the position of the anomaly. The rough position of the conductive horizon was then identified in the cliff section. Two bands were identified as highly conductive using a Geonics EM15 'metal detector' and samples LA421 and 422 were taken from them (locations SH 5147 3790, SH 5145 3790 respectively).

b) Clogau Formation

At Blaen-y-cwm a single traverse line was measured using EM and magnetic equipment across the full width of the exposure of the Clogau Formation in an area where exposure allowed reasonably representative sampling. When the EM anomaly was located the metal detector and susceptibility meter were used to locate one highly conductive sample (LA 423), one poorly conductive but strongly magnetic sample (LA 424) with one non-magnetic, non-conductive sample (LA 425) to be used as a control. (Sample locations are SH 7127 2211, SH 7123 2214 and SH 7122 2219 respectively).

Petrographic notes

Both the Dolgellau Member samples are black, banded, fine-grained mudstone with little or no development of any cleavage. The organic carbon is finely disseminated, having a general mesh-like distribution around clastic grains. In LA 422 the banding is more pronounced than LA 421 and the organic material is more plentiful in the finer-grained bands. Framboidal pyrite occurs disseminated through the rock, but there are concentrations of irregular, pitted pyrite crystals containing inclusions of chalcopyrite and spha-lerite, and small cubic crystals in bands parallel to the bedding.

The three samples of mudstone from the Clogau Formation consist of light and dark bands; the former containing more quartz, the latter being finer-grained and containing most of the carbonaceous material. All three rocks show a weak cleavage at a high angle to the bedding. The carbonaceous material tends to occur in stringers and in LA 423 and 425 some of it is re-oriented parallel to the cleavage. There are sulphides in all three rocks. Framboidal pyrite is rare. In LA 423, the good conductor, corroded and altered chalcopyrite, pyrite and minor sphalerite are concentrated into certain sedimentary bands, while sphalerite in association with quartz and feldspar occurs in concentrations along the cleavage. In hand specimen pyrite was also observed in the cleavage. The magnetic sample, LA 424, contains abundant pyrrhotite, rare chalcopyrite, sphalerite and ? pyrite in large patches and disseminations. In the third, non-magnetic, non-conducting, sample sulphides are rare and limited to small amounts of sphalerite and pyrite in fractures parallel to the cleavage.

Laboratory investigations

a) Resistivity. Precise measurements of resistivity were made on four of the samples, first saturated in calcium chloride solution and then dry to test for grain resistivity (Table 4). Approximate resistivity was also measured with dry probe terminals on a resistance meter on dry rocks.

b) Organic carbon content. The organic carbon content and the degree of crystallinity were measured by evolved gas analysis (Table 4). The temperature at which maximum CO_2 evolution took place varied considerably. High temperature peaks indicate a relatively high proportion of elemental carbon, whereas low temperature peaks suggest higher levels of hydroxyl and oxygen-containing groups.

c) Physical properties. The saturated, dry and grain densities, effective porosity and void ratio were all measured. In addition the magnetic susceptibility was measured on the three samples from the Clogau Formation. Selected results are shown in Table 4.

Discussion

It can be seen from Table 4 that the measured physical properties of the samples from the Clogau Formation (LA 423-425) are not particularly anomalous, which suggests that the anomalous components indicated during sample collection in the field either are not represented in the sample or were missed during laboratory testing. The implication of this is that the anomalous compo-nent is probably restricted in its distribution and might be easily missed during sampling with the methods that were used.

All the samples tested show low porosity and could not contain sufficient ground water to cause the low resistivities that have been measured. However, the good conductors have greater porosity in general than the other rocks, which leads to the general conclusion that though the conductivity is probably related to the mineralo-gical composition of the rocks the porous nature

Table 4. Physical properties and organic carbon content of mudstone samples

No.	% Organic C	Crystallinity	Dry Density g/cm^3	Effective Porosity %	[1]Magnetic Susceptibility c.g.s. x 10^{-6}	[2]Wet Resistivity Ω m	Dry Resistivity Ω m
LA 421	1.19	low	2.67	3.77	-	1.06	4.62x10^3
LA 422	1.40	low	2.60	5.15	-	6.25	insufficient sample
LA 423	0.26	high	2.79	0.54	168	3426.0	>3.4x10^7
LA 424	0.53	medium	2.86	0.47	278	2055.3	>2.9x10^7
LA 425	0.69	high	2.67	4.44	37	insufficient sample	insufficient sample

(2) Resistivity of CaCl$_2$ solution is 0.11628Ωm   (1) 1 SI unit of susceptibility = 4 c.g.s. units

is a contributory factor to the total behaviour as a conductor.

The various tests of resistivity appear to show some contradictions in any one specimen; tests with the resistance meter agreed fairly well with the wet resistivity, probably because both techniques avoid measurement of the resistance of dry fractures, the first because the fractures would be filled with electrolyte, and the second because probing with the terminals allows the selection of low resistance paths for measurement. The dry measurements of resistance, however, are much higher than the wet resistivity indicating that porosity is an important factor, but the electrode contact resistance involved might be very large and give much higher values of resistivity.

The results of the tests on the Dolgellau Member samples indicate the cause of the conductivity fairly clearly, and hence the cause of the EM anomaly. A relatively high value of porosity and low value of wet resistivity are found but the dry resistivity is only moderate. This indicates a lower grain resistivity than non-anomalous samples. The blackness of the rocks results from the high proportion of organic carbon, which shows low crystallinity and forms a widely distributed meshwork. This is presumably more or less disrupted by cleavage and other fractures; it is these breaks in the current flow path which are linked by ground water contained in the fractures.

In the Clogau Formation the explanation is not so clearly provided possibly because of the sampling difficulties mentioned above. Mineralogical investigations on samples collected during the first part of the investigation demonstrate the presence of bands of sulphide minerals which were not observed in the ones used here. The resistivity along these bands, as measured by a resistance meter, was quite low, but much higher values were obtained normal to them. In all samples the porosity is low and wet resistivity is high; the dry resistivity was even higher indicating that even the low porosity in these samples does affect the resistivity, although contact resistance might be considerable. Mineralogical studies indicated that carbon is not distributed as

a mesh but in stringers and is moderately to highly crystalline. This reduces the possibility of grain to grain contact which is necessary for low resistance. It is suggested, therefore, that in the Clogau Formation, it is the sulphide minerals, which are widely abundant and distributed in such a way as to allow free current flow that cause the high conductivity and the EM anomalies. Under ideal conditions the sulphide-rich bands are linked across the bedding and to carbon-rich bands by cleavage planes containing conducting minerals.

Conclusions

1. Porosity, permitting saturation of rocks with ground water, while enhancing the conductivity of the rocks is not sufficient to be the cause of the electro-magnetic response.

2. In the Dolgellau Member the EM anomalies are almost certainly a reflection of the abundance and form of organic carbon in the rocks and are not related to sulphides in the area examined. No more than 1.40% organic carbon was found in the samples tested, though as much as 6% organic matter by weight was determined by thermo-gravity elsewhere in the area.

3. Within the Clogau Formation the picture is less clear, but it is considered that the ideal conducting medium is a rock containing bands rich in sulphides cross-cut by fractures filled with sulphides, thereby creating a mesh of conductive minerals. The carbonaceous bands would add a little to the overall conductivity.

4. These explanations fit the observations in the field that the conductive horizon in the Dolgellau Member is continuous along strike whereas in the Clogau Formation EM anomalies, which appear to depend on the distribution of cleavage and the presence of redeposited sulphides in it, are discontinuous.

5. No analyses for sulphur were carried out on the five samples reported here. However, in the original twenty two samples only three contain more than 3% sulphur. Fifteen contain less than 0.9% and among the Clogau samples none contained more than 1.32% which is equivalent to about 2.5% pyrite. It appears, therefore, that, depending on

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the distribution of the minerals, rocks with comparatively low sulphide contents can be conductive.

6. The implications of these findings for mineral exploration are a) that the fairly uniform, linear EM anomaly over the Dolgellau Member reflects the carbon content and is unlikely to conceal any concentrations of stratabound sulphides, and b) that in most places the EM anomaly over the Clogau Formation can be explained by low concentrations of non-economic sulphides.

CURIE TEMPERATURE DETERMINATIONS

Introduction

Samples of magnetic rock were collected in the Harlech Dome to enable their magnetic suscepti- bility to be measured and to identify the magnetic minerals using petrographic techniques. It was considered worthwhile to use Curie temperature determinations as an independent identification of the magnetic minerals and for comparison with the petrographic results. Specimens LA 423-425 are from the Clogau Formation, the first two being magnetic and the last being a non-magnetic control. Specimen LA 426 is a shale from the Maentwrog Formation with a fair magnetic susceptibility. A magnetic sandstone from the Rhinog Formation (LA 429) was selected as a representative of the rock containing detrital magnetite which caused magnetic anomalies over that formation.

Method

The temperature at which the ferro-magnetism of a mineral disappears (the Curie temperature) is diagnostic of that mineral. It is therefore possible to identify the magnetic components in a rock specimen by heating up a sample and moni- toring its magnetic moment as a function of temperature. This is done using a magnetic balance both as the sample is heated (CT1 in Table 5) and as it cools (CT2 in Table 5), so as to identify differences due to alteration of minerals during heating. The values of magnetic moment measured prior to heating give an indication of the

reliability of the result: the higher the magnetic moment, the greater the sensitivity of the Curie point determination.

Results

Values of Curie temperature around 320° C (Table 5) indicate the presence of pyrrhotite, around 580° C magnetite and up to 680° C hematite. The second Curie temperature (CT2) indicates alteration of the primary magnetic mineral, probably as a result of heating during the experi- ment.

Two specimens of Clogau Formation (LA 423 and 424) which have reasonably high values of susceptibility have very similar heating curves, characterised by a rapid decrease in magnetic moment until about 330° C, followed by a second decrease at about 550° C. The cooling curves show no steep gradient. This suggests that pyrrhotite is the dominant magnetic mineral present with smaller amounts of magnetite.

In the third specimen from the Clogau Formation (LA 425) there is a gradual decrease of magnetic moment until about 615° C, followed by a 'tail-off' suggesting a magnetic component of higher Curie temperature, which is probably hematite. The Maentwrog Formation samples LA 426 showed an increase in magnetic moment to reach a maximum at 480° C of 0.09 emu/gm. This behaviour, which did not reverse during the cooling, indicates high temperature oxidation of an homogenous titano- magnetite to form a more magnetic component which is destroyed at higher temperature.

The sample of sandstone (LA 429) has a single well-defined Curie temperature of 575° C indicat- ing pure magnetite.

Conclusions

The Curie temperature determinations made on the three samples from the Clogau Formation confirm the petrographic findings that magnetisa- tion is caused by pyrrhotite. The magnetic component in the Rhinog Formation sample, however, is magnetite. The sample from the Maentwrog Formation contains pyrrhotite in vein- lets and disseminated which was not recorded by the Curie temperature determinations.

Table 5. Curie temperature and magnetic measurements on five samples of sedimentary rock

Specimen No.	Rock type	Curie temperature °C CT1	CT2	Magnetic moment emu/gm	Susceptibility cgs x 10⁻⁶
LA 423	shale	340	580	0.09	168
LA 424	shale	330	585	0.18	278
LA 425	shale	? 615		0.04	37
LA 426	shale	550	635	0.05	142
LA 429	sandstone	575		1.0	1578

SPECIAL INVESTIGATIONS

GEOCHEMISTRY AND RELATIONSHIPS TO MINERALISATION OF SOME IGNEOUS ROCKS FROM THE HARLECH DOME

Introduction

Early in the Mineral Reconnaissance Programme it was decided to collaborate with the Department of Geology, University College of Wales, Aberystwyth, who were undertaking a long-term study of the igneous geology of the Harlech Dome, on an investigation of certain aspects of the metallogenic history of the area. The results have already been published (Allen and others, 1976). A brief summary of the paper, concentrating on the conclusions reached, is given below.

Summary

80 igneous rock samples from the Harlech Dome were analysed for major and trace elements (Cu, Pb, Zn, As, Mo, Ba, Zr). The petrography and field relations of the rocks were described and their geochemistry was discussed. The rocks were divided on a field and petrographic basis into: 27 intermediate and 8 basic intrusions in the Cambrian; 20 samples of drill core from the Coed-y-Brenin porphyry copper deposit; 8 lavas and leucocratic basic intrusions of Ordovician age; 10 dolerites intruding Ordovician volcanics, and 7 Ordovician tuffs. Statistical techniques were used to look for significant element associations and differences between rock groups. The following conclusions were reached:

1. Intrusions in the Cambrian sediments differ sufficiently both chemically and petrographically from those in the Ordovician to support the circumstantial field evidence which indicates that there was a pre-Arenig period of basic and intermediate intrusion, probably associated with the Rhobell Fawr volcanism, and a later, probably Ordovician, period of basic intrusion.

2. The chemistry of the unmineralised intermediate intrusions bears a strong similarity to that of diorites associated with porphyry copper deposits in the Caribbean and thought to be typical of an island-arc environment. The Coed-y-Brenin deposit shows characteristics of both the 'diorite' and the 'Lowell and Guilbert' type of deposit; this indicates the difficulty of rigidly classifying mineral deposits.

3. The Coed-y-Brenin intrusive rocks are richer in K_2O, Cu and Mo, and poorer in Na_2O, CaO, MnO and Zn than the unmineralised Cambrian intrusive rocks. These differences probably reflect the mineralisation and hydrothermal alteration which has affected the Coed-y-Brenin rocks; it does not necessarily follow that the two suites are of different magmatic origin. A few unmineralised Cambrian intrusives, which contain high K_2O, may have been affected by the same hydrothermal alteration. The fact that none

of the Ordovician intrusives is similarly affected probably indicates a pre-Ordovician age for the hydrothermal event.

4. Soda metasomatism has affected both Cambrian and Ordovician igneous rocks, implying that it is post-Ordovician in age and was superimposed on the local hydrothermal potassium metasomatism and, by implication, the Cu mineralisation.

5. It is postulated as a working hypothesis that the disseminated copper mineralisation, accompanied by potash metasomatism, locally affected the intermediate intrusions soon after their emplacement in an island-arc environment at the close of Cambrian times. Further igneous activity occurred in the Ordovician, after which there was a period of soda metasomatism. Vein mineralisation also post-dated the Ordovician intrusions, and may even have involved the remobilisation of earlier deposits during the Caledonian orogeny. It is the later events that are probably recorded by the available age-dating results.

6. If this hypothesis is correct, any further exploration for disseminated copper deposits in the Harlech Dome region should be confined to pre-Ordovician rocks. By the use of statistical techniques it should be possible to use the geochemistry of intermediate intrusive rocks as a method of prospecting for porphyry copper mineralisation.

INTRUSION-BRECCIAS IN THE HARLECH DOME

Introduction

During the course of the routine 6-inch mapping of the eastern side of the Harlech Dome a number of previously unrecorded breccia pipes, dykes and sills were located. In the light of these discoveries the Glasdir copper mine was re-examined and it was found that the deposit could be interpreted as a mineralised breccia pipe. The five other known breccia pipes were then re-visited and examined for signs of copper. In this section only the pipes are considered.

A description of the Glasdir mine and a discussion of the mode of origin of the breccia, the age of the mineralisation and the significance of these new data on the interpretation of the metallogenic history of the Harlech Dome are contained in a paper by Allen and Easterbrook (1978). This section contains a shortened version of the account of Glasdir and brief descriptions of some other intrusion-breccias.

Geological setting

All the intrusion-breccias recorded so far lie within a NNE-trending zone 16 km long and up to 3 km wide (Fig. 14), which is radial to the reconstruction of the late-Tremadoc Rhobell Fawr volcano proposed by Wells (1925). They intrude either the Maentwrog or Ffestiniog Flags formations or intrusive rocks which are co-magmatic with the Rhobell volcanic episode (Wells, 1925; Allen and others, 1976). All the pipes and

Legend:

Cambrian | Ordovician

- Aran Volcanic Group
- Rhobell Volcanic Group
- Mawddach Group
- Harlech Grits Group
- Main intrusive complexes
- ✳ Breccia pipe
- △ Intrusion-breccia sill or other kind of intrusion

0   1 Km
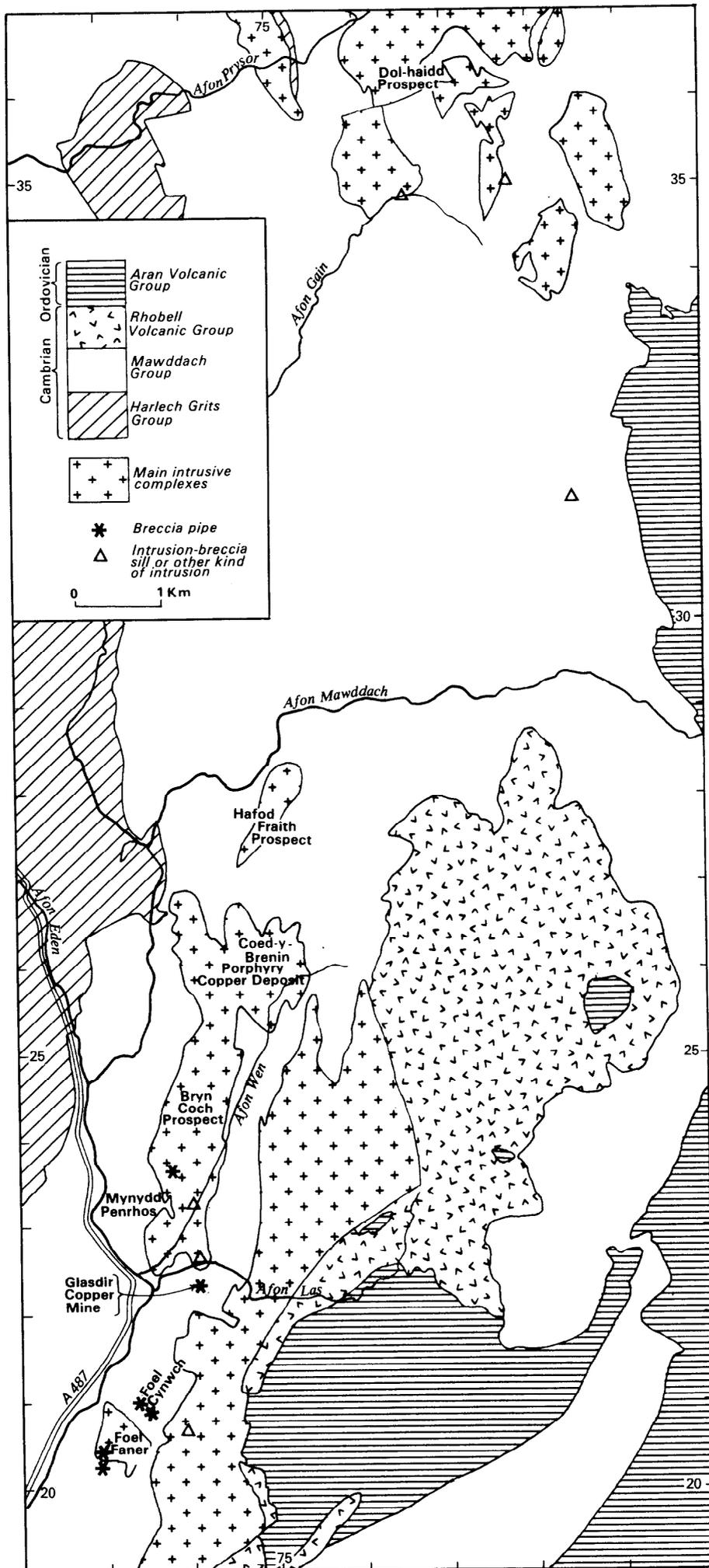
Fig.14 Sketch map of eastern Harlech Dome showing location of intrusion-breccias.

dykes and some sills lie in the southern part of the zone, which also contains the Coed-y-Brenin porphyry copper deposit and the Bryn Coch and Hafod Fraith prospects (see Part 2). There is a close spatial association between these intrusion-breccias and large intrusive complexes. At the northern end of the zone there are several intrusion-breccia sills, again in an area of abundant intrusions.

Many of the intrusion-breccias are cleaved and it is argued that they formed during the waning stages of the Rhobell volcanic episode. The mineralisation, recorded in the Glasdir pipe, is believed to have taken place shortly after intrusion of the breccia.

Glasdir

This mine (Grid ref: SH 741 223) produced over 13,000 tons of 10% Cu concentrate between 1872 and closure in 1914, 8275 oz Ag in 1913 and 1914, and 735 oz Au in 1914 (Morrison 1975). The ore was worked both opencast and by stoping from a series of levels and shafts driven to about 213 m below ground level. The workings are now flooded to the bottom of the pits, of which there are two, situated on the south-eastern side of a prominent rocky knoll. They lie on an arc about 155 m long and concave to the north-west and are separated by an 18 m wide bridge which tapers downwards. The mine was flooded soon after closure and the only information about the workings is contained on a diagram showing the condition of the mine on abandonment, which was lodged with the Mines Registry (Plan MT 6512).

Apart from the annual production figures there is little contemporaneous data available on the orebody. Phillips (1918) gives its dimensions as 155 m long by 9-15 m wide near surface, where the grade was 1.5-2.0% Cu; 109 m by 6 m at 30 m below adit, where the grade averaged 1.5% Cu, and 9 m by 1.5 m at 152 m below adit where the grade had reduced to 0.5% Cu. In contrast to these figures, Andrew (1910), who visited the mine while it was working, said that the average grade was 1% Cu at adit level rising to nearly 2% at deeper levels.

The lode, which appears to have been vertical, was described by Andrew (op. cit.) as shattered flags and shales impregnated with chalcopyrite. He commented on the unusual paucity in the lode of quartz, which was present only as small blebs distributed through the orebody.

A re-examination of the area around the mine showed that the two pits lie inside the south-eastern margin of an oval area of breccia measuring 200 m by 100 m and elongate north-eastwards. The country rock around the breccia consists of thinly interbedded light and medium grey silty mudstone, siltstone and fine sandstone of the Ffestiniog Flags Formation with some thin sills of microdiorite. The bedding dips about 20° to the east or east-south-east. The rocks are weakly cleaved and metamorphosed to low greenschist facies.

The breccia contains randomly oriented angular or sub-angular fragments only of the rock types found in the adjacent country rock. Most of them are between 30 cm and 1 cm maximum diameter, but there are some rafts of unbrecciated rock several metres wide in the area of the bridge between the pits. The matrix of the breccia usually consists of quartz and chlorite with less common muscovite and apatite but in rocks from the orebody calcite is also present.

Euhedral pyrite is present in all parts of the breccia. In the orebody pyrite, marcasite, which in one sample exceeds pyrite in proportion, arsenopyrite, chalcopyrite, covellite and sphalerite are present. The pyrite and arsenopyrite occur both disseminated through the breccia fragments and in association with the other sulphides in the matrix. They crystallised immediately following the quartz and chlorite. Chalcopyrite, which in places is rimmed by covellite, is interstitial to them. Sphalerite, which occurs as inclusions in both pyrite and chalcopyrite is probably the product of exsolution. Hematite is present as a rim to pyrite, whereas specularite occurs as small, disseminated flakes. Calcite shows signs of being a late-stage replacement mineral. The quartz, which is strained, and some fractured pyrite crystals give indications of a deformation after mineralisation.

An XRF examination of a number of samples collected from the tip and in situ from the bridge area confirmed Cu and As as the main metallic elements, excluding Fe. Zn is present in all samples in minor or trace amounts; Pb and Ag in trace amounts in over half the samples, but Mo was identified in only one. Semi-quantitative analyses of vanner concentrates from six samples gave average contents of 1 ppm Sb, 4 ppm Ag, 12 ppm Zn, 707 ppm Cu, and 750 ppm As, calculated in terms of the whole rock.

Other intrusion-breccia pipes

Foel Faner:	Two pipes close together at SH 7290 3038 and SH 7290 2028. The northern one measures 64 m by 36 m and contains minor pyrite and chalcopyrite. The southern pipe, 140 m by 145 m, contains only pyrite.
Foel Cynwch:	Two pipes at SH 7335 2098 and SH 7350 2097 are less than 100 m in diameter. Pyrite is present in both.
Mynydd Penrhos:	One pipe at SH 7376 2366 measures 150 m by 45 m. Pyrite is present in the matrix.
Afon Lâs:	At SH 7405 2267 an intrusion of uncertain, but possibly pipe-like, shape measures 6 m in width. Euhedral pyrite is disseminated throughout the rock and occurs with chalcopyrite in veinlets.

Discussion

At Glasdir the mineralised zone appears to be confined to the outer parts of the breccia pipe and the only available plan of the mine shows that only

the adit level and possibly part of the 85 m
(280 ft) level intersect unmineralised parts of the
breccia pipe. In his report on the mine, Phillips
(1918) commented that, on hearsay evidence, at
the time of closing there was good ore at the
bottom of the workings, that a fault in the lode cut
off the pay ore and that German interests
controlled the mine and caused it to be closed
down on account of the war. He concluded,
however, that in his view the impoverishment of
the ore which pinched out at depth was the most
probable cause of closure and for this reason
doubted whether there was any justification for
re-opening the mine.

A characteristic of breccia pipes which have
been worked for high grade ores in many parts of
the world is that mineralisation is usually best
developed at the margins of the pipes and that it
is persistent in irregular-shaped, sometimes
disconnected bodies to great depths. Accepting
this analogy it would seem that a case can be made
for a further investigation of the Glasdir pipe to
look for more mineralisation both at depth and in
other parts of the pipe.

All the other pipes contain evidence of
hydrothermal activity in the form of quartz and
chlorite in the matrices, and chalcopyrite has
been noted in one of the Foel Faner pipes and in
the pipe-like body at Afon Lâs, but no further
work has been done on them.

Conclusions

It is considered that the Glasdir pipe is worthy
of investigation to determine the likelihood of
more copper mineralisation either below the known
orebody or in other parts of the pipe. Further
investigations are also warranted on the other
five pipes and the intrusion-breccia in the Afon
Lâs, with special emphasis on the Foel Faner
pipe which contains chalcopyrite.

FLUID INCLUSIONS AS A GUIDE TO MINERAL EXPLORATION IN THE HARLECH DOME

Introduction

To gain a better understanding of the relation-
ship between vein-type and disseminated-type
mineral deposits in the Harlech region, a fluid
inclusion [1]study was initiated to examine the
physico-chemical nature of the ore fluids respon-
sible for each style of mineralisation. It was
hoped that by characterising these fluids, any
significant differences which existed could be used
to evaluate the significance of geochemical and
geophysical anomalies associated with weak quartz
veining or sulphide impregnations. Since no
previous fluid inclusion study had been made of
the deposits it was equally important that both
styles of mineralisation be examined with respect
to their regional setting.

Sampling

To satisfy the above requirements, samples
were taken of the quartz gangue associated with
each type of deposit. As well as being the
principal gangue mineral, quartz was chosen
because of its suitability for fluid inclusion work.
As a model for the porphyry-type disseminated
copper deposits, 21 vein samples were selected
from the Coed-y-Brenin borehole cores now held
for R.T.Z. by I.G.S. For the more widely
distributed vein deposits an extensive collection
was made of the major quartz veins on the south-
east and south flanks of the Harlech Dome,
supplemented by similar material from numerous
minor workings to the north and east resulting in
a total of 127 samples. Unlike the Coed-y-Brenin
cores no borehole material existed for the vein
deposits and sampling was largely confined to
waste dumps adjacent to abandoned mines. By
adopting this approach little consideration could
be given to the problem of chemical variation in
the fluids during mineral deposition or the
temporal relationship between individual deposits.
The sampling was however considered sufficiently
representative to allow for internal variation
within each deposit to be recognised.

Analysis

The quartz samples were prepared for standard
thermometric analysis [2]as doubly polished thin
slices (Brumby and Shepherd 1978). According
to their morphology and genesis the inclusions
were classified into two main groups:
  (a) Primaries are those formed during crystal
       growth
  (b) Secondaries are those formed along micro-
       fractures after the cessation of crystal
       growth
Particular attention was given to the effects of
tectonic deformation on pre-existing inclusions.
After an initial optical examination of the quartz
slices 672 inclusions were selected for detailed
quantitative analysis.

Results

Twenty of the 148 samples showed evidence of
severe tectonic deformation causing complete
obliteration of the pre-existing primaries due to
intercrystalline deformation and recrystallisation.
A further 17 demonstrated an intermediate degree
of disruption in which the original inclusions were
drawn out into linear arrays with considerable

1. Fluid inclusions represent tiny droplets of the
    mother liquor occluded in the host material
    during crystal growth. For ore minerals,
    they provide a unique sample of the original
    mineralising fluid and in their simplest form
    appear as microscopic vacuoles filled with a
    liquid and co-existing vapour phase.

2. Thermometric analysis is a non-destructive
    technique for examining fluid inclusions during
    controlled heating and freezing. The obser-
    vations recorded provide thermodynamic data
    for estimating such parameters as the
    temperature of mineral formation, the salinity
    of the ore fluids, the partial pressure of carbon
    dioxide and other geochemical variables.

FIG.15. SALINITY OF PRIMARY INCLUSIONS FOR VEIN-TYPE ("V" QUARTZ) AND DISSEMINATED-TYPE ("D" QUARTZ) DEPOSITS

"V" Quartz n = 217 inclusions (solid line)
"D" Quartz n = 53 inclusions (dashed line)
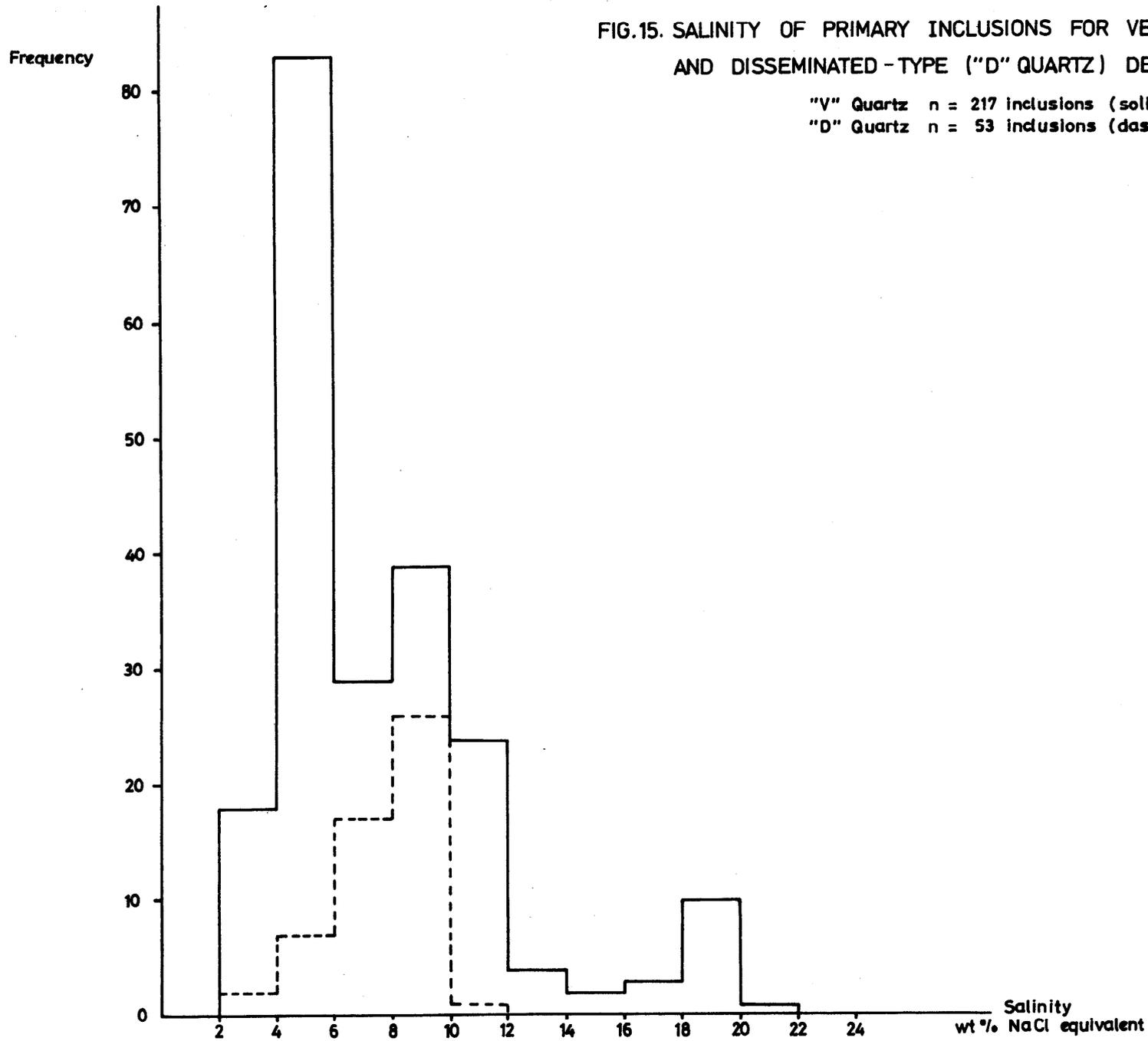
change in their liquid/vapour phase ratios. Only 13 could be described as free from deformation; the remaining 98 samples showing discrete pockets of deformation in otherwise moderately strained quartz. Where preserved, the primary inclusions occurred as rounded or multifaceted forms in isolated groups or short planar arrays in contrast to the secondaries which occupied irregular or continuous fractures. Three main types of primary inclusion were recognised in the quartz gangue:-

Type I: Simple, 2-phase systems comprising aqueous liquid and co-existing vapour.
Type II: Simple, 3-phase systems. As for type I but containing an additional solid, opaque "daughter mineral" phase.
Type III: Complex, 3-phase systems comprising aqueous liquid, liquid carbon dioxide and a vapour phase enriched in gaseous carbon dioxide. (For convenience inclusions developing liquid carbon dioxide on cooling below room temperature are also included in this category).

Only 50% of the inclusions provided complementary temperature (T) - salinity (S) data, the remainder providing values for either temperature or salinity. From the type III inclusion estimates were made of the partial pressure of carbon dioxide in the ore fluids.

Though the values for individual parameters indicate some degree of polymodality (Figs 15 and 16), the actual coherence of groupings is most apparent in Figs 17 and 18. It is evident that the secondaries, irrespective of their environment, are generally more saline than the ore fluids and overlap thermally with the cooler periods of mineral deposition.

Quartz from veins in both kinds of deposit under investigation were found to contain characteristic types of fluid inclusions.

(a) Disseminated-type deposits 'D' quartzes (Fig. 17)

Apart from general observations the mineral paragenesis for the Coed-y-Brenin deposit (SH 749 260) remains undescribed, and although the quartz veins carry small amounts of sulphide and are intimately involved in the process of mineralisation, their precise relationship to the zones of disseminated pyrite/chalcopyrite is still unknown. Despite this uncertainty, the inclusion assemblage pattern is very well defined. The highest temperatures recorded are for type III inclusion (range 245° - 205°C) which contains 8-14 wt% NaCl equiv. The second cluster of data points, representing a lower temperature regime (range 245° - 130°C : mean 165°C), is dominated by type I and II inclusions. These have a mean salinity of 7.6%, significantly lower than for the coexisting type III inclusion.

(b) Vein-type deposits 'V' quartzes (Fig. 18)

This style of mineralisation is characterised almost exclusively by type I inclusions with only a minor contribution of types II and III. Compared to the disseminated deposits the T-S pattern suggests an overall higher temperature regime of formation (range 135-310°C) accompanied by a decrease in salinity (< 6%). A further distinctive feature is the appearance in some veins of a high temperature, high salinity fluid during mineralisation.

Discussion

Excluding samples from areas 1 and 2 (Fig. 19), the ore fluids responsible for the two contrasting styles of mineralisation are distinctly different. The predominance of type II inclusion in the 'D' quartzes (area 3) and their virtual absence for the corresponding 'V quartzes (area 4) is perhaps the most important difference. The formation of liquid CO_2 in inclusions at or below room temperature indicates a CO_2 partial pressure > 73 atmospheres. On heating such inclusions, the massive build-up of internal pressure due to non-condensable CO_2 exceeds the mechanical strength of the host mineral, causing them to rupture before their homogenisation temperature. This phenomenon was noted for several 'V' quartzes from the Prince of Wales (SH 701 196), Wnin (SH 702 210) and Blaen-y-cwm (SH 716 223) lodes (area 4) implying a locally enhanced level of CO_2 in the fluids. The distinction between vein-type and disseminated type deposits is further sharpened by the occurrence of opaque solid phases in a high proportion of the 'D' quartz inclusions. To precipitate a visible solid phase on cooling, in inclusions < 50 μ m, requires the trapping of highly metalliferous fluids. Assuming the Coed-y-Brenin deposit represents a porphyry copper deposit in the North American Cordilleran sense, there is a noticeable lack of hypersaline inclusions (ie. + 30 wt.% NaCl equiv.). These are generally regarded as prime indicators, having been recognised in 90% of North American porphyry copper deposits (Nash 1976). Exceptions do exist and the importance of moderately saline fluids in the genesis of disseminated copper deposits of the porphyry type should not be discounted.

As seen in Fig. 18 the 'V' quartzes show a much wider temperature - salinity range than the 'D' quartzes, due in part to their greater geographic spread. Within this framework there are however certain features specific to the vein-type deposits. Firstly, the inclusions have higher homogenisation temperatures and lower salinities. Secondly, a small proportion of the type I inclusions contain a highly saline fluid (16 - 19 wt% NaCl equiv.) similar to that observed in the secondary inclusions of both 'D' and 'V' quartzes. By definition the secondaries refer to post-ore circulation during later tectonic reactivation of the veins. If this occurred soon after mineralisation but before final dewatering of the sediments, the fluids involved would most likely be local formation waters. Earlier episodic discharge of

FIG. 16. HOMOGENIZATION TEMPERATURES OF PRIMARY INCLUSIONS FOR
VEIN-TYPE ("V" QUARTZ) AND DISSEMINATED-TYPE ("D" QUARTZ) DEPOSITS

"V" Quartz n = 217 inclusions (solid line)
"D" Quartz n = 53 inclusions (dashed line)
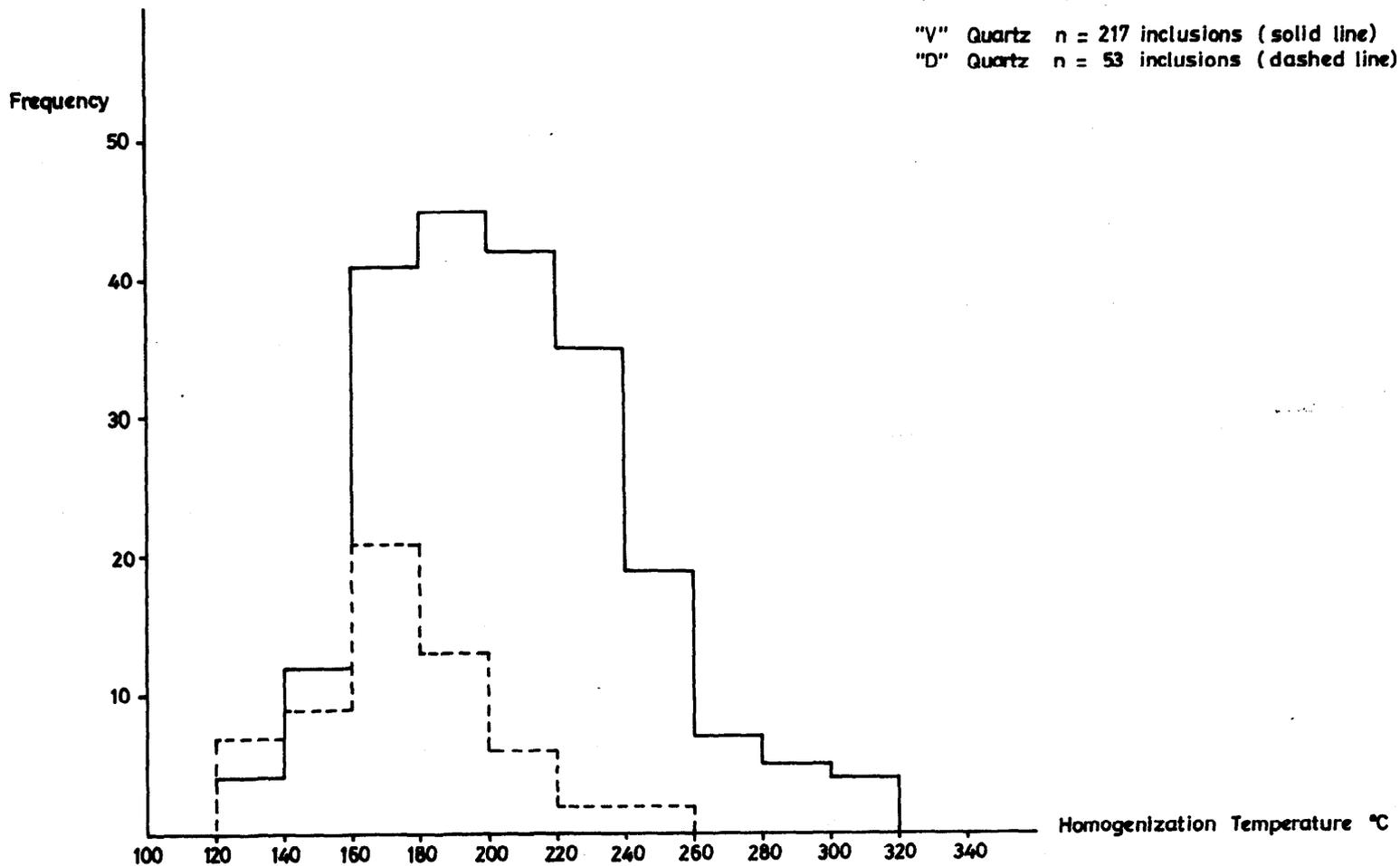
FIG. 17. TEMPERATURE – SALINITY DIAGRAM FOR PRIMARY AND SECONDARY INCLUSIONS IN THE DISSEMINATED – TYPE ("D" QUARTZ) DEPOSITS
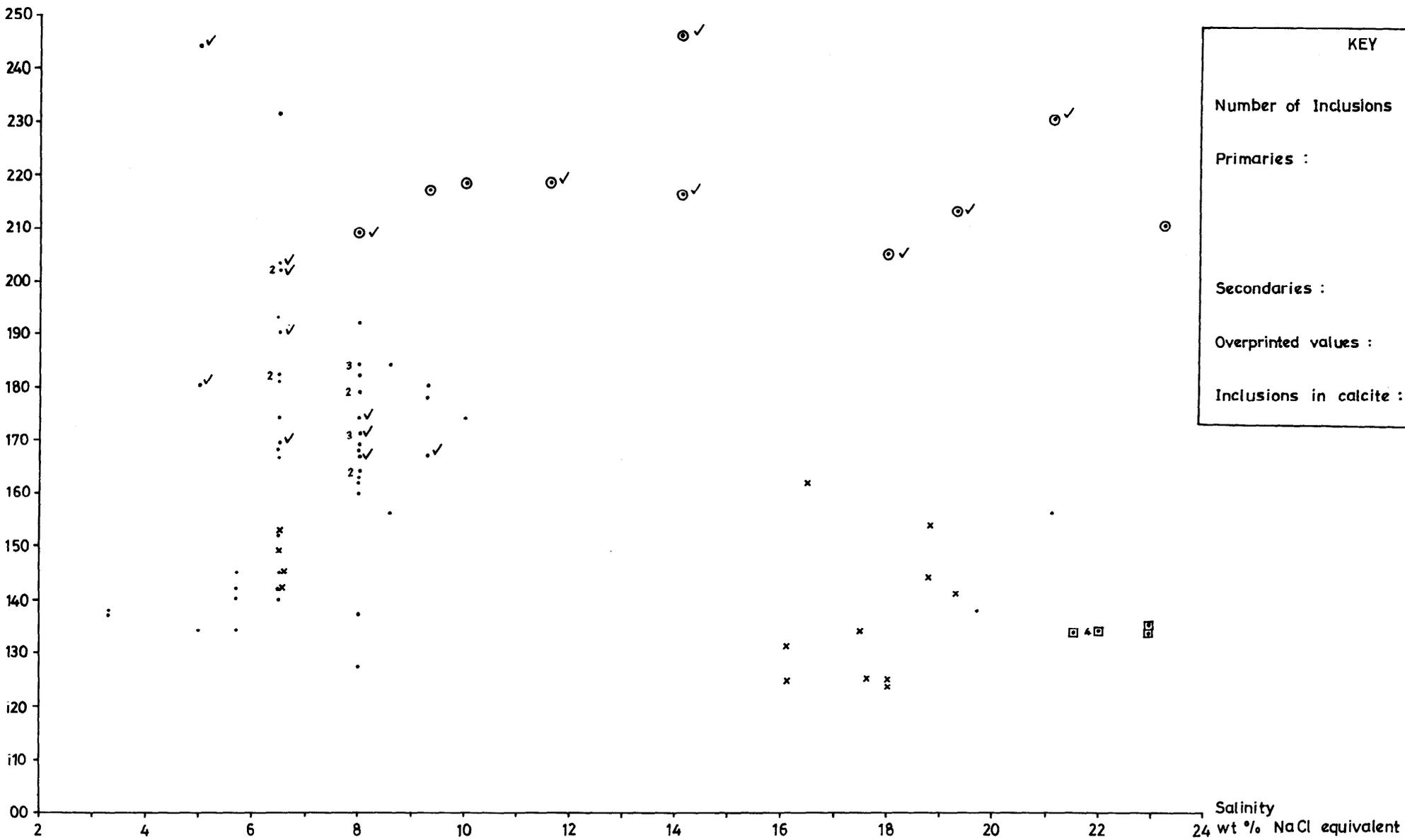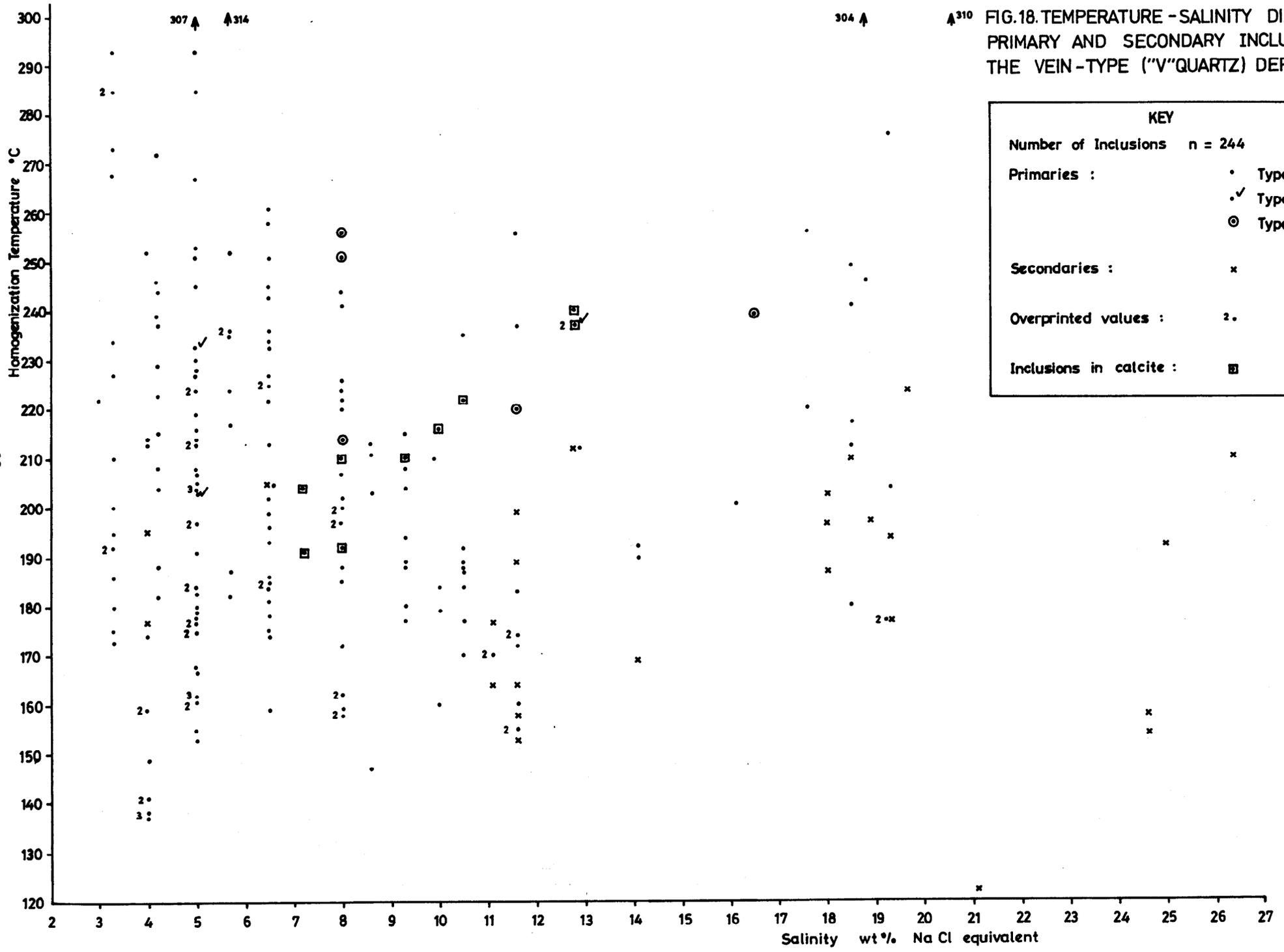
FIG.18. TEMPERATURE – SALINITY DIAGRAM FOR PRIMARY AND SECONDARY INCLUSIONS IN THE VEIN – TYPE ("V" QUARTZ) DEPOSITS

KEY

Number of Inclusions   n = 244

Primaries :		
	•	Type I
	•✓	Type II
	◎	Type III
Secondaries :	×	
Overprinted values :	2•	
Inclusions in calcite :	▣	

EXPLANATION

⬭ Coastal drift deposits

⬭ Main outcrop of Ordovician rocks

⬭ Main outcrop of Mawddach Group
(including Rhobell Volcanic Group)

⬭ Main outcrop of Harlech
Grits Group
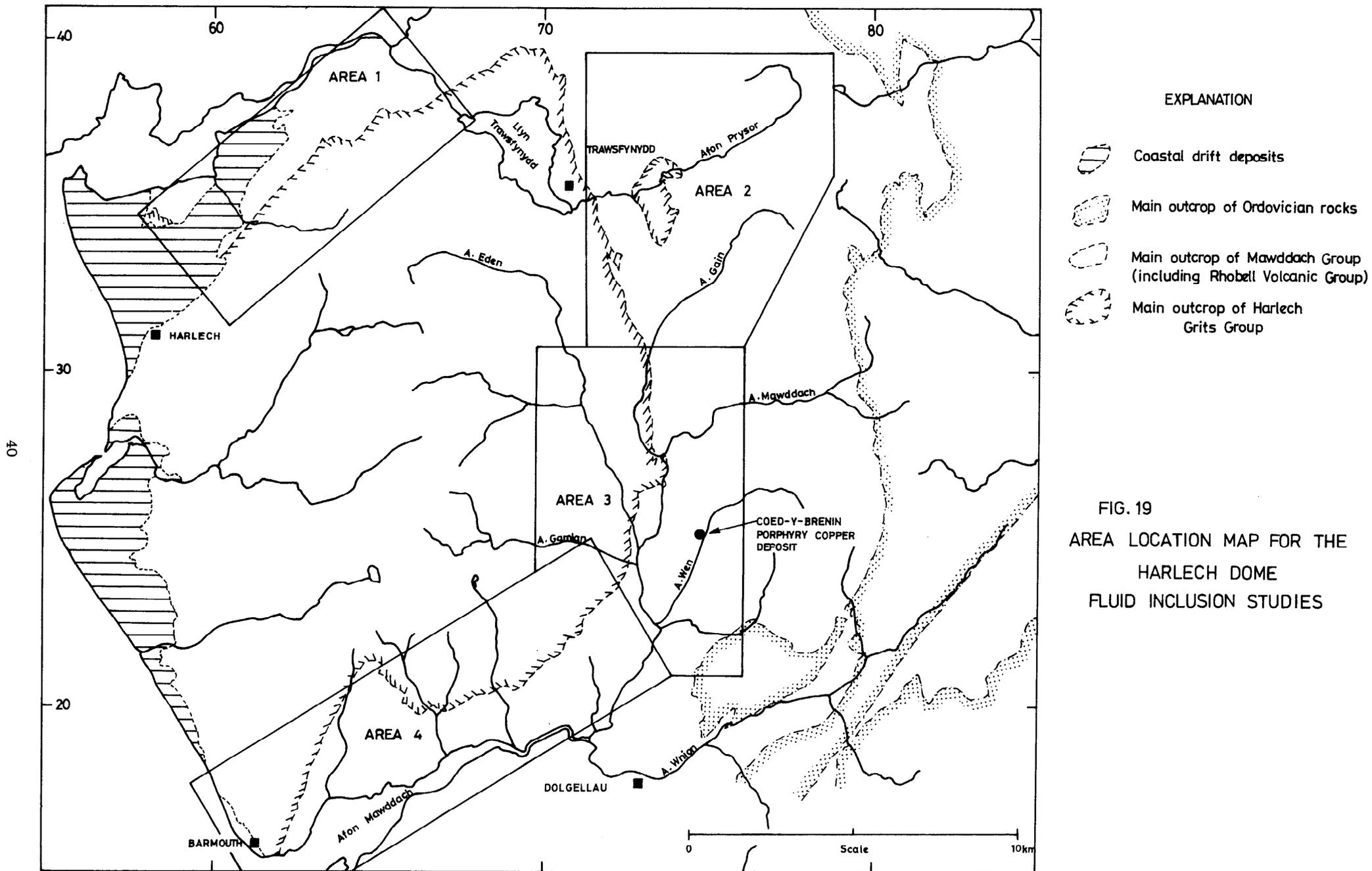
FIG. 19

AREA LOCATION MAP FOR THE
HARLECH DOME
FLUID INCLUSION STUDIES

these waters into the hydrothermal system during mineralisation with subsequent thermal equilibration would generate mineralising fluids of variable salinity, or, if unmixed, fluids indistinguishable from those in the secondary inclusions. The high temperature type I inclusions with high salinities are believed to have originated via this latter mechanism. In order to maintain compositional identity, it follows that heating must have been predominantly by thermal conduction at greater depth.

Generalised regional variation of ore fluids

A complete interpretation of the regional variation is complicated by the tectonic deformation of inclusions from deposits on the eastern flank of the Harlech Dome (areas 2 and 3). Since both areas lie within a zone of major faulting it is assumed that movement along these faults was the dominant cause of deformation. With the exception of Coed-y-Brenin, for which 21 samples were available, few if any of the primary inclusions were preserved in the limited number of samples taken from other deposits. The data for this eastern zone does not therefore permit any form of systematic variation to be studied.

In the least tectonised area 4, the vein-type deposits show the highest temperatures and lowest salinities for the whole Harlech region. Used descriptively, the Clogau-Vigra vein system SH 680 205 to SH 664 193 constitutes a form of 'thermal centre'. Eastwards into area 3, salinity increases whilst temperature decreases. For some veins peripheral to the Coed-y-Brenin deposit, the fluids closely approximate to those of the 'D' quartz type 1 inclusions. They lack the characteristic liquid CO_2 and daughter mineral phases but probably represent an outer fringe of the disseminated sulphide zone and its associated 'D' type quartz veining. The pattern for area 3 appears to continue into area 2, though at the Prince Edward Mine SH 746 387 the fluids appear slightly hotter and less saline.

Unfortunately, the criteria used for interpreting the mineralisation in areas 2, 3 and 4 cannot be applied to the quartz-calcite-chalcopyrite veins of area 1. The presence of type II and III inclusions, whilst suggesting an affinity to the 'D' quartzes, conflicts with the higher homogenisation temperatures. Geographically area 1 is closest to the Pb-Zn-Cu veins of the Moelwyn Hills (SH 70.50) a region underlain by the Tan-y-Grisiau granite. Little is known about these deposits and the classification of area 1 is best deferred until further studies have been completed.

Gold and base metal deposition

Gold production in area 4 has largely been confined to three mines - Clogau (SH 677 204). Vigra (SH 663 192) and Cefn-Coch (SH 719 233). The richness of these deposits is in marked contrast to relatively unproductive mines working similar veins in adjacent areas; eg. Cae-mur Hywel (SH 643 189), Caegwian (SH 647 195), Nantgoch (SH 655 189), Foel Ispri (SH 703 201), Prince of Wales (SH 701 196), Blaen-y-cwm

(SH 716 223) and Berth-lwyd (SH 722 236). Clearly the optimum conditions for gold deposition were realised in only a restricted number of environments. The fluid inclusion data, albeit fragmentary, provides an insight into these controls. Quartz from the Clogau-Vigra veins is characterised by high temperature, low salinity inclusions (< 6wt% NaCl equiv.) whereas the unproductive vein quartz contains more saline or CO_2 enriched inclusions. Experimental work by Seward (1973) and thermodynamic calculations by Helgeson and Garrels (1968) combine to verify the role of chloride and thiosulphide complexes as the probable carriers of gold in ore solutions. It is postulated that at Clogau, Vigra and Cefn-Coch native gold was deposited from cooling, weakly saline hydrothermal fluids ascending along open channelways on the southern flank of the Harlech Dome. For the unproductive veins, higher salinity and CO_2 levels tended to counteract the effect of decreasing temperature thereby preventing dissociation of the gold complexes. Being moderately saline the fluids were also capable of transporting considerable quantities of Pb, Zn and Cu. This agrees well with the observed correlation between highly saline inclusions and veins carrying large amounts of galena and sphalerite; eg. Blaen-y-cwm and Prince of Wales.

In proposing the above hypothesis no attempt has been made to account for the deposition of gold in areas 2 or 3.

Conclusions

The results of the present study confirm the feasibility of differentiating between vein-type and disseminated-type mineralisation using fluid inclusions in the associated quartz veins. Inclusions containing liquid CO_2 and opaque daughter minerals are considered characteristic of the Coed-y-Brenin deposit. For the higher temperature vein-type deposits of the Dolgellau Gold-belt, inclusions having salinities < 6 wt% NaCl equivalent are tentatively correlated with productive auriferous quartz veins.

Part 2: Detailed investigations by area

INTRODUCTION

In Part 2 the details are presented of investigations carried out in 26 individual areas. Their locations and the type of work carried out in each are shown on Enclosure 1. The areas, which are listed in alphabetical order, all contain geophysical anomalies which were recognised from the airborne survey.

Initially, 48 areas containing EM anomalies were identified on the airborne survey. After examining the maps, flight records and all available geological data (see Part 1) 36 were selected for examination on the ground. Sixteen of these were found to be related to simple stratigraphic conductors in the Dolgellau Member and the Clogau Formation (see p. 11-14) and are not reported here. Of the 20 that were examined there were coincident EM and magnetic anomalies in eight.

The aeromagnetic data show the area to have a highly variable magnetic character. For the purposes of this study the area was divided into 11 zones (see Part 1) within each of which it was possible to explain most of the magnetic effects by reference to the known surface geology. In some places, however, ground investigations were necessary either to confirm interpretations or because there was no obvious explanation using the available geological data.

After the ground geophysics and preliminary geological investigations were carried out, geochemical surveys were carried out in 18 areas. Signs of mineralisation were found in 14.

In two areas, Garth Gell and Glanllafar, detailed ground work was carried out as part of an investigation into the nature and causes of the EM and magnetic anomalies. These reports are contained in this part.

Each area reported in this part is covered by a complete report containing all relevant geological and geochemical data and selected geophysical data. The full details of the geophysical work are available from the Applied Geophysics Unit.

Conclusions, recommendations and references for the whole of this report are presented at the end of this part.

AREA REPORTS

BANCIAU'R EISTEDDFOD
Centre point: SH 7950 3230
6-inch sheet SH 73 SE

Geology

The area (Fig. 20) consists of an eastward-dipping, faulted succession of sporadically cleaved Cambrian and Ordovician rocks, in places covered by peat. Dark grey mudstone of Cambrian age is unconformably overlain by the basal Ordovician Garth Grit Member of the Allt Lwyd Formation. This is a coarse-grained, poorly stratified quartzose sandstone. Conformably above it black and grey banded siltstone and mudstone pass gradually upwards into a thick succession of massive grey volcanic sandstones. These are either feldspathic or lithic and the fragments are mostly of volcanic origin, rarely quartz. Most of these rocks contain disseminated sulphide, usually pyrite. On top of the volcanic sandstones are poorly bedded crystal tuffs of the Benglog Volcanic Formation consisting mainly of angular feldspar crystals with a few igneous and sedimentary lithic fragments. A faulted dolerite sill was possibly intruded after earlier movements of the fault. There is no record of any mineralisation in the area.

Geophysics

In the EM ground survey three traverses (Fig. 21) were measured over an isolated anomaly of 150 ppm which is seen on one flight line only. All the traverses show the anomaly, although it is only completely defined on traverse A at about 350 m E. This work confirms the airborne anomaly, although its position is in error by some 200 m which is not unusual in such featureless terrain. The trend of the ground anomaly is north-north-east, which does not correspond to any known geological structure and it occurs over dolerite, volcanic sandstone, crystal tuff and two faults. None of the rock types is likely to be conductive, but there is peat in the area, which can give rise to acid ground water, which if suitably contained, for example in a fracture zone or in peat- or drift-filled depressions, could lead to anomalous EM values.

Conclusions

The most likely explanation that the EM anomaly is caused by conductive overburden suggests that no further investigations in this probably barren area are justifiable.

BENGLOG
Centre point: SH 8010 2380
6-inch sheets SH 72 SE, 82 SW

Geology

This area has moderate relief and relatively sparse drift cover. It contains a complex succession of lower Ordovician volcanic rocks which dips east-south-east to eastwards at a moderate angle. It is divided into a number of fault blocks. The main, north-east trending faults are parallel to the Bala Fault which lies near this area.

On the western edge of the area the Cambrian Cwmhesgen Formation (Fig. 22) is unconformably

DRIFT

Quaternary

- ~~ Peat
- ▽ Boulder Clay

SOLID

Cambrian Ordovician

Z^A	Intermediate crystal tuff	} Benglog Volcanic Formation
S^V	Volcanic sandstone	
All	Banded siltstone, mudstone, rare sandstone	} Allt Lŵyd Formation
GaG	Coarse sandstone of Garth Grit Member	
{ Dyn	Grey siltstone of Dol-cyn-afon Member	} Cwmhesgen Formation

Aran Volcanic Group

INTRUSIVE

D   Dolerite

SYMBOLS

- ⟋⟋ Geological boundary, Solid
- ⟋⟋ Geological boundary, Drift
- ⟋⟋ Fault, crossmark indicates downthrow side
- ⟋38 Inclined strata, dip in degrees
- ◄42 Inclined cleavage, dip in degrees

SCALE
0   100   200m

Fig 20 Geology of the area around Banciau'r Eisteddfod.

SCALE
0   100   200m

- ⟋ Contours of in phase component of airborne EM in ppm.
- ⟋⊣ EM traverse line, bar indicates the beginning
- ⟋⟋⟋ Area of <100% in phase component of ground EM.
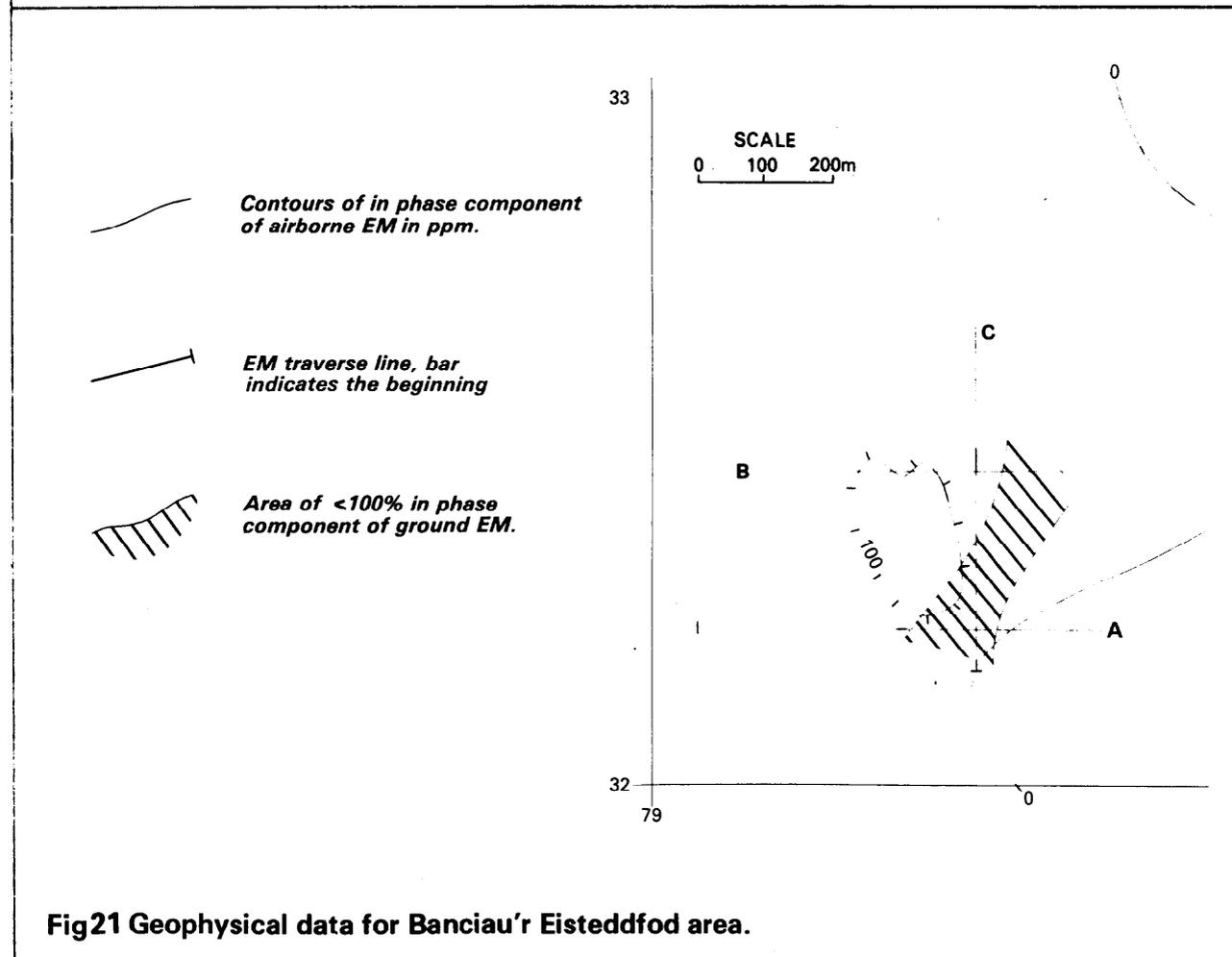
Fig 21 Geophysical data for Banciau'r Eisteddfod area.

overlain by the Allt Lwyd Formation which consists of striped black and grey siltstones in the lower part and grey volcanic sandstones, conglomeratic in places, and with thin beds of acid tuff in the upper part. Overlying this is a complicated succession of basic agglomeratic tuff, tuffite and black or grey banded mudstone, itself tuffitic in parts. This is overlain by the Benglog Volcanic Formation of andesitic crystal tuff interbedded in the upper parts with basalt flows. The highest unit is an acid ash-flow tuff. There are several dolerite sills.

Mineralisation

Four trial workings have been located; two in crystal tuff are now collapsed while one is still open; the fourth is in dolerite and consists of two adits, one above the other, possibly linked by a shaft.

The trial at SH 8057 2362 contains a large grassed-over tip. Very little quartz is in evidence except for a thin vein in the roof of the adit. At SH 8035 2366 the working appears to have been a shaft. It is now filled in and the tip, which is grassed over, consists mostly of black mudstone and crystal tuff. About 100 m north-east of this, at SH 8036 2371, there is a collapsed adit, dug in crystal tuff. There is no tip, but among the debris around it are small pieces of quartz. The tuff in an outcrop above the adit is speckled with sulphide which in polished thin section was found to be pyrite with minor chalcopyrite. There is no tip near the workings in the dolerite sill (SH 8060 2403), but in the scree below it there are fragments of quartz with galena. According to Bick (1978) a vein of galena marked the entrance to the highest adit here and the ore was present with pyrite in "thick bands". Apparently the workings are more extensive than they appear from the surface expression.

Geophysics

A belt of north-trending airborne EM anomalies with values of up to 300 ppm was investigated by a series of 7 E-W traverses (Fig. 23) using the Geonics EM 17 slingram apparatus.

All the traverses show anomalous values. Interpretation of the data shows that the conductive body dips to the east at 60° at SH 802 244 and probably to the west at an indeterminate angle at SH 801 240. The conductive body appears to be very thin at SH 801 242 and at SH 802 237 and may be discontinuous.

In the northern part of the area the conductive body, which dips in the same direction as the bedding, corresponds closely to the upper part of the mudstone unit in the Aran Volcanic Group immediately beneath the Benglog Volcanic Formation. Where the conductor dips west the bedrock is concealed beneath boulder clay and head but it appears to coincide with the lower part of the crystal tuff unit.

Geochemistry

Because of the variable drift cover soil, rock chip and drainage samples were all collected in this investigation.

a. Drainage sampling. Water and sediment samples were taken at fourteen sites in small streams around the EM anomaly. At five of them enough sediment was obtainable to make panned concentrates. Four additional sites, three in the Afon Eiddon and a fourth at SH 8050 2247, were sampled during the reconnaissance drainage survey. A summary of all the results obtained from these samples is given in Table 6. Element distributions could not be determined with any certainty on such a small number of samples so threshold levels for the reconnaissance drainage survey were used; values determined as anomalous on this basis are shown in Fig. 24.

Lead anomalies in the Afon Eiddon are at least in part derived from the old trial workings in the catchment as suggested by the high lead values amongst the scree samples. The presence of higher levels of zinc in panned concentrates than in sediments suggests zinc mineralisation as well, but the lack of zinc anomalies in the scree samples suggests that it may be derived from a different source.

All the small stream sites show large amounts of barium in sediment and the median value is well above the threshold level for the Harlech Dome. Where panned concentrates were taken the results for barium, though anomalous, are lower than the sediment values. This, coupled with the general lack of high Fe, Mn and Co anomalies in sediments, and the presence of the highest Ba values adjacent to volcanic bedrock, suggests that barium is largely present in feldspar.

Most of the samples from the most westerly stream sampled show only weak anomalies. The exception, from the upper part of the stream, is a sediment containing anomalous Ni, Co, Mn, Ba and Zn, which is tentatively explained as a result of bedrock geology and hydrous oxide precipitation effects. The Ti, Ce, Fe and weak Zn in panned concentrate anomalies from the central part of the area, directly over the EM anomaly, probably reflect the compositions of the sedimentary and volcanic bedrock but some values, such as 681 ppm Pb and 16.6% Fe in panned concentrates from sites yielding low lead and iron in sediments and 113 ppm As in sediment, appear too high for this to be a satisfactory explanation. As dispersion trains here appear to be short, it is suspected that mineralisation is present in the vicinity.

b. Soil sampling. Six traverses were sampled at 20 m intervals across the ground EM anomaly and a small unconfirmed airborne anomaly to the east which is in the vicinity of one of the old mine workings (Fig. 24). Soils collected on the three northern traverses are of boulder clay taken from small pockets between 'fixed scree' or bedrock, whilst the samples on the southern traverses largely consist of boulder clay taken from beneath organic topsoil. Results are summarised in Table 7 and shown in full in Fig. 25.

All three elements show roughly lognormal distributions. Distinctly anomalous values are clearly defined by large breaks in the distribution patterns for all three elements and the threshold

DRIFT

~~	Peat	
@	Scree and Head	
▽	Boulder Clay	

SOLID

Z^R	Acid tuff	
B	Basalt	Benglog Volcanic Formation
Z^A	Intermediate tuff	
AVG	Sedimentary rocks, undivided	
Z^B	Basic tuff	Aran Volcanic Group
Z^R	Acid tuff	
Zz, Zz^B	Tuffite, basic tuffite	
S^V	Volcanic sandstone	Allt Lŵyd Formation
All	Banded siltstone and sandstone	
Dyn	Grey silty mudstone of Dol-cyn-afon Member	Cwmhesgen Formation

INTRUSIVE IGNEOUS

D	Dolerite

SYMBOLS

_ _ _ _ Geological boundary, Drift

_ _ _ Geological boundary, Solid

_⊥_ Fault, crossmark indicates downthrow side

↗42 Inclined strata, dip in degrees

◀ Inclined cleavage, dip in degrees

☼ Trial working

Quaternary

Ordovician

Cambrian

46
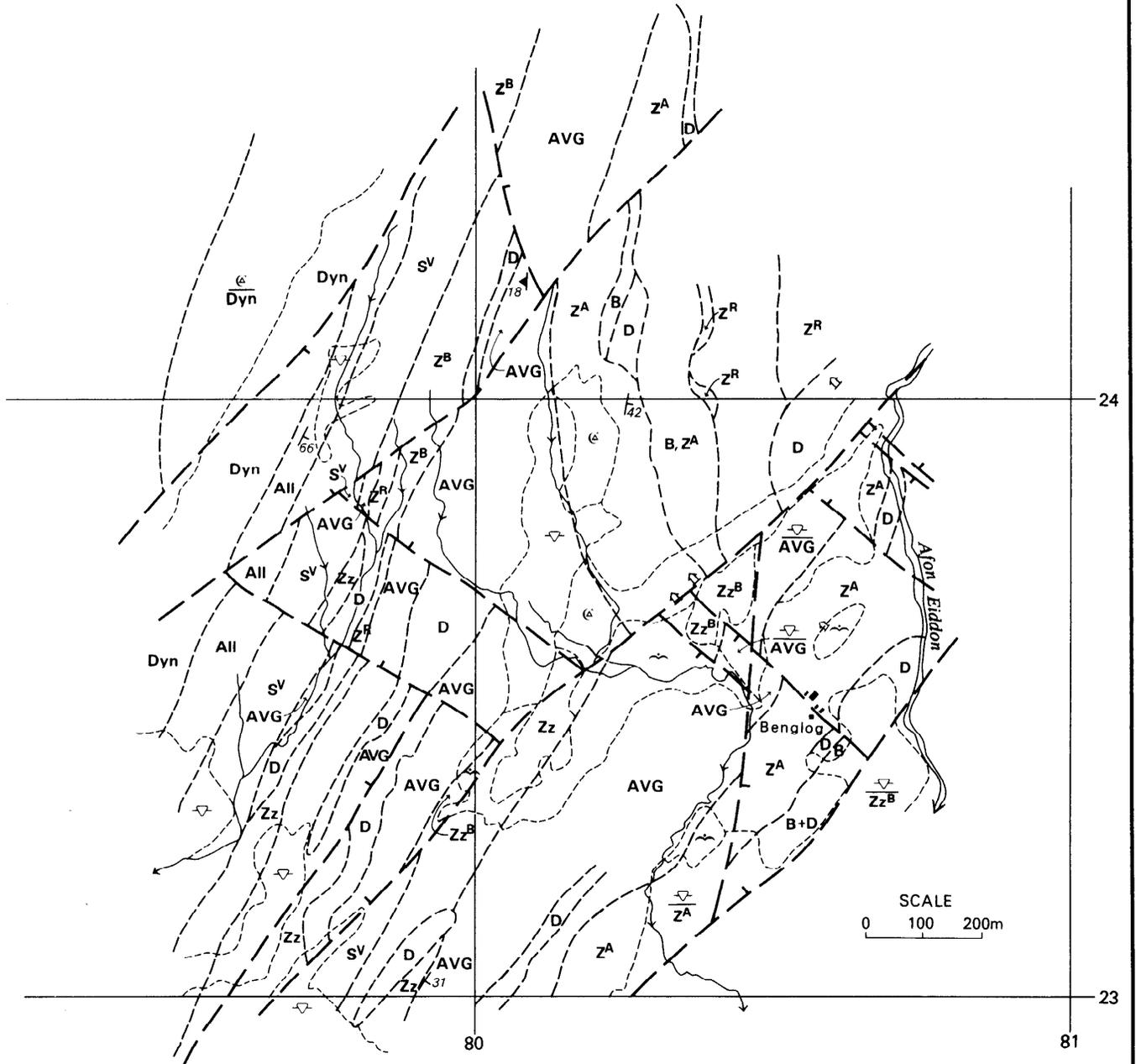
Fig22 Geological map of the Benglog area.
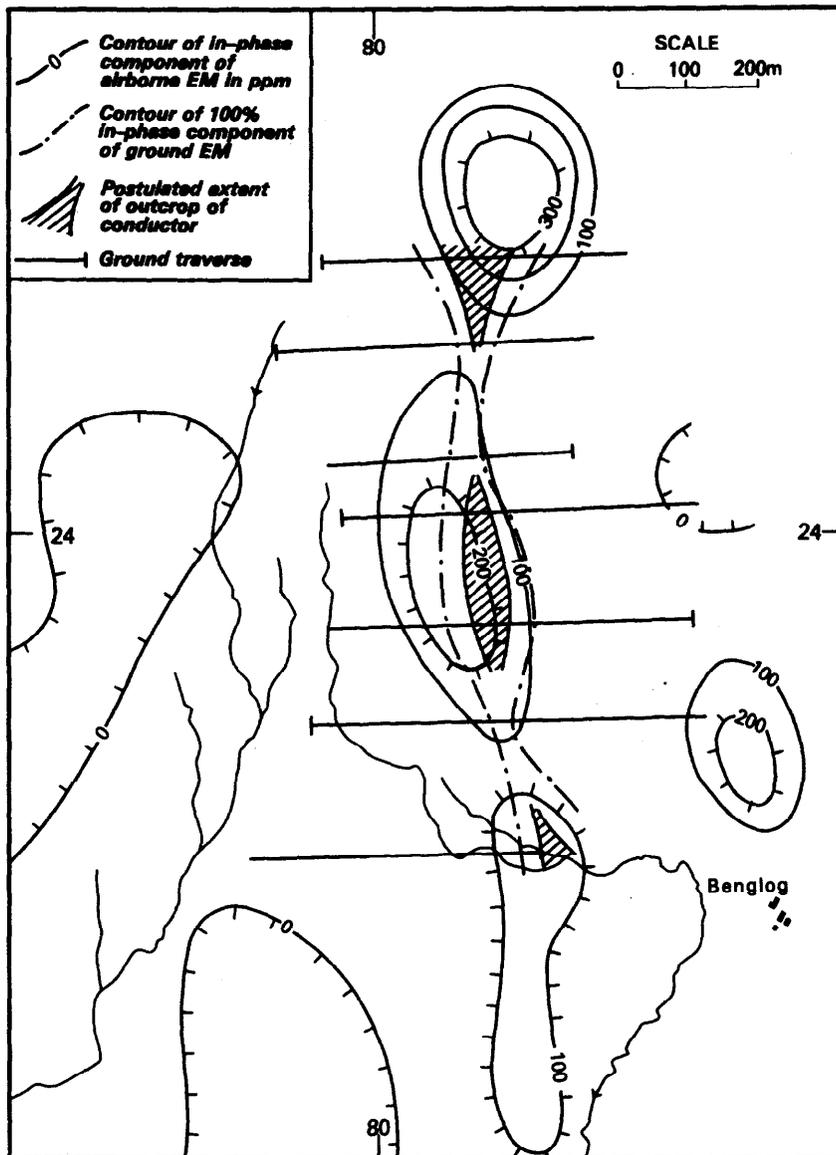
Fig 23 Geophysical data for the Benglog area.
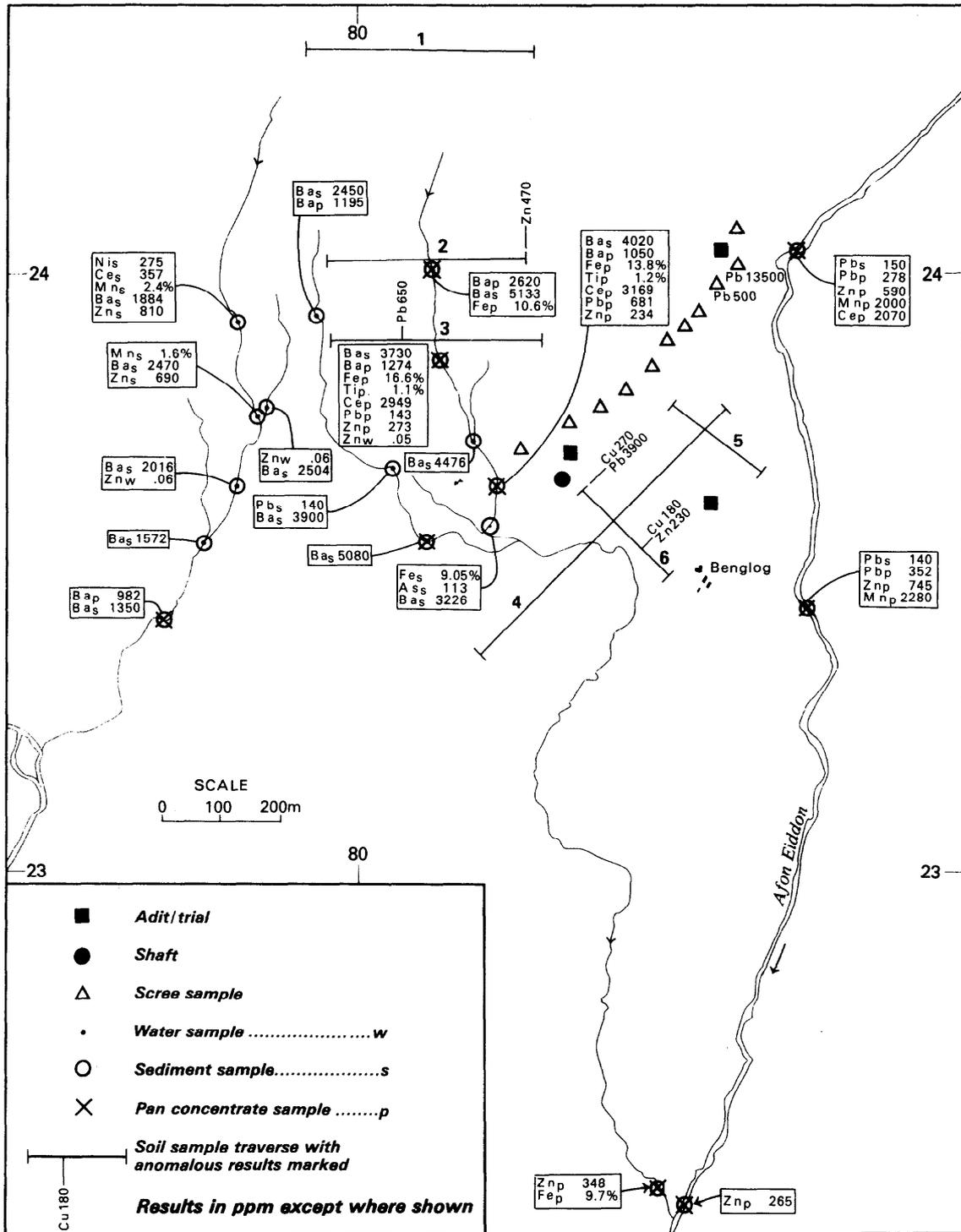
Fig.24   Location of geochemical samples and anomalous results
in the Benglog area.

Legend:
- ■ Adit/trial
- ● Shaft
- △ Scree sample
- · Water sample ....w
- O Sediment sample...................s
- X Pan concentrate sample ....p
- Soil sample traverse with anomalous results marked

Results in ppm except where shown

Map labels and values:

Bas 2450
Bap 1195

Nis 275
Ces 357
Mns 2.4%
Bas 1884
Zns 810

Mns 1.6%
Bas 2470
Zns 690

Bas 2016
Znw .06

Bas 1572

Bap 982
Bas 1350

Znw .06
Bas 2504

Pbs 140
Bas 3900

Bas 5080

Bas 4476

Bas 3730
Bap 1274
Fep 16.6%
Tip 1.1%
Cep 2949
Pbp 143
Znp 273
Znw .05

Bap 2620
Bas 5133
Fep 10.6%

Bas 4020
Bap 1050
Fep 13.8%
Tip 1.2%
Cep 3169
Pbp 681
Znp 234

Fes 9.05%
Ass 113
Bas 3226

Pbs 150
Pbp 278
Znp 590
Mnp 2000
Cep 2070

Pbs 140
Pbp 352
Znp 745
Mnp 2280

Znp 348
Fep 9.7%

Znp 265

Zn 470
Pb 650
Pb 13500
Pb 500
Cu 270
Pb 3900
Cu 180
Zn 230
Cu 180

Benglog

Afon Eiddon

SCALE
0   100   200m

80
80
24
23
1
2
3
4
5
6

48

Fig.25 Benglog; copper, lead and zinc in soil samples collected along the traverse lines shown in Fig.24

Table 6. Summary of analytical results in parts per million for drainage samples from the Benglog area

SEDIMENTS (n = 18)

	Median	Arithmetic Mean	Standard Deviation	Maximum	Minimum
Cu	15	16.7	7.81	30	5
Pb	80	85.0	34.7	150	40
Zn	280	353	213	810	80
As	36	40.2	25.6	113	3
Ba	2460	2535	1644	5133	248
Fe	64049	62743	16599	90567	41166
Mn	3327	5232	5967	24093	766
Co	23	56.8	82.6	357	10
Ni	26	47.0	63.9	275	8
Mo	<1	-	-	3	<1

WATER (n = 18)

	Median	Arithmetic Mean	Standard Deviation	Maximum	Minimum
Cu	<0.01	-	-	0.01	<0.01
Zn	0.03	0.03	0.015	0.06	0.01

PANNED CONCENTRATES (n = 9)

	Median	Arithmetic Mean	Standard Deviation	Maximum	Minimum
Cu	15	25.4	19.6	62	10
Pb	74	196	212	681	54
Zn	265	336	199	745	169
Ba	942	958	731	2620	384
Fe	79540	97494	34185	166590	69760
Mn	1400	1426	542	2280	490
Ni	22	22.8	6.49	30	11
Ti	8970	9619	2435	14110	7120
Ce	1029	1785	1560	4767	91
Sn	<9	-	-	15	<9

Table 7. Summary of analytical results in parts per million for 71 soil samples from the Benglog area

	Median	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Cu	10	20	37	14	26	49	270	10
Pb	50	461	120	59	119	240	3900	10
Zn	80	88	71	66	150	342	470	10

Table 8. Summary of analytical results in ppm for 11 rock chip samples from the Benglog area

	Median	Arithmetic mean	Standard deviation	Maximum	Minimum
Cu	20	24	15.4	55	5
Pb	40	1307 (42)	4046 (22.8)	13500 (100)	20
Zn	140	136	40.3	200	70
Fe%	7.5	6.99	1.20	8.40	1.80

Results for Pb in brackets are for 9 samples, excluding two very high results.

level was taken for convenience as the geometric mean +2 x geometric deviation. Values defined as anomalous are shown on Fig. 24. The very large copper and lead anomalies at the north-west end of traverse 6 (Fig. 24) are the product of contamination from old mine tips, but it is considered probable that the other anomalies reflect underlying mineralisation.

c. Rock chips. Eleven rock samples were taken from the base of the scree slope below Allt-y-Benglog because of the lack of soil and streams on the high ground hereabouts. A summary of the results is given in Table 8.

Two samples contained large amounts of lead; these could be related to the presence of galena in the scree derived from the old workings on the hillside. All other samples gave results which were unexceptional for the lithologies concerned, and there were no indications of the zinc enrichments noted in the Afon Eiddon.

Conclusions

The airborne EM anomaly was confirmed on the ground and found in part to coincide with a mudstone formation in the Aran Volcanic Group. In the area around SH 804 244, however, the available, though sparse, data suggest that the conducting body dips contrary to the local bedding and it is possible here that the anomaly does not have a simple stratigraphic origin.

The results of the geochemical survey point to the presence of scattered lead-zinc vein mineralisation both in the vicinity of the EM anomaly and elsewhere in the area. The only evidence of copper mineralisation is in two trial workings.

Scattered vein mineralisation is unlikely to cause an EM anomaly and it must be concluded that neither the ground geophysics nor the geochemical work has provided a satisfactory explanation for the airborne EM anomaly.

The general association of weakly anomalous elements and a submarine volcanic succession raises the possibility of stratabound mineralisation in the area and the lead-zinc vein mineralisation may merely be an indicator of this. Two main factors may be taken into account. Firstly, the high barium values may indicate a general enrichment of this element, which is common in association with that type of mineralisation. Secondly the cobalt and nickel anomaly may be indicative of the Co-V-Cu-Ni association which Shiikawa and others (1974) show characterise mudstones underlying stratabound mineralisation in some parts of Japan.

It is recommended that this area is investigated more fully for signs of stratabound mineralisation, in the first instance involving more detailed drainage and soil sampling, chemical and mineralogical studies of the bedrock and further investigation of the EM anomaly.

BRYN COCH
Centre point: SH 7390 2450
6-inch sheet SH 72 SW

Introduction

This is a hilly, forested area lying between the steep-sided valleys of the Afon Wen and Afon Mawddach. The investigation of this area began with ground follow-up of geophysical anomalies on Bryn Merllyn and was followed with a geochemical survey after the discovery of copper mineralisation in new road cuttings on Bryn Coch.

Geology

Scree on the river valley sides and boulder clay in the depressions between the hills conceal much of the solid exposure. The succession, which dips at moderate to steep angles towards the east-south-east, consists of dark grey laminated sandstone of the Maentwrog Formation and light grey siltstone and fine-grained sandstone of the Ffestiniog Flags Formation, intruded by a large body of microtonalite (Fig. 26).

The microtonalite is conformable and forms a complex, probably multiple, intrusion containing rafts and wedges of sedimentary rocks. It is a medium-grained, sparsely porphyritic rock with phenocrysts of plagioclase, and chloritic pseudomorphs after amphibole set in a matrix of quartz, which is interstitial to a mesh of zoned plagioclase crystals and, unusually in the Harlech Dome, some chlorite pseudomorphs after biotite. Accessory minerals include ilmenite, pyrite, chalcopyrite, apatite, sphene and orthite. In some rocks the plagioclase is partly altered to sericite, chlorite and minor calcite, while in others alteration products are epidote, sericite and chlorite.

Mineralisation

Several quartz veins trending north-west and north-north-east occur in the eastern half of the area. Those on the hillside above the Afon Wen constitute Roberts' Mine and were worked for copper in the 1840s (Hall, 1976). On Bryn Coch there are trial levels and small open cuts presumably driven to investigate adjacent exposed quartz veins which carry pyrite, chalcopyrite and secondary malachite. Pyrite is present in disseminations parallel to bedding and in 2 mm-thick veins with quartz in the lower part of the Ffestiniog Flags Formation and in mudstone of the Maentwrog Formation. In addition, there are scattered slightly sigmoidal lenses of quartz, often with pyrrhotite, minor chalcopyrite and covellite.

Malachite staining is present in joints, and abundant disseminated pyrite and chalcopyrite has been found in the intrusive rocks and enclosed sedimentary rocks in road cuttings below Roberts' Mine and around Bryn Coch. This area is about 1.5 km south west of the porphyry copper deposit proved by RTZ at Capel Hermon and the Bryn Coch microtonalite is part of the same complex of intrusives. Rice and Sharp (1976) showed that

DRIFT

	~~	*Peat*
	ⓒ	*Scree*
	⋎	*Boulder Clay*

SOLID

Ff *Interbedded sandstone* ⎱ *Ffestiniog*
    and siltstone ⎰ *Formation*

Mw *Grey mudstone*

MwS *Sandstone and* ⎱ *Maentwrog*
     silty mudstone ⎰ *Formation*

INTRUSIVE

pMt *Microtonalite*

P *Intermediate, undivided*

SYMBOLS

─ ─ ─ *Geological boundary, Solid*

─ ─ ─ ─ *Geological boundary, Drift*

─ ─ ─ *Quartz vein*

⊤27 *Inclined strata, dip in degrees*

⋔ *Adit, abandoned*

▲²⁰⁰ *Rock chip sample site, with Cu values in ppm.*

≈≈≈≈ *Forest road*
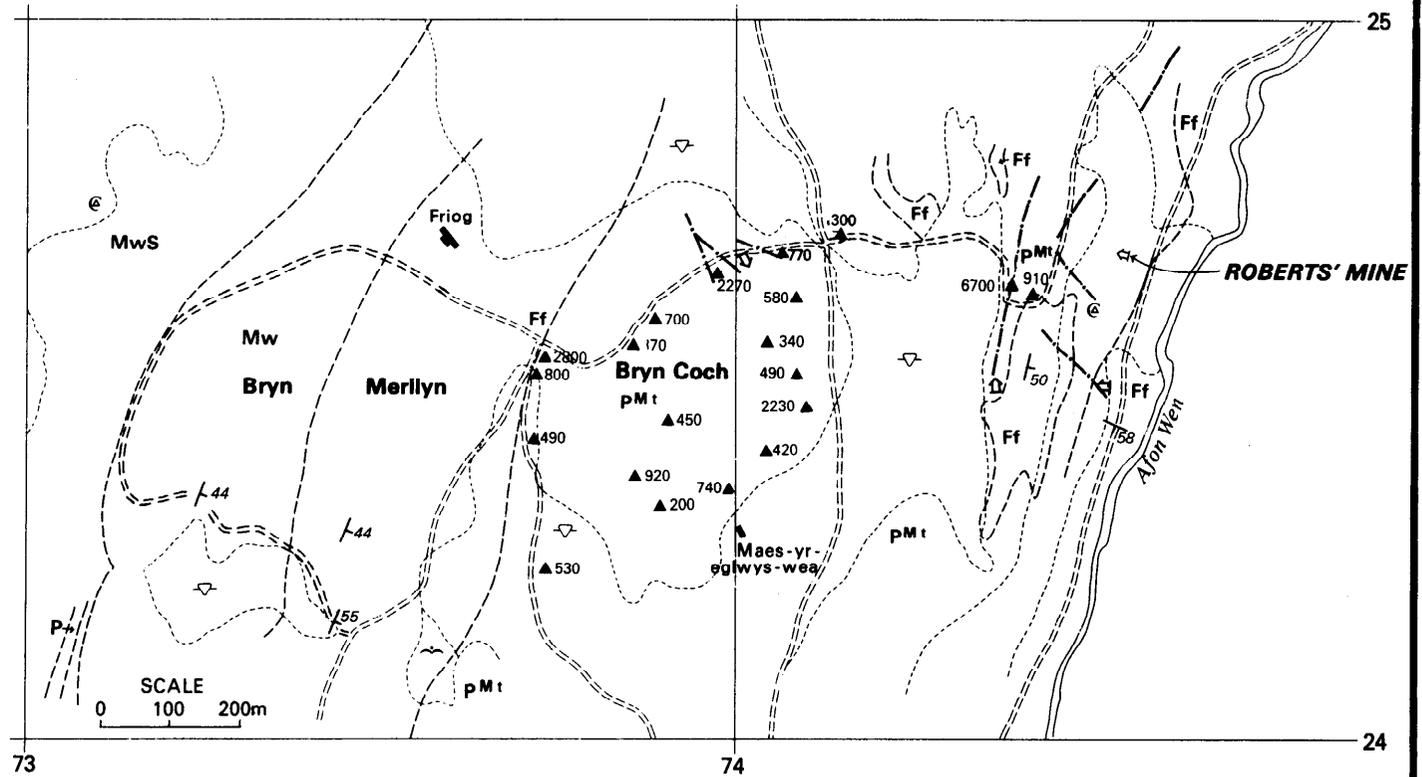
Fig 26 Geological and geochemical data for Bryn Coch area.

the 0.2% Cu zone at Coed-y-Brenin did not close in this direction.

Geophysics

An isolated airborne EM anomaly of 200 ppm associated with an intense magnetic anomaly of 500 nT on Bryn Merllyn was investigated by measuring two traverses at right angles to each other, using ABEM Demigun slingram equipment and a fluxgate magnetometer.

The ground EM anomalies, though not well defined on traverse A (Fig. 27) confirm the airborne anomaly. On traverse B a strong positive anomaly is seen which suggests a sheet some 200 m wide at some depth below the traverse. The magnetic results show a more complex anomaly pattern on the ground than in the air, which suggests that the magnetic material is in thinner units than is suggested by the aero-magnetic maps.

The EM anomalies correspond to the outcrop of the grey mudstones of the Maentwrog Formation but they are apparently only intermittently conductive, suggestive of discontinuous zones of sulphide mineralisation or carbon within the succession. The magnetic anomalies occur on the eastern limit of the intense area of magnetic activity of the Harlech Dome, the gradient dropping steadily to the east. The anomaly may be due to pyrrhotite in the Maentwrog Formation, which dips to the east at this point.

Geochemistry

A drainage site sampled at SH 7395 2395 during the reconnaissance survey contains the southern part of Bryn Merllyn and Bryn Coch within its catchment. Anomalous results were recorded in sediment for copper (2500 ppm), arsenic (168 ppm), molybdenum (26 ppm) and cobalt (189 ppm). The only anomalous result recorded in the panned concentrate is 431 ppm copper, but arsenic and molybdenum were not determined. The combination of anomalous elements in the sediment suggests either the presence of disseminated copper mineralisation in the catchment of metal-rich drift deposits, derived from the area of known copper mineralisation in the north.

Soil sampling carried out by RTZ and reported by Rice and Sharp (1976) show copper (< 300 ppm) and molybdenum (< 10 ppm) anomalies in the boulder clay east and north of Bryn Coch but no anomalies over the hill itself or on Bryn Merllyn. Arsenic (< 50 ppm) anomalies, which are possibly related to pyritiferous rocks (Rice and Sharp, 1976), were recorded in soils on the eastern flank of Bryn Merllyn and on the steep western side of the Afon Wen valley. It was not clear from their work whether the source of these copper anomalies in soil, assuming that they were transported, was in the adjacent Bryn Coch area, or further north.

The discovery of copper mineralisation in new road exposures around Bryn Coch suggested that a relatively local source existed for both the soil and the drainage anomalies and twenty rock chip samples were taken from available exposures on and around Bryn Coch to ascertain the copper

content of the rocks. A range of other elements was also determined on the samples to provide evidence of the style of mineralisation and alteration. Nineteen of the samples are of microtonalite and one, from SH 7443 2466 is a highly pyritised siltstone from the Ffestiniog Flags Formation (Fig. 26).

The results (Table 9) indicate a considerable enrichment of copper in these rocks. The minimum value of 200 ppm is well in excess of normal background levels for this lithology (93% microtonalite samples taken from elsewhere in the Harlech Dome showing values < 200 ppm.) The samples with the highest copper contents do not correspond in all cases with samples containing either quartz veining or the largest amounts of visible chalcopyrite. Element levels also indicate weak arsenic and molybdenum enrichment in some rocks, with the highest arsenic result (91 ppm, nearest neighbour 32 ppm) occurring in the pyritised flag sample. All lead and zinc values fall within the expected range of background values for microtonalite.

Element distributions could not be ascertained with certainty because of the small sample population, but two patterns are evident: copper, zinc, molybdenum, vanadium, chromium and barium show lognormal form with a distinct group (three or four results) of high values, whilst other elements (except lead) show a simple, roughly lognormal form. The range of lead results was so small compared with the precision of the analytical method that no distribution was clear, and this element was excluded from any statistical tests. Correlation and factor analysis on log-transformed data show a distinct lack of strong inter-element associations. Arsenic, molybdenum and copper show independent behaviour. Barium only shows a positive correlation (95% significance level) with cobalt. Vanadium, zinc, iron and manganese show a strong positive association with each other in a four-factor analysis and are positively inter-correlated (99% significance level). Chromium and nickel are significantly (95% level) correlated and nickel correlates with zinc, vanadium and cobalt (95% level). The independent behaviour of so many elements may be the product of small, complex sample populations, but suggests that despite the relatively unaltered appearance of many of the samples several distinct alteration and mineralisation processes are interacting in these rocks, which will require more detailed chemical and mineralogical work to elucidate.

The high copper results, the lack of high lead and zinc values and the weak molybdenum enrichment suggest that this is a disseminated mineralisation similar to that at Coed-y-Brenin. The high arsenic values may reflect the pyritic halo of the disseminated deposit.

Conclusions

The airborne EM anomaly on Bryn Merllyn was confirmed on the ground and, like the magnetic anomaly, was demonstrated to be probably stratigraphically controlled. The available evidence suggests that pyrite, pyrrhotite
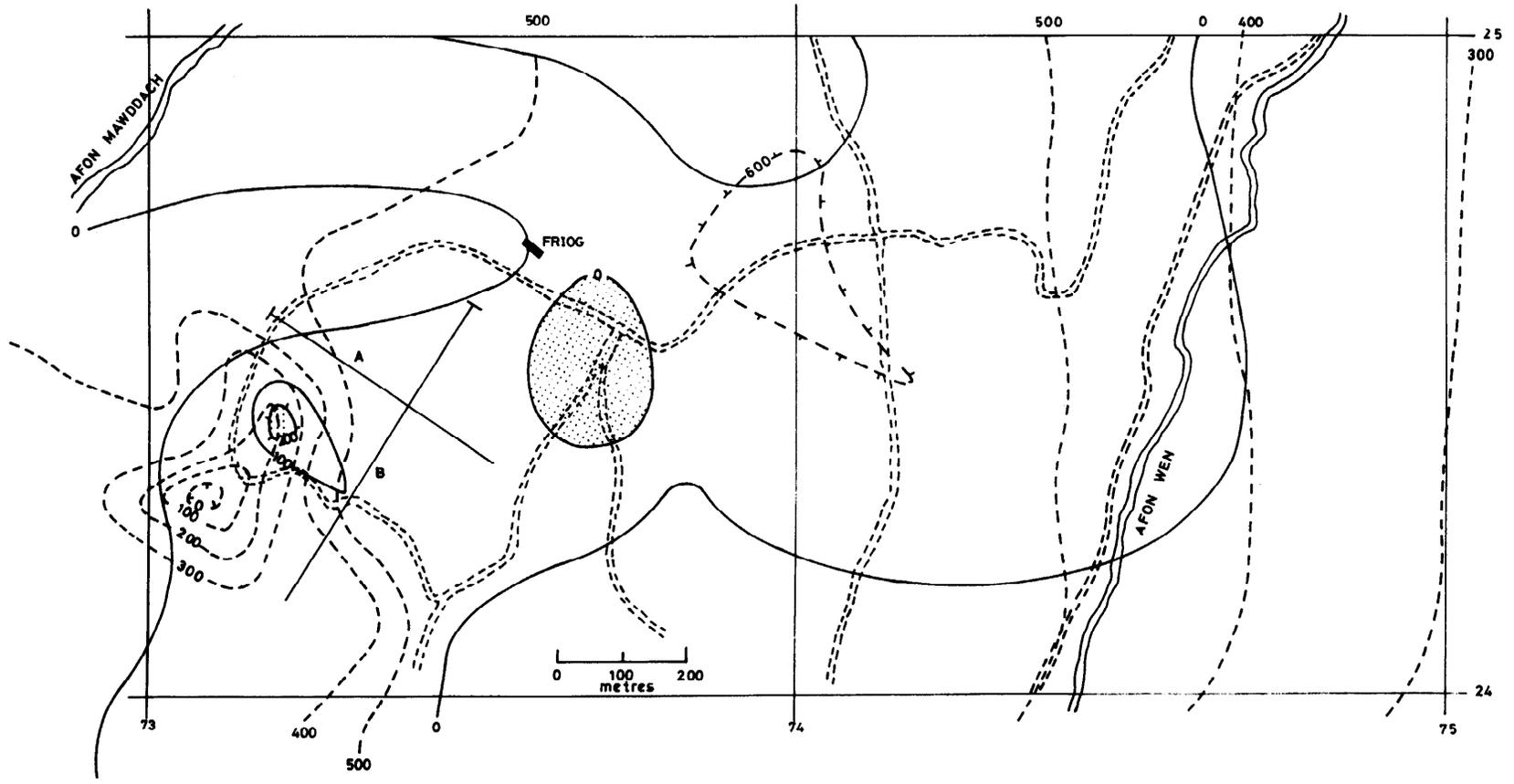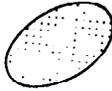
FIG. 27.   GEOPHYSICAL DATA FOR THE BRYN MERLLYN and BRYN COCH AREA.

Table 9. Summary of analytical results in ppm on 20 rock chips from the Bryn Coch area

	Median	Arithmetic mean	Standard deviation	Geometric mean	Maximum	Minimum
Cu	640	1175	1514	752	6700	200
Pb	10	13.5	4.9	12.8	20	10
Zn	50	59	21.2	56	110	30
Mo	6.5	11.5	10.7	8.0	35	2
As	9.5	15.3	19.0	11.0	91	5
V	161	181	80	168	307	68
Cr	25	39	50	24	226	4*
Mn	767	821	433	716	1933	195
Fe	53490	57560	18090	54580	94700	20020
Co	16.5	19.1	11.8	17.0	60	9*
Ni	29	33	20.6	28	86	7*
Ba	275	408	298	316	1076	125

* denotes value below the detection limit

and possibly carbon in the mudstone may be the causes.

The soil and drainage geochemical anomalies around Bryn Coch are most probably related to the disseminated copper mineralisation revealed by rock chip sampling over and around that area. The composition of the rock chips suggests that the disseminated mineralisation is the same molybdenum-poor type as the Coed-y-Brenin deposit, and it may represent either an extension of that deposit or a separate body. Further work is thought justifiable to define the full areal extent of the mineralisation and to evaluate it in terms of its potential as an ore deposit.

CRAIGLASEITHIN
Centre point: SH 738 332
6-inch sheet SH 73 SW

Introduction

This area lies to the north of the Afon Gain and east of Moel Oernant. It is of moderate relief, rising northwards in a series of steps to a high point at about SH 7345 3325 and then falls off gradually towards the Afon Prysor. The ground is badly drained and covered in rough grass. The southern part was an artillery range for many years.

Geology

Thick boulder clay is present only in the southern and eastern parts of the area. Elsewhere the drift, often with a thin cover of peat, forms patchy infills between craggy rock outcrops. An area of bouldery drift around SH 739 332 is possibly morainic (Fig. 28).

The principal stratigraphic units are the Gamlan, Clogau and Maentwrog formations. The lowest, the Gamlan Formation, consists of greenish grey, dark grey and purplish grey laminated silty mudstone with rare bands of siliceous siltstone. In the northern part of the area these rocks are interbedded with thick units of coarse-grained quartzose sandstone. In the south, sandstone, which is usually pyritic, occurs as rare thin beds. Overlying the Gamlan Formation, the Clogau Formation consists of laminated black mudstone with sparse sandy laminae. This passes abruptly into the Maentwrog Formation, consisting of an interbedded succession of grey silty mudstone, siltstone and fine-grained sandstone. In places the sandstone beds reach 1 m in thickness, but mostly they are interbedded with silty mudstone in units less than 10 cm thick.

The greater part of the area is underlain by a large intrusion of porphyritic microtonalite around which the effects of thermal metamorphism are confined to within about 20 m of the contact. The western margin of the intrusion is faulted against the Maentwrog Formation. On the south and south-east the intrusion is concordant with the overlying sedimentary rocks of the Gamlan Formation and has apparently domed the strata above it. In the northern part of the area it is markedly discordant breaking through into higher formations and interfingering with them at the top. The rock is strongly porphyritic with phenocrysts of feldspar and amphibole, both now pseudomorphed, and quartz. The groundmass is a microcrystalline mosaic of quartz, feldspar, chlorite, sericite and calcite partly recrystallised into plates of quartz and feldspar defined by a mesh of micas. Some rocks consist of stubby feldspar crystals about 0.1 mm long set in quartz, sericite, chlorite and calcite. Accessory minerals consist of apatite, zircon, sphene, pyrite and rare ilmenite. Chalcopyrite was not recognised, but in places there are tiny spots of malachite.

There are several thin sills of microdiorite above the main intrusion and several thin, north-west trending dykes of highly altered dolerite.

North of the main intrusion the roughly north-north-east striking sedimentary rocks dip at moderate angles towards the east. On the north-eastern side of the intrusion the Maentwrog Formation has been folded along north-north-west axes in a zone which can be traced south-south-

Fig 28 Geological map of Craiglaseithin area.

DRIFT

Quaternary
- ⁓   Peat
- ℰ   Scree and head
- ▽   Boulder clay

SOLID

Maentwrog Fm

Cambrian
- **MwS**   Interbedded sandstone and mudstone
- **Clu**   Black laminated mudstone   } *Clogau Fm*
- **Gn**   Greenish-grey and purplish-grey silty mudstone, with some sandstone   } *Gamlan Fm*
- **S**   Coarse-grained quartzose sandstone

INTRUSIVE IGNEOUS

- **D**   Dolerite
- **P**   Intermediate, undivided (including, possibly some dolerite)
- **pMt**   Microtonalite

SYMBOLS

- - - - -   Geological boundary, Solid
- · · · · ·   Geological boundary, Drift
- ⊥   Fault, crossmark indicates downthrow side, where known
- —··—   Quartz vein
- ↗¹⁸   Inclined strata, dip in degrees where known
- ⊅   Adit, abandoned

Mawddach Group Harlech Grits Group

Llyn Gelli-Gain

Afon Gain

SCALE

0   100   200m

eastwards for two or three kilometres, but close to the contact the bedding has been contorted presumably by the intrusion.

There are several north-west faults, which both preceded and post-dated the intrusion. The north-east faults preceded the dykes. Mudstone in all parts of the area possesses a cleavage.

Mineralisation

Numerous quartz veins cut the microtonalite and the surrounding country rocks. Many of them occur adjacent to the western faulted margin of the intrusion and in places form swarms of thin en echelon veins in the microtonalite. They appear to fill tension gashes probably related to the faulting. Elsewhere, numerous veinlets are present in the country rock immediately adjacent to the contact and have an origin probably related to the intrusion. In the microtonalite some of the veins, 2 metres or more in thickness, trend north-west or east-north-east and are mineralised. Besides sulphides most contain chloritic inclusions and some have black pyrolusite in fractures and small vugs. Adjacent to one vein there is a thin zone of chloritic alteration in the microtonalite.

Several of these quartz veins have been excavated and at about SH 7408 3239 there are two adits, now abandoned, into an extension of one of the veins into the roof sedimentary rocks. About 400 m south-west of these adits, at SH 7386 3209, another short trial adit follows a 15 cm thick, vertical, west-trending quartz vein with no signs of mineralisation. There appear to be two distinct suites of sulphides, both present in north-west trending veins. In one, pyrite and chalcopyrite are dominant, and there is usually malachite staining on fractures. In the other, sphalerite, galena and pyrite are the principal sulphides with lesser amounts of chalcopyrite and arsenopyrite. An XRF scan of a sample from the tip outside the adit near SH 7408 3239 confirmed Zn, Pb, Cu and As, and showed substantial amounts of Co and slight traces of Ag and Cd.

Sulphides are present in the sedimentary rocks in few places. Pyritisation of sandstone in the Maentwrog Formation was observed adjacent to the microtonalite intrusion at SH 7429 3313 and at one or two more distal sites. At SH 7454 3273 pyrrhotite and chalcopyrite were observed in joints in sandstone; pyrite occurs in mudstone intercalations and pyrrhotite is disseminated throughout even the thinnest sandstone beds.

Geophysics

To the north of the Craiglaseithin intrusion there is a 1 km long north-south zone of airborne EM anomalies over 200 ppm in amplitude and a smaller area of anomalies of 50 ppm 0.5 km to the south across the intrusion. Eleven traverses (Fig. 29) using slingram were measured across the airborne anomalies and over possible connections between the two areas.

The pattern of the airborne anomaly north of the intrusion was confirmed and correlates reasonably with the outcrop of the Clogau Formation. On the three northern traverses,

for example Traverse A, Fig. 30, a double conductor with a dip of 40° east is indicated.

South of the intrusion the pattern is less obvious and while confirming the presence of the airborne anomaly, it cannot be ascribed to any one formation. It is found mainly over Gamlan Formation, which is moderately conductive, and over a small wedge-shaped area of Clogau Formation, which appears to exhibit very variable conductivity with some large anomalies (Fig. 30 traverses B and C).

It is not possible to conclude that the anomalies in the south are stratigraphic but correlation between traverses does suggest that they lie along strike.

Geochemistry

During the reconnaissance drainage survey four sites were sampled in this area; only sediment was collected at SH 7378 3232 and water at SH 7393 3214 (Fig. 31). The values considered anomalous by comparison with threshold levels determined for the Harlech Dome are shown in Fig. 31. In general, higher metal values occur in the sediments than in the panned concentrates from the same site, which suggests that much of the anomalous metal is not in heavy detrital phases. At SH 7473 3248 the presence of appreciable tin in the panned concentrate suggests that the other metal anomalies at this site are either due to, or are being enhanced by, contamination. An examination of the stream indicated that contamination due to dumped metal is not strong. Therefore, as the known mineralisation and old workings lie to the west of this stream catchment, it is quite possible that some hidden extension of the mineralisation is present in the area. Anomalous results at the other sample sites can be directly related to old trials and known mineralisation in the catchments, which effectively masks any contribution from unknown sources.

Four soil traverses trending north-east and roughly 200 m apart were sampled at 20 m intervals over the southern EM anomaly and adjacent parts of the intrusion. Two additional short traverses (Nos 3 and 4 in Fig. 31) were sampled at the same interval to improve coverage across a moraine and scree-infilled basin (Fig. 28). Where no soil was developed, rock chip samples were taken from bedrock, or, less often, from blocky scree. Most of the soil samples, from depths of 25-120 cm, are clay with rock fragments taken from beneath organic rich topsoil or peat, but a few contain some organic-rich material.

A summary of results for the 161 soil and 31 rock chip samples collected on these traverses is given in Tables 10 and 11. The one mudstone sample contains no abnormally high or low values of any element determined (Cu 35 ppm, Pb 20 ppm, Zn 60 ppm) compared with the microtonalite samples. All the results are plotted along traverse lines in Fig. 32.

Lead and zinc in soils show roughly lognormal distributions with poorly developed inflexion points on cumulative frequency curves at 110 ppm Pb (93% level) and 300 ppm zinc (95% level); these were taken as the threshold levels. Copper in soil

FIG. 29.   GEOPHYSICAL DATA FOR CRAIGLASEITHIN AREA
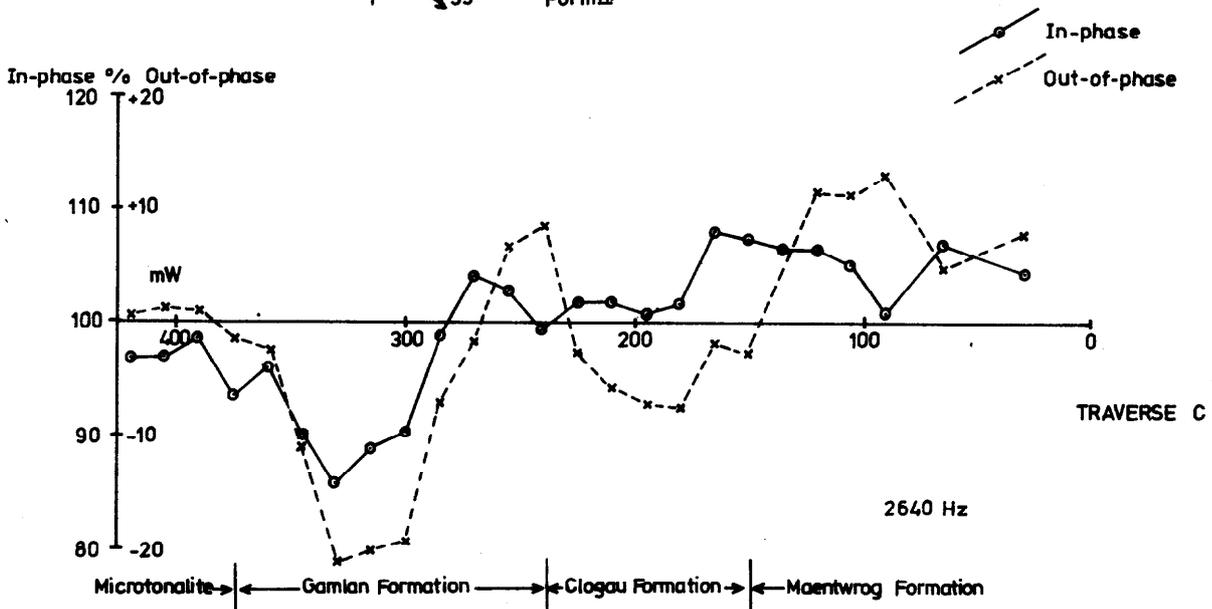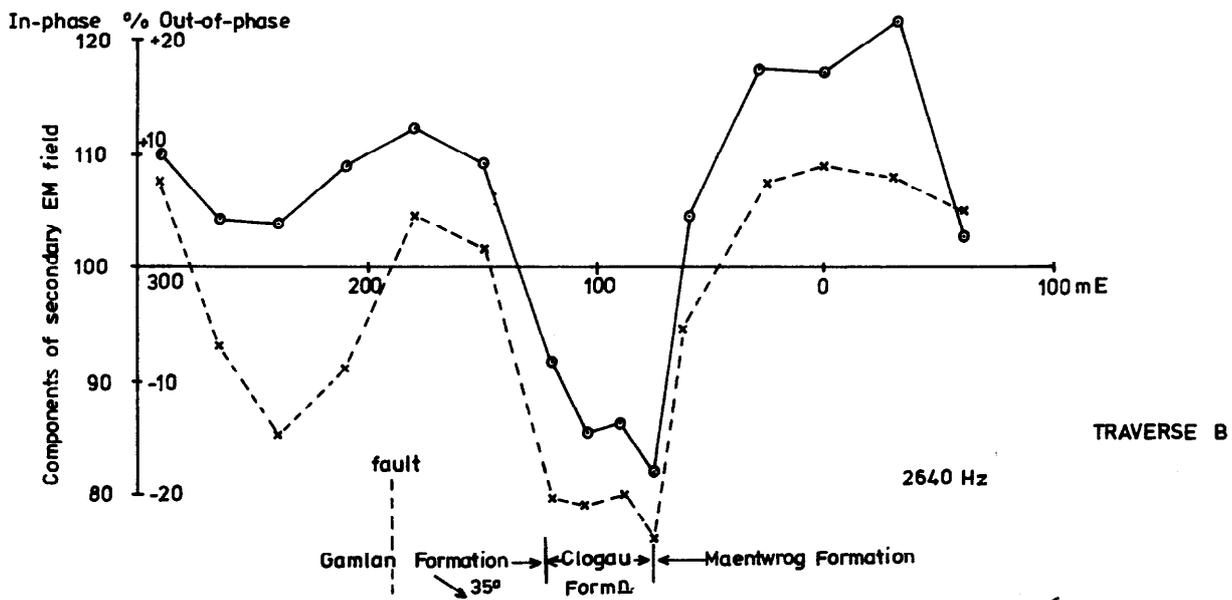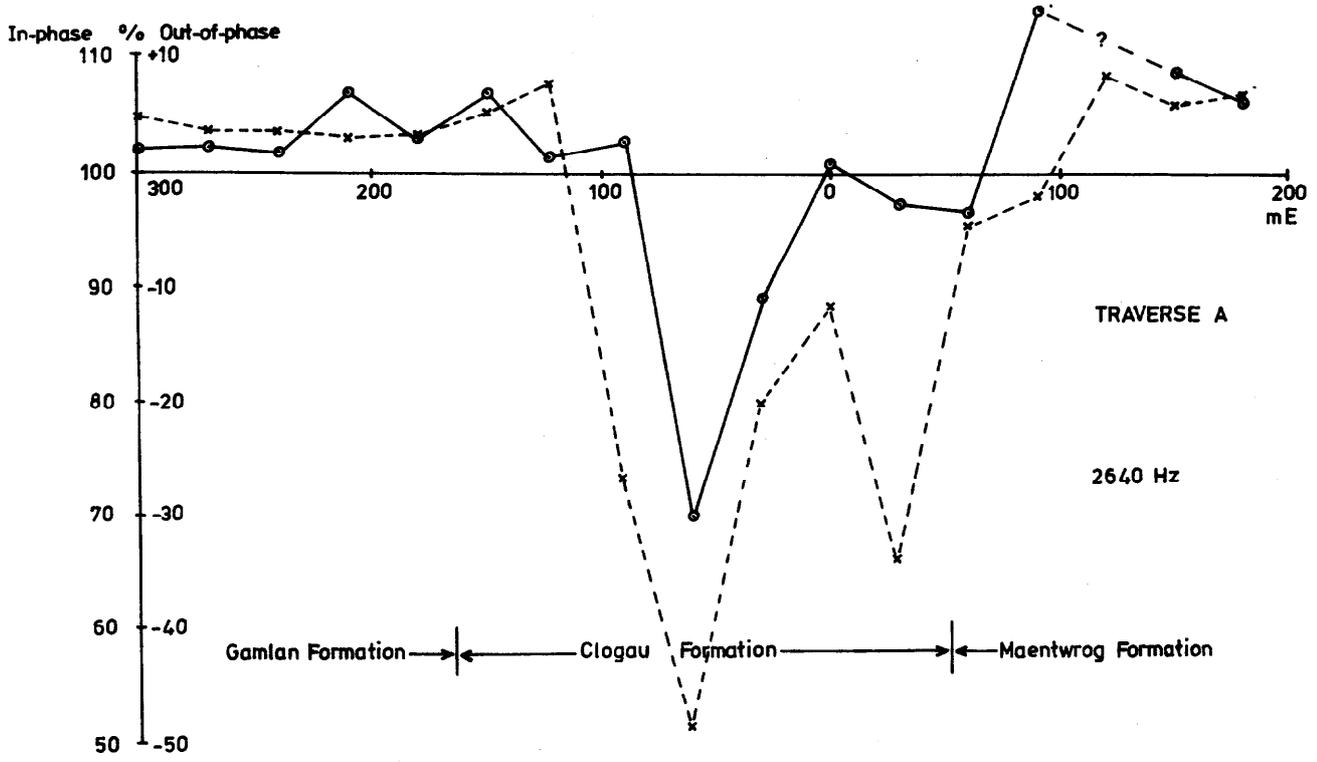
FIG.30. SLINGRAM EM DATA ALONG TRAVERSES A,B,& C AT CRAIGLASEITHIN

FIG. 31.   GEOCHEMICAL DATA FOR CRAIGLASEITHIN AREA

Table 10. Summary of analytical results in ppm for 161 soil samples from Craiglaseithin

	Median	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Cu	25	42	31	32	70	153	235	5
Pb	50	67	53	57	96	163	460	20
Zn	80	116	128	81	179	393	740	10

Table 11. Summary of analytical results in ppm for 31 rock chip samples from Craiglaseithin

	Median	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Cu	50	74	93	50	114	260	500	5
Pb	20	17	6.4	16	24	35	30	10
Zn	50	47	13	45	60	79	70	30

shows a lognormal distribution distorted at low levels by an excess of values below 30 ppm. This is probably related to a distinctly lower copper background in the sedimentary rocks compared with the microtonalite. As no inflexion point was discernible the threshold was set arbitrarily at 100 ppm (95% level).

Distributions are less clearly defined in the rocks because of the small number of samples and, in the case of lead and zinc, the small range compared with analytical precision. An inflexion point is present in the copper distribution at 100 ppm (90% level) whilst lead and zinc show no clear pattern. In view of the lack of any high results all Pb and Zn values in rocks are assumed to belong to background populations.

The rock samples show enrichment only in copper, indicative either of a weak disseminated mineralisation or wallrock enrichment in the microtonalite adjacent to veins.

The traverse diagrams (Fig. 32) demonstrate both the highly variable metal content of the subsoil and the lack of correlation between adjacent rock and soil samples. There are two main reasons for this: firstly the soil is not developed here from underlying bedrock, and secondly the selective mobility and concentration of elements, brought about by groundwater movement under variable Eh and pH conditions is high. The latter is a common feature of peaty upland environments and therefore soil anomalies may be transported. An example near the south-eastern end of traverse 1 is a high Zn value recorded in boggy, peaty soil, adjacent to rock samples with only background Zn values. In the opposite sense, high levels of Cu in bedrock on the southern half of traverse 5 are not recorded in the adjacent soil samples.

In the area as a whole anomalies and other high values are present in soils associated with (i) boggy ground, particularly adjacent to streams, (ii) the margin of the microtonalite intrusion,

(iii) suspected faults, and (iv) a north -west trending zone of quartz veins which have been tried for copper in at least two places. The anomalies in boggy ground are characterised by high zinc values and probably do not reflect underlying mineralisation. The high values in soils over faults and the margin of the intrusion may also not reflect substantial mineralisation along these structural planes, but simply mark the presence of channelways along which metal-rich groundwaters travel. However, the rough coincidence of soil anomalies on traverse 5 with an EM anomaly, the margins of the microtonalite and north-west-trending faults suggests that here, at least, hidden mineralisation is present under the soil anomalies.

Conclusions

The northern EM anomaly coincides with the known extent of the Clogau Formation, but there is no similar explanation to account for the small EM anomaly south of the intrusion.

In addition to geochemical anomalies caused by contamination, known mineralisation and concentrations in the secondary environment, the geochemical work indicates the presence of hidden, previously unknown, mineralisation, in the area of the EM anomaly and in the stream catchment on the eastern margin of the area. In addition there is weak, disseminated or wall rock copper mineralisation in the microtonalite.

The form of the hidden mineralisation is uncertain, but it is most likely to be dispersed sulphides in sedimentary and intrusive rocks along fractures and joints perhaps associated with faults. The basis for this assumption is that orientation work at Hafod-y-fedw and elsewhere suggests that the EM anomalies are more likely to be related to this type of sulphide mineralisation than veins. However, some hidden veins similar to those already tried may also be present.

61
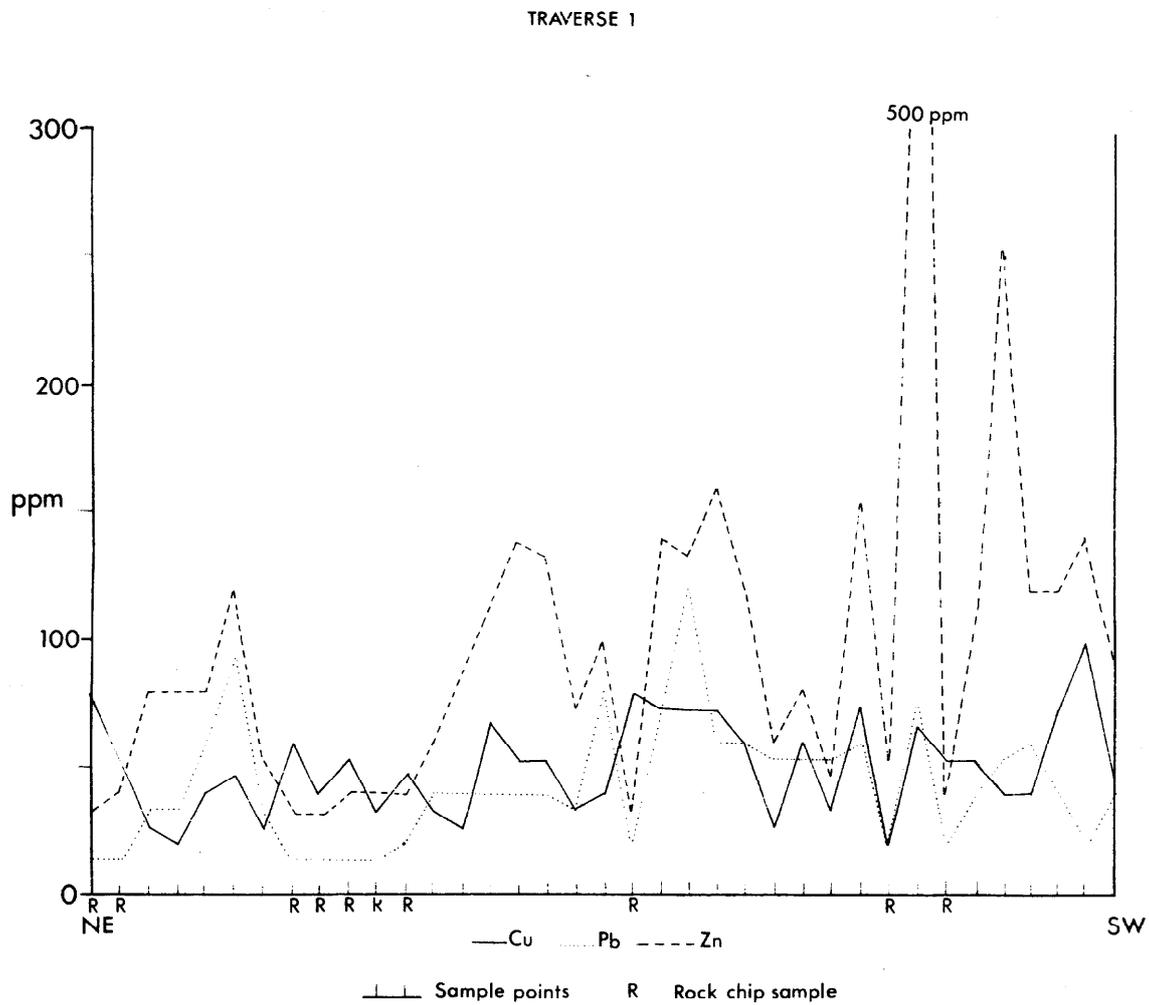
Fig. 32A. Craiglaseithin; copper, lead and zinc in soil and rock chip samples collected along traverse line 1 shown in Fig. 31

TRAVERSE 2
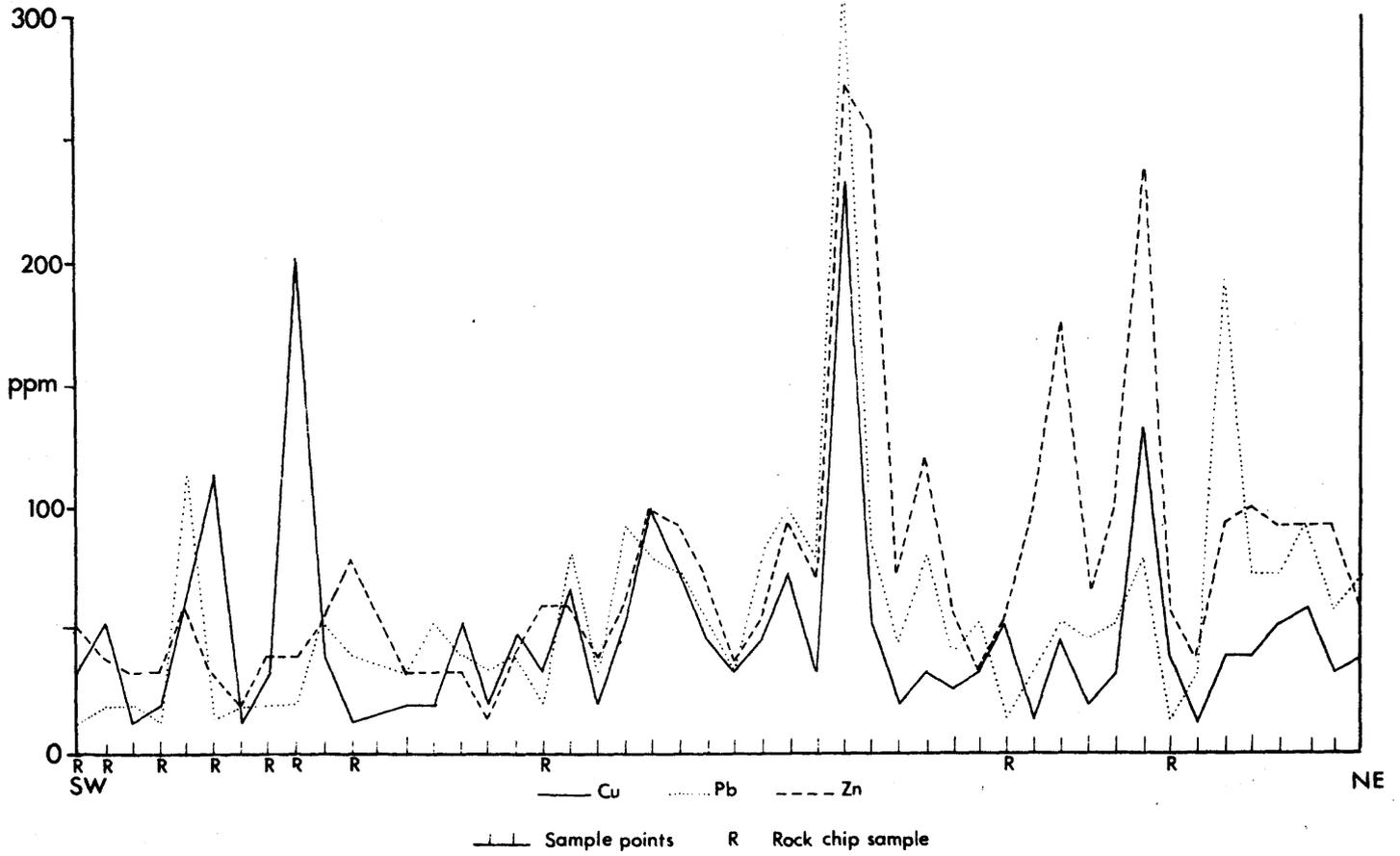
Fig. 32B. Craiglaseithin; copper, lead and zinc in soil and rock chip samples collected along traverse line 2 shown in Fig. 31
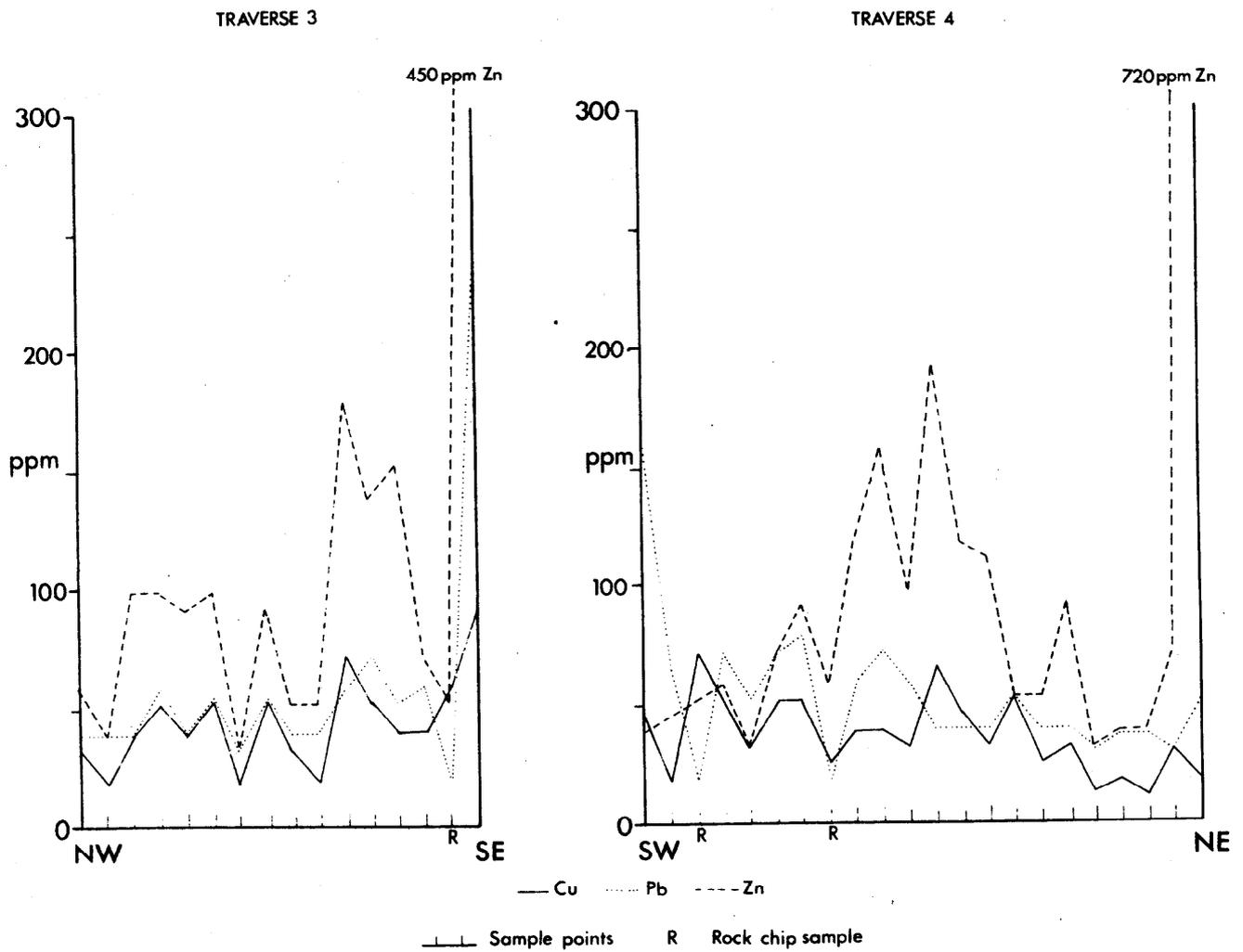
Fig. 32C. Craiglaseithin; copper, lead and zinc in soil and rock chip samples collected along traverse lines 3 and 4 shown in Fig. 31
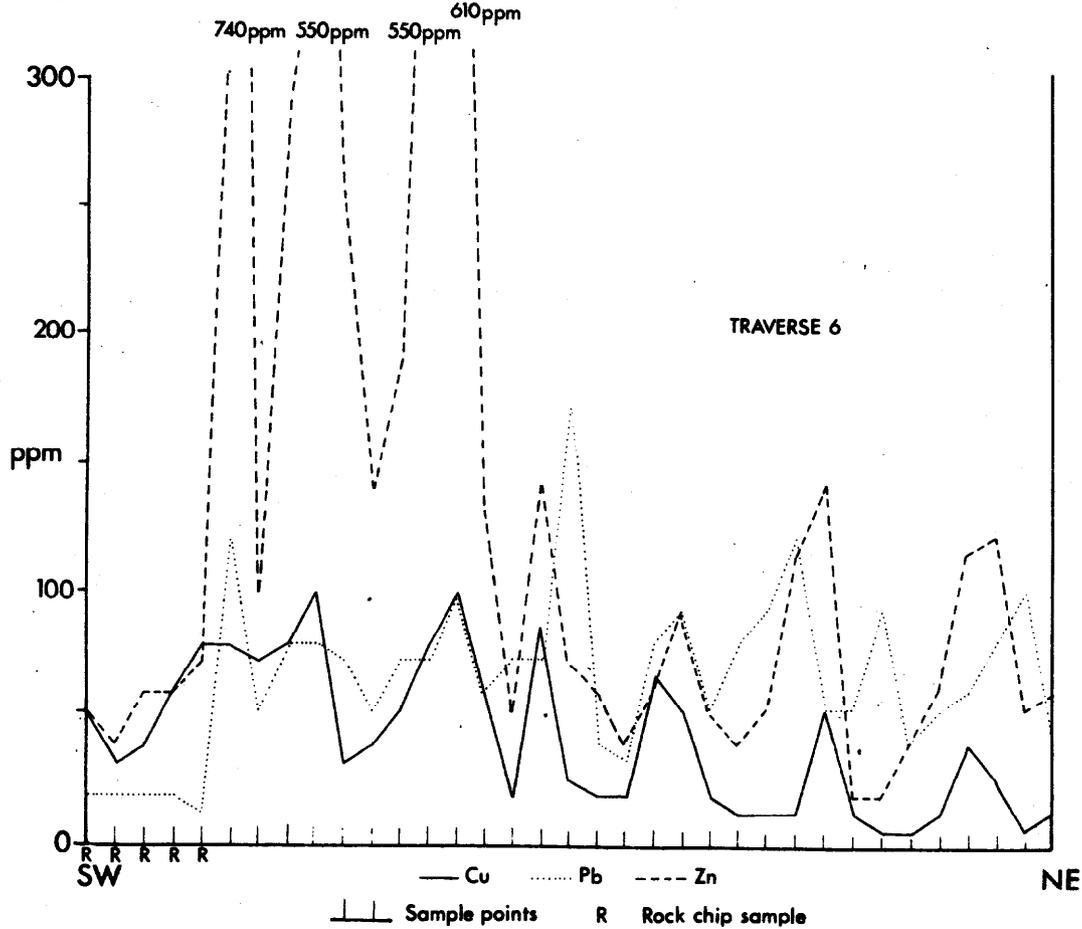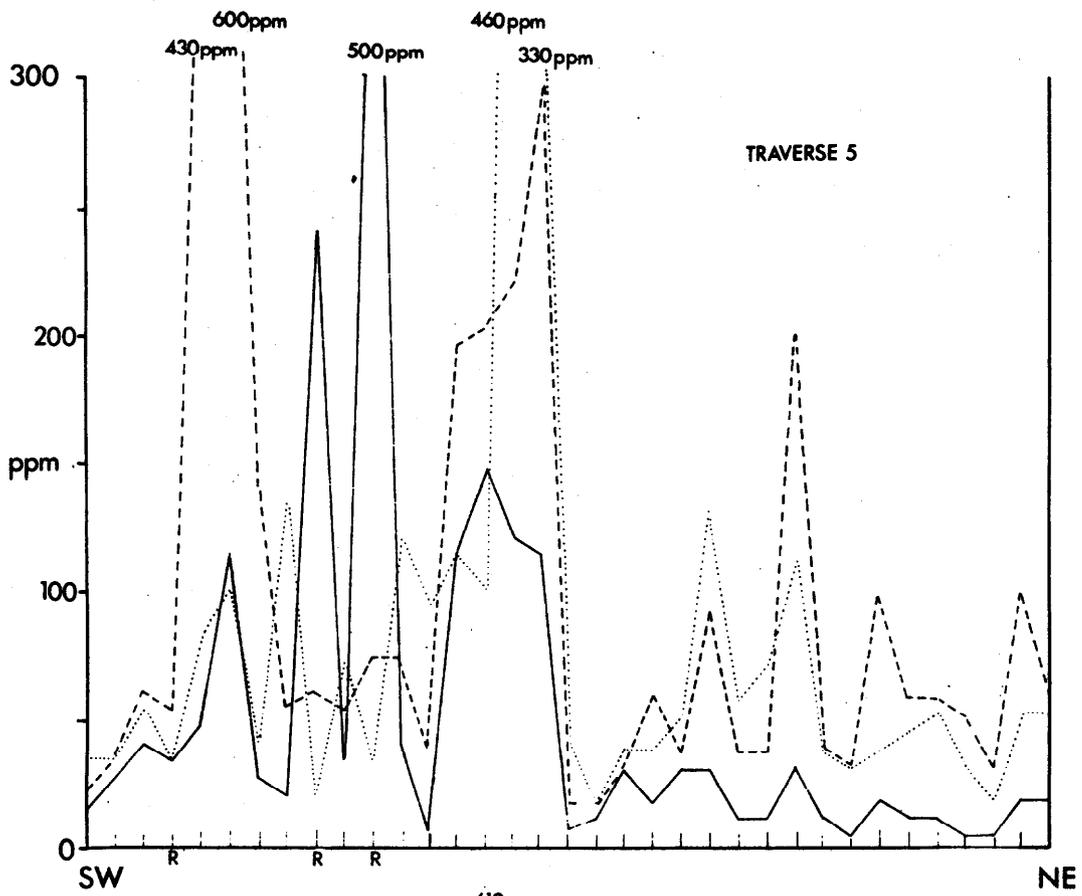
Fig. 32 D. Craiglaseithin: copper, lead and zinc in soil and rock chip samples collected along traverse lines 5 and 6 shown in Fig. 31

Some further assessment work may be worthwhile here, but the evidence to date suggests that whilst mineralisation is present it is not likely to be developed in sufficient amounts to be an economically attractive proposition.

DOL HAIDD
Centre point: SH 773 367
6-inch sheet SH 73 NE

Introduction

This area, to the south of the steep-sided Prysor valley, is a peat-covered upland area of moderate relief and poor drainage.

The investigation was carried out in two parts. In the first part the airborne EM anomalies at Allt Wen were investigated with ground geophysics. Geochemical surveys were also carried out over this anomaly and over part of the Dol Haidd intrusion because of visible signs of mineralisation. In the second part, when the mapping was completed, an I.P. survey, accompanied by soil sampling, was carried out over the ground between these two areas and to the south-east.

Geology

The superficial deposits include extensive spreads of boulder clay and peat between the hills, and large areas of head and scree on the steep hillsides.

In simplest terms the eastward-dipping succession consists of cleaved sedimentary rocks of the Ffestiniog Flags and Maentwrog formations, which have been intruded by laccoliths and sills of microtonalite and dykes of dolerite. The area is crossed by a kilometre-wide north-west trending zone containing several strong faults and both these and the intrusions disturb the bedding locally (Fig. 33).

The Ffestiniog Flags Formation consists of grey silty mudstone and siltstone interbedded with quartzose sandstone beds rarely exceeding 20 cm thick. The underlying Maentwrog Formation consists of medium to dark grey cleaved mudstone which, in the upper parts, contains thin sandy laminae and rare sandstone beds. The proportion of sandstone increases downwards and in the north-west of the area there is a basal unit of thick sandstone beds.

There are more than a dozen intrusions of microtonalite in the area, penetrating all levels of the Maentwrog anf Ffestiniog Flags formations and probably forming an interlinked system of laccoliths, sills and dykes. In places such as on the south-east side of the Dol Haidd intrusion, in the Braich-y-Ceunant, there is a complex interfingering of intrusive and adjacent country rock, accompanied by brecciation along contacts and veining of intrusive rock in the sedimentary rock. The microtonalite contains euhedral phenocrysts of plagioclase and amphibole. The feldspar, which is usually albitised, is altered to sericite with minor chlorite and calcite, whereas the amphibole phenocrysts are always pseudomorphed by chlorite and calcite. The groundmass usually consists of a fine-grained equigranular mosaic of feldspar and quartz with subordinate chlorite, calcite and a little epidote. In a few specimens trachytic texture is exhibited; in others, especially from dominantly fine-grained intrusions, the groundmass is composed of a medium-grained mesh of plagioclase crystals some of which are unaltered, with quartz filling the interstices.

Several dolerite dykes, which cut the Dol Haidd intrusion, are highly altered and appear to pre-date the quartz veining.

Mineralisation

There are many quartz veins in the area. Some trending north-west and up to 3 m thick and one trending east-north-east occur in major faults. Most of the veins contain pyrite. Chalcopyrite has been found in veins at SH 7728 3685 and SH 7603 3686, while at SH 7658 3634 arsenopyrite is also present. Several veins contain malachite staining in fractures.

One of the veins, presumed to be the one which crops out at SH 7663 3635, has been worked in a trial level at SH 7665 3619. Samples of vein material from the tip contain calcite, quartz, pyrite and chalcopyrite with less conspicuous sphalerite and galena. Another vein, which contains traces of chalcopyrite and pyrite, has been tried at surface at SH 7728 3685 and can be traced for over a kilometre along a north-west-trending fault. At SH 7704 3712 there is a shallow digging along a discordant contact between microtonalite and siltstone at a position which is close to the north-western projection of this vein. Though there are no signs of the vein here there are thin veinlets of pyrite and chalcopyrite in the sedimentary rocks.

Besides veins there are signs of disseminated mineralisation in two places. Firstly, in the north-western part of Dol Haidd intrusion malachite was observed lining joints in the microtonalite. Pyrite is disseminated throughout this intrusion and a little chalcopyrite has been observed in places. Secondly, in Braich-y-ceunant at SH 7672 3613 and for about 200 m upstream rocks of the Maentwrog Formation are intruded by a number of thin sills and dykes of porphyritic microtonalite. At some contacts the sediments are brecciated and impregnated by intrusive rock. Pyrite is abundant in joints and disseminated through both rocks, while chalcopyrite is locally abundant. This location is close to a trial level and a number of samples taken from the tip show that mineralised country rock was encountered in the workings (Table 12). The analyses indicate that the vein mineralisation, while dominantly cupriferous, has, in common with gold lodes in the Gold-belt, associated high Zn and Pb values. By contrast, all the samples of mineralised country rock have very low Pb and Zn in association with high Cu, a relationship which compares with that found in the porphyry copper mineralisation at Coed-y-Brenin.

FIG. 34. GEOPHYSICAL DATA FOR DOL HAIDD AREA

Contours of in-phase component of airborne EM in ppm

Ground EM traverses

chargeability >50ms
apparent resistivity
<500 Ω.m
>2000 Ω.m

I.P. traverses showing areas of anomalous values

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Table 12. Copper, lead and zinc contents of samples from a trial level at Dol Haidd

	Sample	Cu ppm	Pb ppm	Zn ppm
1	Highly altered microtonalite with pyrite and chalcopyrite aggregates and carbonate veins	2700	70	60
2	Chips from several boulders of pyritised microtonalite	160	50	40
3	Altered baked siltstone with pyrite	110	40	40
4	Pyritised dark grey mudstone	950	40	50
5	Brecciated, altered microtonalite	15	10	20
6	Calcite-quartz-pyrite-chalcopyrite vein	15000	6000	5600

Geophysics

The initial ground EM survey was aimed at confirming an extensive, but irregular, area of airborne EM anomalies with values up to 100 ppm. The anomalies have an easterly trend. The area is also crossed by a zone, trending north-north-west, marked by strong negative magnetic anomalies with a variation of up to 250 nT.

Seven ground EM traverses (Fig. 34) measured over the target failed to confirm the airborne anomalies. Many of the traverses show non-systematic variations which might in part be due to a large power-line running east-north-east in the northern part of the airborne anomaly. As no other cause can be suggested for the remaining part of the airborne anomaly it must be assumed that it is due to EM noise, possibly from a tele-vision transmitter 4 kilometres to the west-north-west. The variations seen in the in-phase components of the ground results are caused by the inaccuracies in slope corrections when operating in steep country.

Three trial IP dipole-dipole traverses were measured over the high ground to the south of the EM survey. The IP results show a number of features, some of which have geological signifi-cance. The higher values of apparent resistivity (Ω 2000 m) generally coincide with outcrops of microtonalite, whereas the low values (Ω 500 m) tend to fall over areas of peat or across major faults as at SH 770 365 and SH 773 361, where there are also values of chargeability above 50 ms. A similar coincidence of low resistivity and high chargeability occurs at SH 777 369. These could result from faults acting as paths for hydrothermal fluids, which could produce either clay or sulphide mineralisation, both of which cause IP anomalies. Elsewhere high values of chargeability occur over peat which covers various rock-types; these anomalies might be due to EM coupling with the IP receiver or unexposed polarised bodies.

Geochemistry

Five reconnaissance survey drainage sites cover this area (Fig. 35). When compared with threshold values established for the Harlech Dome all the stream sediments yielded anomalies. Panned concentrate anomalies are only found at sites downstream of old trials and near a farm at SH 7559 3643 where a weak tin anomaly suggests that contamination is at least a contributary cause to the anomalies at this site.

All sediment samples show anomalous arsenic values, and all except one contain anomalous amounts of zinc, cobalt and manganese as well as a high iron content. It is significant that the exception is the only sample collected in a peaty upland environment (at SH 7781 3732) and this is the only site to show an anomalous water result. These sediment anomalies, together with weak copper and lead anomalies in sediment are, therefore, probably related to the generation of hydrous oxide precipitates in the lower reaches of the streams. The presence of high arsenic results, the lack of copper in water anomalies, and to a lesser extent, the presence of moderate zinc but only weak copper enrichment suggest vein-type mineralisation in the area.

Soil samples were collected in two phases: 'A Series' traverses were placed to investigate airborne geophysical anomalies and observed signs of mineralisation; the 'B Series' were sampled in conjunction with the IP traverses. Soil samples, which were collected at 20 m intervals, consisted mainly of boulder clay taken below organic rich topsoil or peat. All the samples on traverse A8 consist of talus fines (Hoffman, 1977).

Rock chip samples were collected (R1-R4, Fig. 35) on Moel Uchaf Dol Haidd where super-ficial deposits were very sparse. All except two, which are dolerite and whose analytical results were indistinguishable from the others, consist of microtonalite. Some samples contain quartz veins, pyrite, malachite staining, and in one case minor chalcopyrite. A summary of the analytical results for the soil and rock samples is given in Table 13.
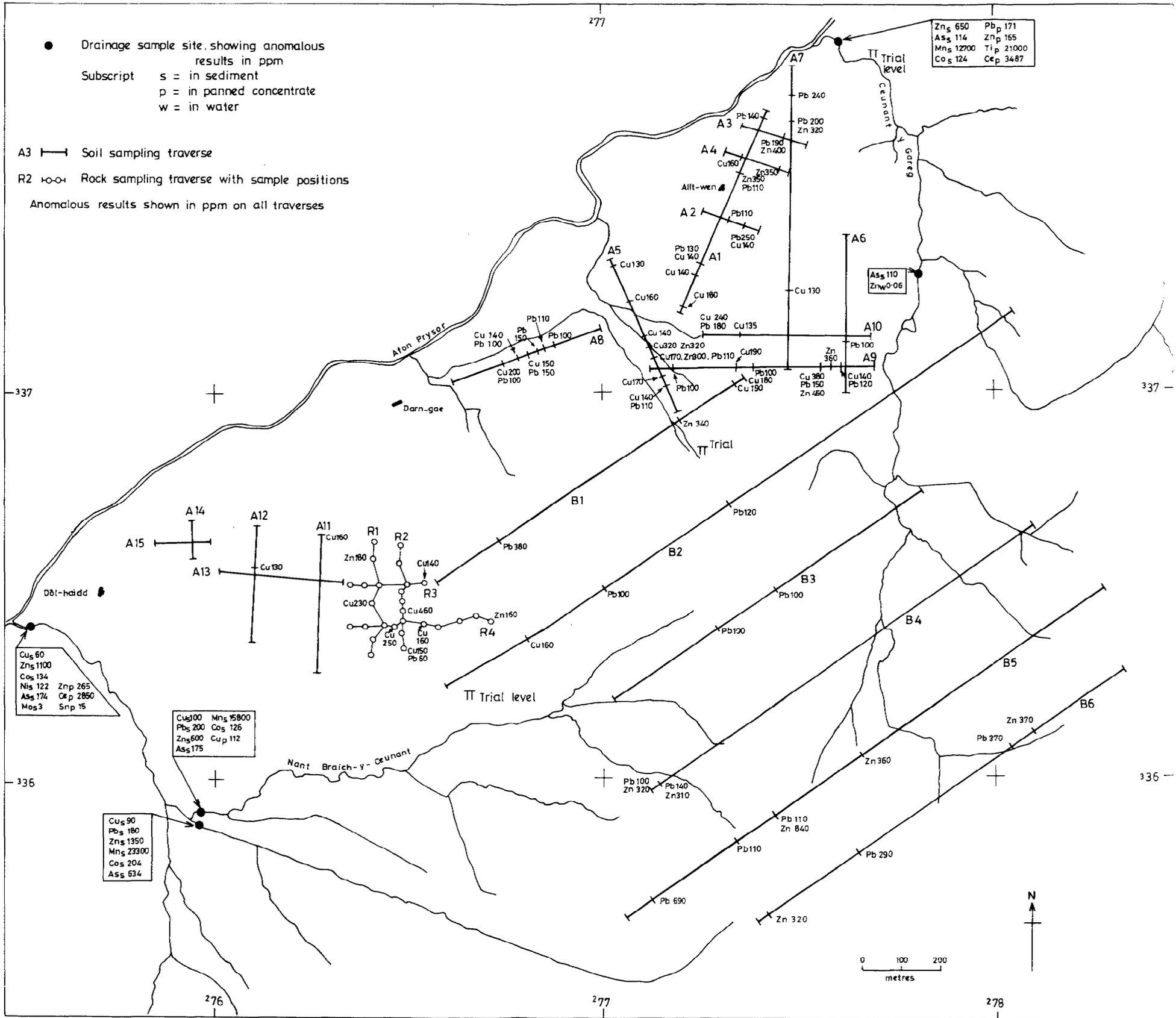
FIG. 35.   DOL HAIDD : LOCATION OF GEOCHEMICAL SAMPLES AND ANOMALOUS RESULTS

Table 13. Summary of analytical results in ppm for rock chips and soils from Dol Haidd

	Median	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Rock Chips (27)								
Cu	60	88	97	56	144	380	460	10
Pb	10	17.4	12.3	15.2	25.9	44.1	60	10
Zn	40	55	41	45	85	162	180	10
Soils (568)								
Cu	25	35	41	21	60	158	380	<3
Pb	42	47	45	39	68	120	690	10
Zn	65	80	75	60	127	269	840	10

The distribution of copper, lead and zinc in rocks is approximately lognormal. Threshold levels were set to coincide with breaks at approximately 100 ppm Cu (80% level), 50 ppm Pb (98% level) and 140 ppm Zn (95% level), in the distributions observed on histograms. The same breaks have been seen on plots of all microtonalite samples analysed from the Harlech Dome (n = 68) and are considered to be significant in terms of mineralisation. Values above these threshold levels are plotted on Fig. 35. It is clear from the traverse diagrams (Fig. 36) that high zinc values show no correlation with high copper content, but the single slightly elevated lead result does correspond with a copper peak. Neither the high copper nor the high zinc values occur in samples containing quartz veins, and it is suspected that the higher zinc values are related to a high content of pyrite. Although chalcopyrite or secondary copper minerals were recorded in nearly all the samples giving high copper results, there was no visible copper mineralisation in the sample which gave the highest copper result. High values do not form a clear spatial pattern and they are probably recording weak, patchily developed disseminated mineralisation in the microtonalite.

All three elements show complex distribution patterns in soils. Copper shows a sigmoidal form on a log cumulative frequency plot with inflexion points at 20 (50% level) and 130 (95% level) ppm, which indicate the presence of two populations whose median values are 20 ppm and 50 ppm. An examination of the traverse diagrams (Fig. 36) shows that the two groups are unrelated to the distribution of the two main lithologies (sedimentary rocks and microtonalite). It is possible, however, that they reflect variations in lithological type within the microtonalite intrusions or variations in alteration and style of mineralisation associated with the intrusions.

The copper threshold level was set at 130 ppm, the upper inflexion point, above which all results can be considered anomalous but, in areas of low background, values above 55 ppm may be significant (97.5% level for the lower population).

The zinc distribution shows inflexion points at

40 (22% level), 170 (90% level) and 300 (97% level) ppm. As in the case of copper the threshold level was set at the higher (300 ppm) level but distinct peaks above approximately 160 ppm may represent the anomalous part of a low population. The lead distribution contains inflexion points indicating the presence of an anomalous group of samples above 95 ppm (96% level). Values of Cu > 130 ppm, Pb > 95 ppm and Zn > 300 ppm are shown on Fig. 35.

Three distinct areas can be distinguished from the anomalous results.

(i)   In the north, covered by traverses A1-A10 and the north-east part of B1, Cu, Pb and Zn anomalies are recorded in the same or adjacent samples and are probably related to vein mineralisation. With one exception, there is no obvious spatial relationship between mapped veins and the anomalies, which, in this peaty, upland environment may be transported. The exceptional case are the anomalies on the southern section of traverse A5, at SH 7720 3692 on traverse B1, and at SH 7734 3676 on B2; these are probably related to the north-west trending structure tried at SH 7728 3685.

(ii)   The western part of the area, containing traverses A11-A15, and the extreme south-western part of traverses B1 and B2, contain no anomalous lead and zinc values. Evidence from geological mapping and rock chip sampling suggests that the few high copper values are related either to weak, patchy, disseminated mineralisation in the microtonalite or chalcopyrite-bearing veins. The western margin of this area coincides with the most westerly north-north-west-trending fault shown on the geological map (Fig. 33), which is related to a major lead anomaly on traverse B1.

(iii)   The south-eastern part of the area, containing traverses B3-B6 and possibly parts of B2, is characterised by an absence of anomalous copper results. Scattered lead and zinc anomalies are recorded across the whole area, and zinc anomalies in particular show a closer coincidence with stream courses than geological structures suggesting a secondary origin. Only the large zinc anomaly at SH 7743 3587 on traverse B5, which is spatially related to a major fault, and
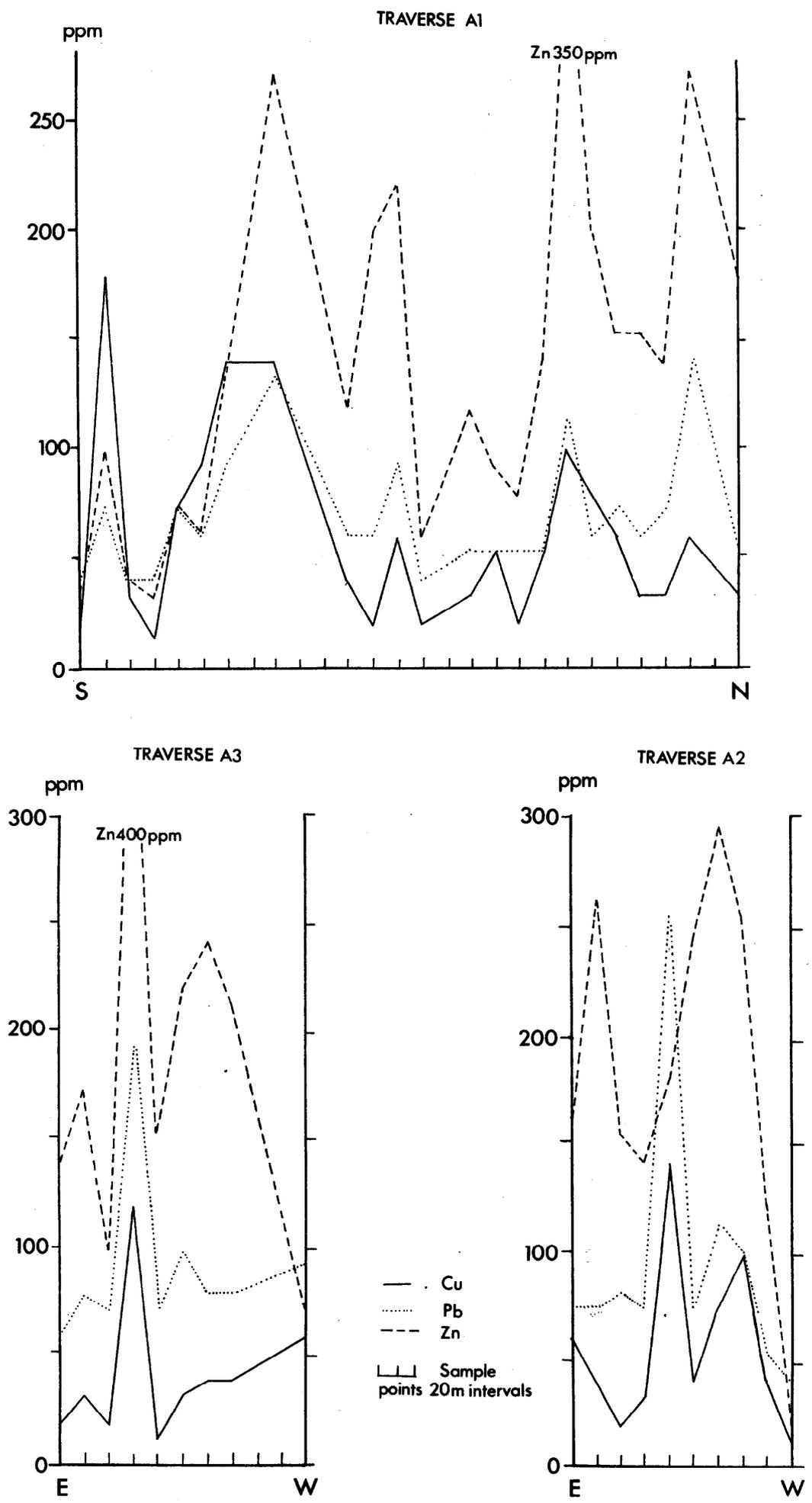
Fig. 36A Dol Haidd; copper, lead and zinc in soil samples collected along traverses A1 — A3 shown in Fig. 35

Fig.36B Dol Haidd; copper, lead and zinc in samples collected along traverses A4 – A6 shown in Fig.35

71
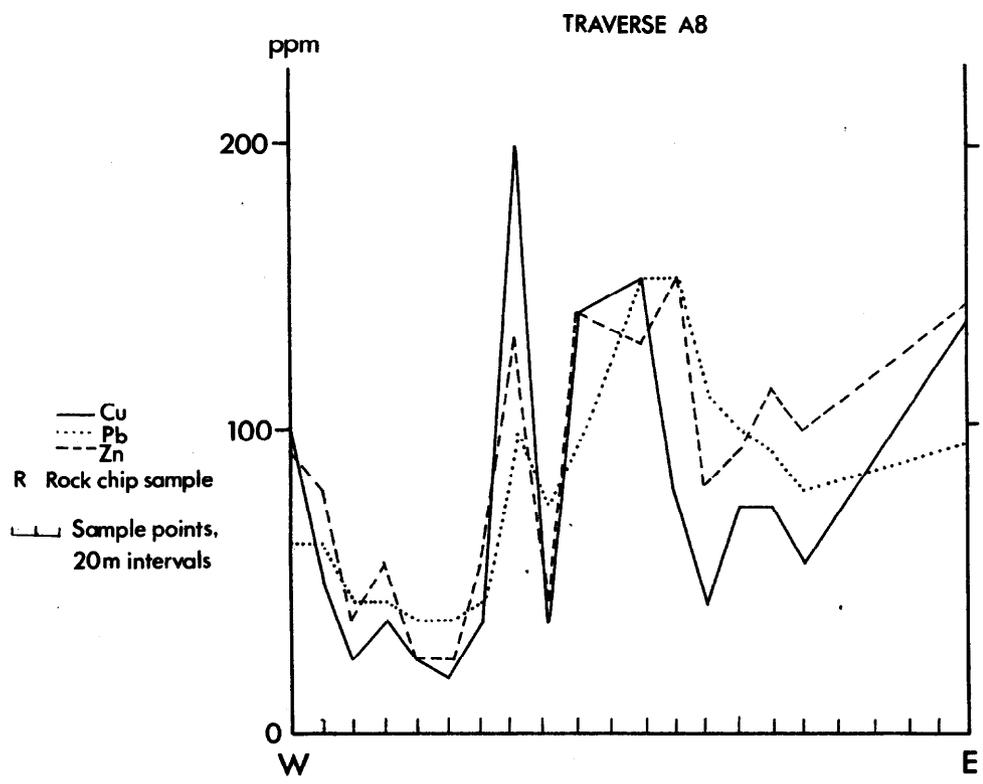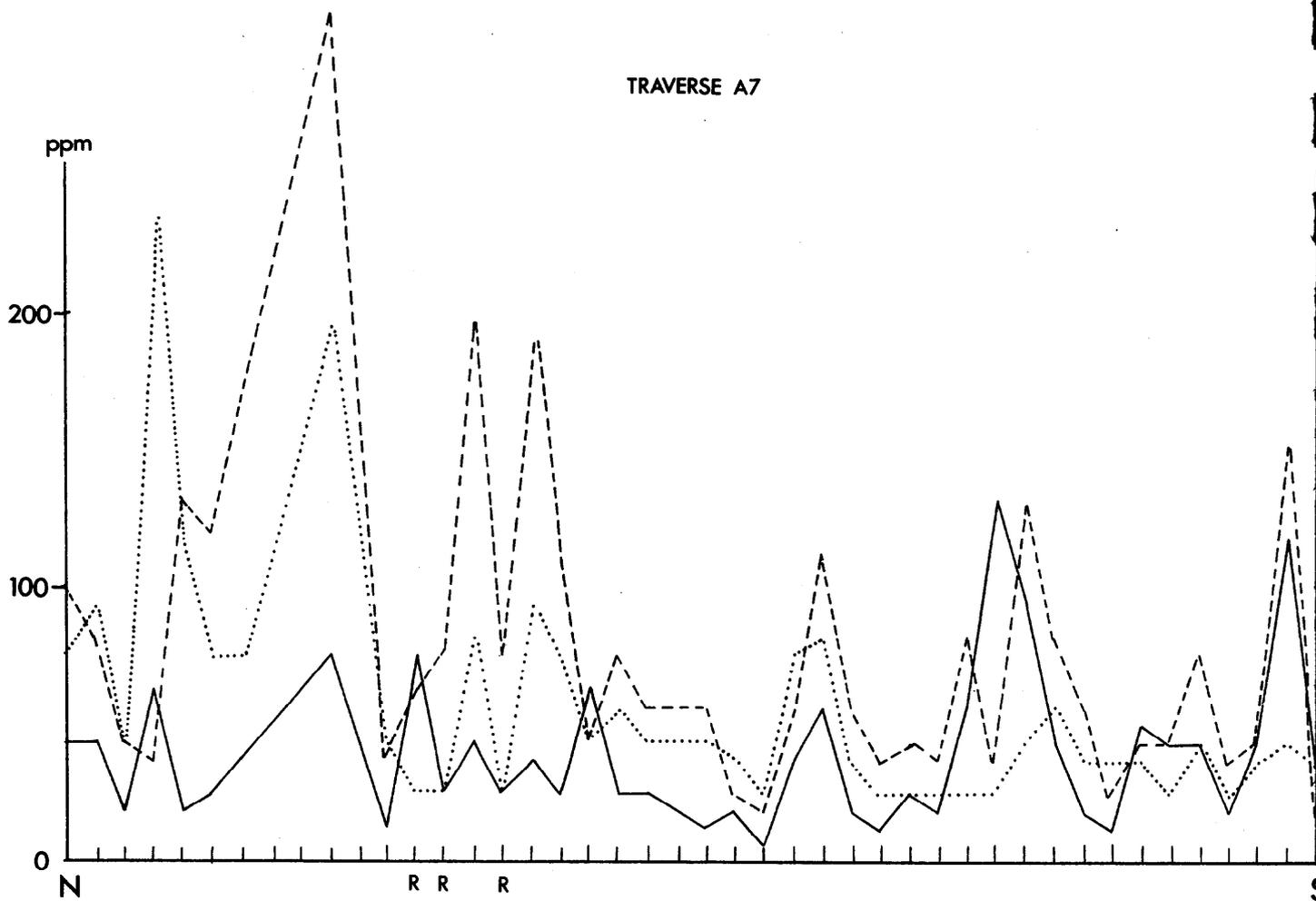
Fig. 36C Dol Haidd; copper, lead and zinc in samples collected along traverse A7 – A8 shown in Fig. 35

72
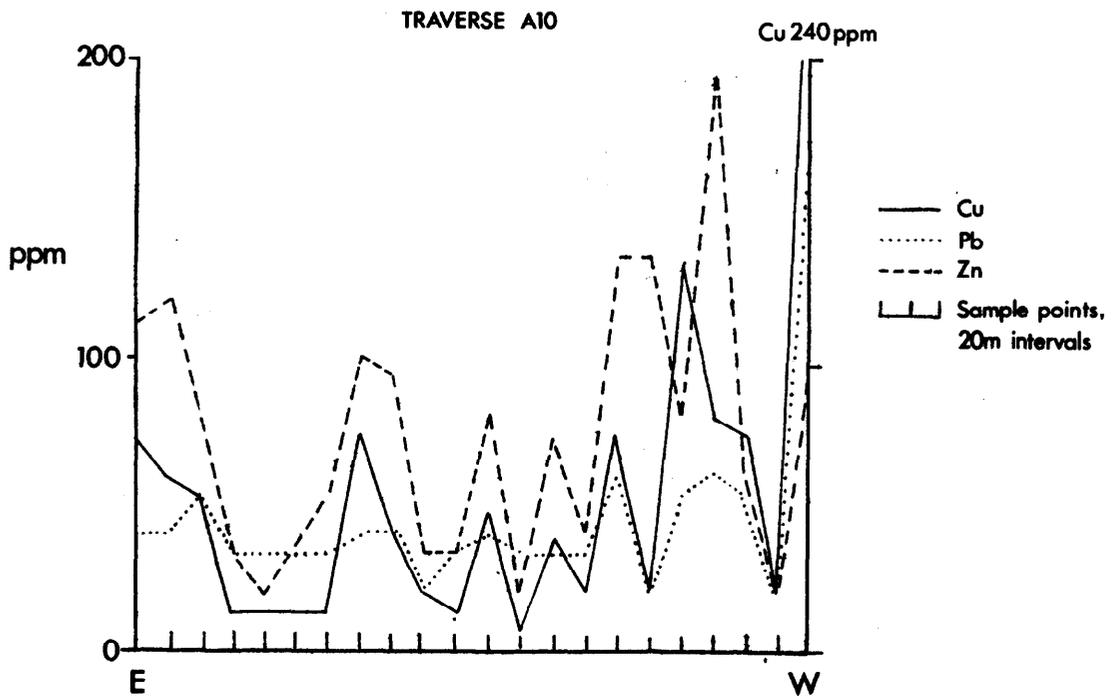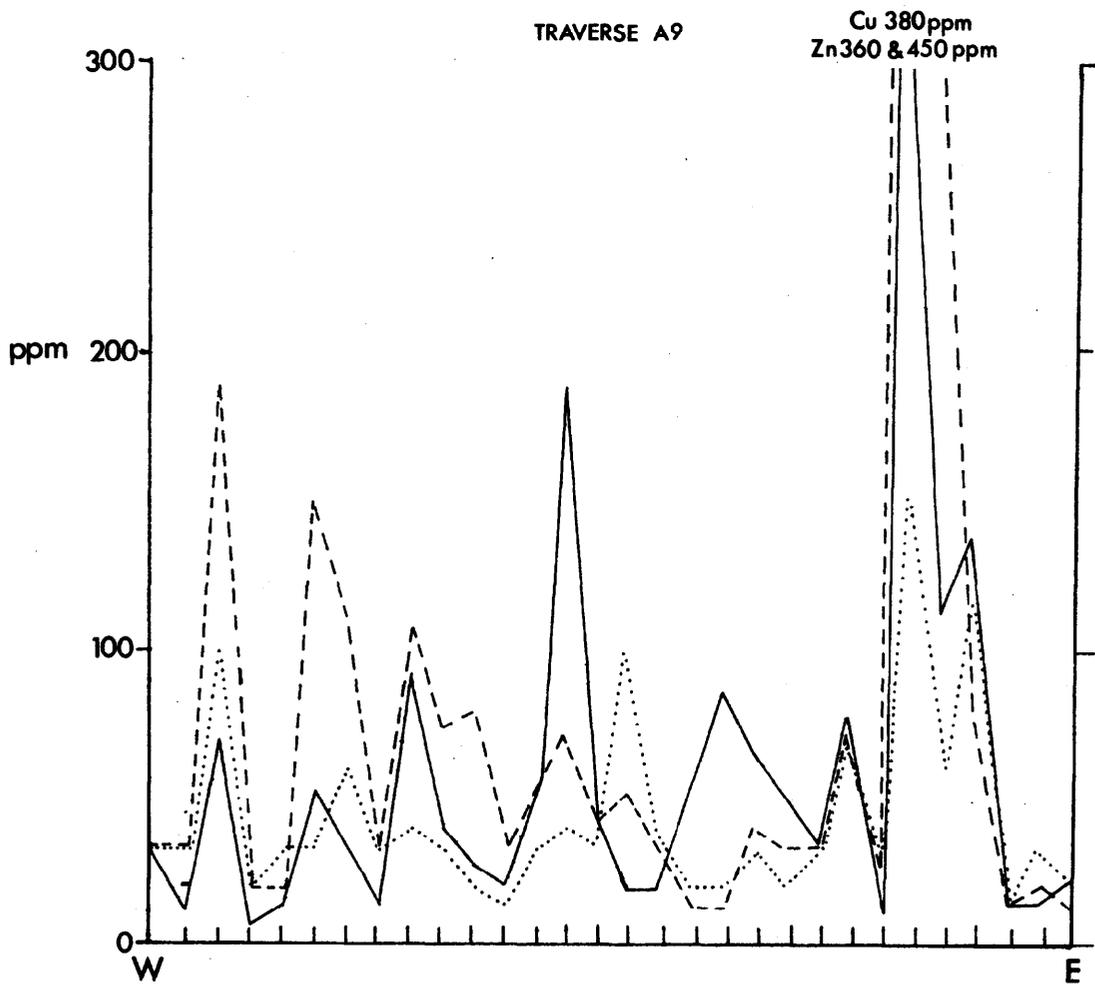
Fig 36D   Dol Haidd; copper, lead and zinc in soil samples collected along traverses A9 – A10 shown in Fig. 35

TRAVERSE A11

TRAVERSE A12

TRAVERSE A13

TRAVERSE A14

TRAVERSE A15

——— Cu   .... Pb   – – – Zn

⌐_⌐_⌐ Sample points, 20m intervals
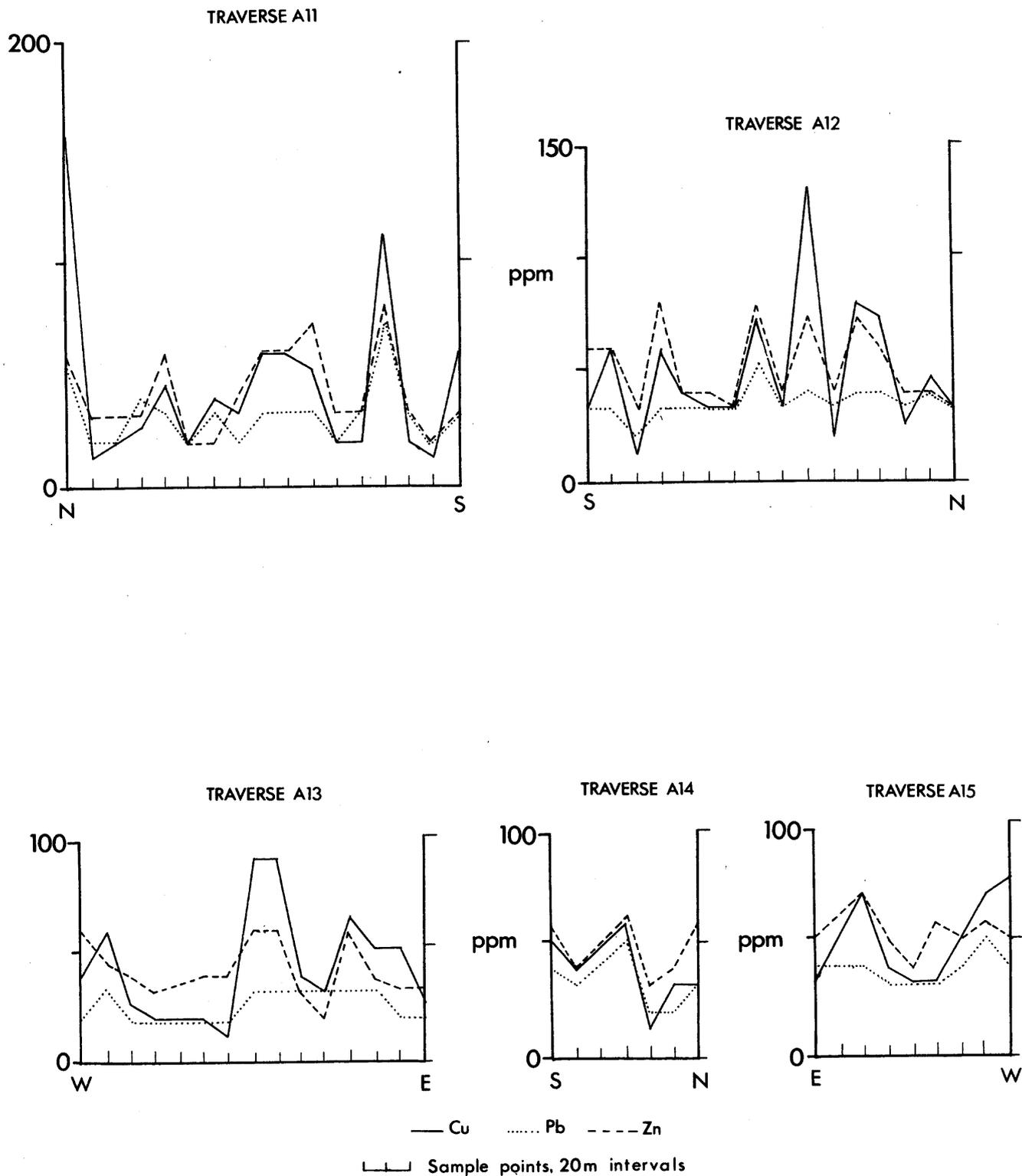
Fig.36E Dol Haidd; copper, lead and zinc in soil samples collected along traverse lines A11 – A15 shown in Fig.35

74
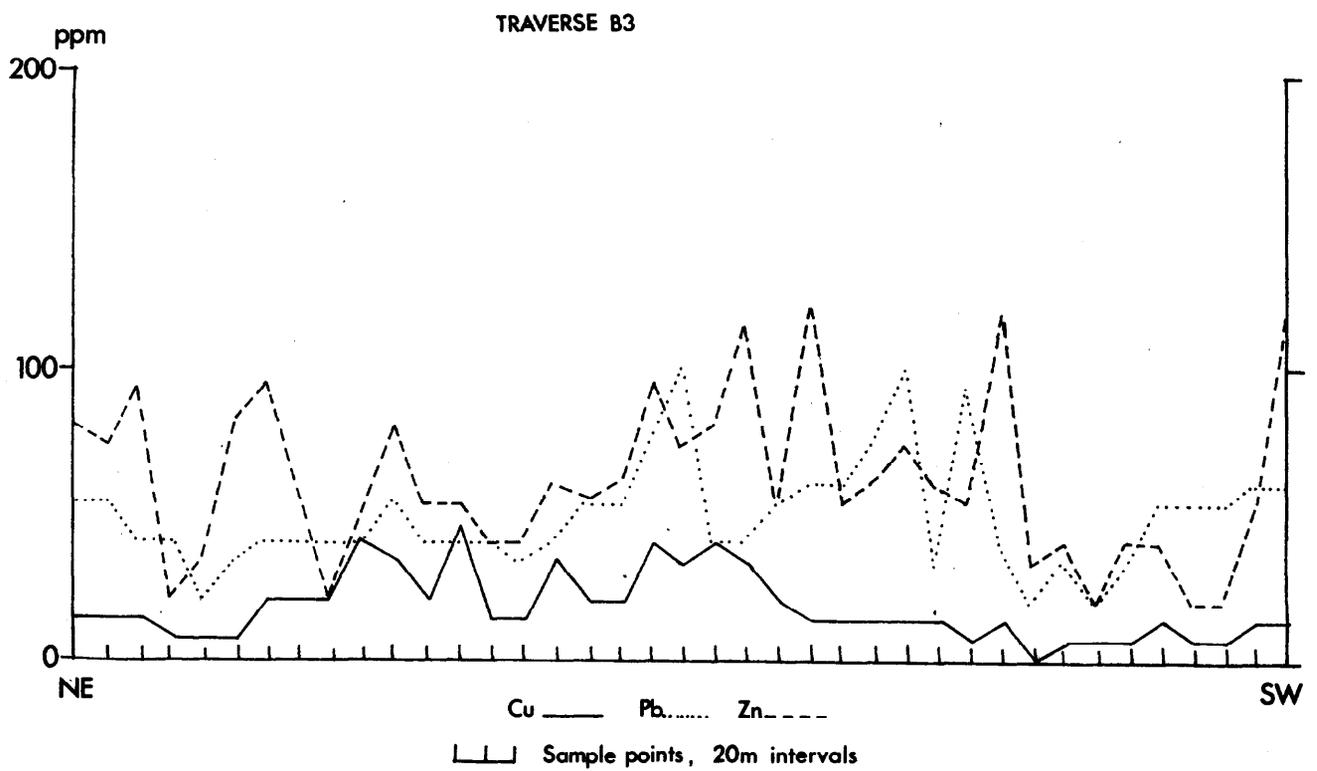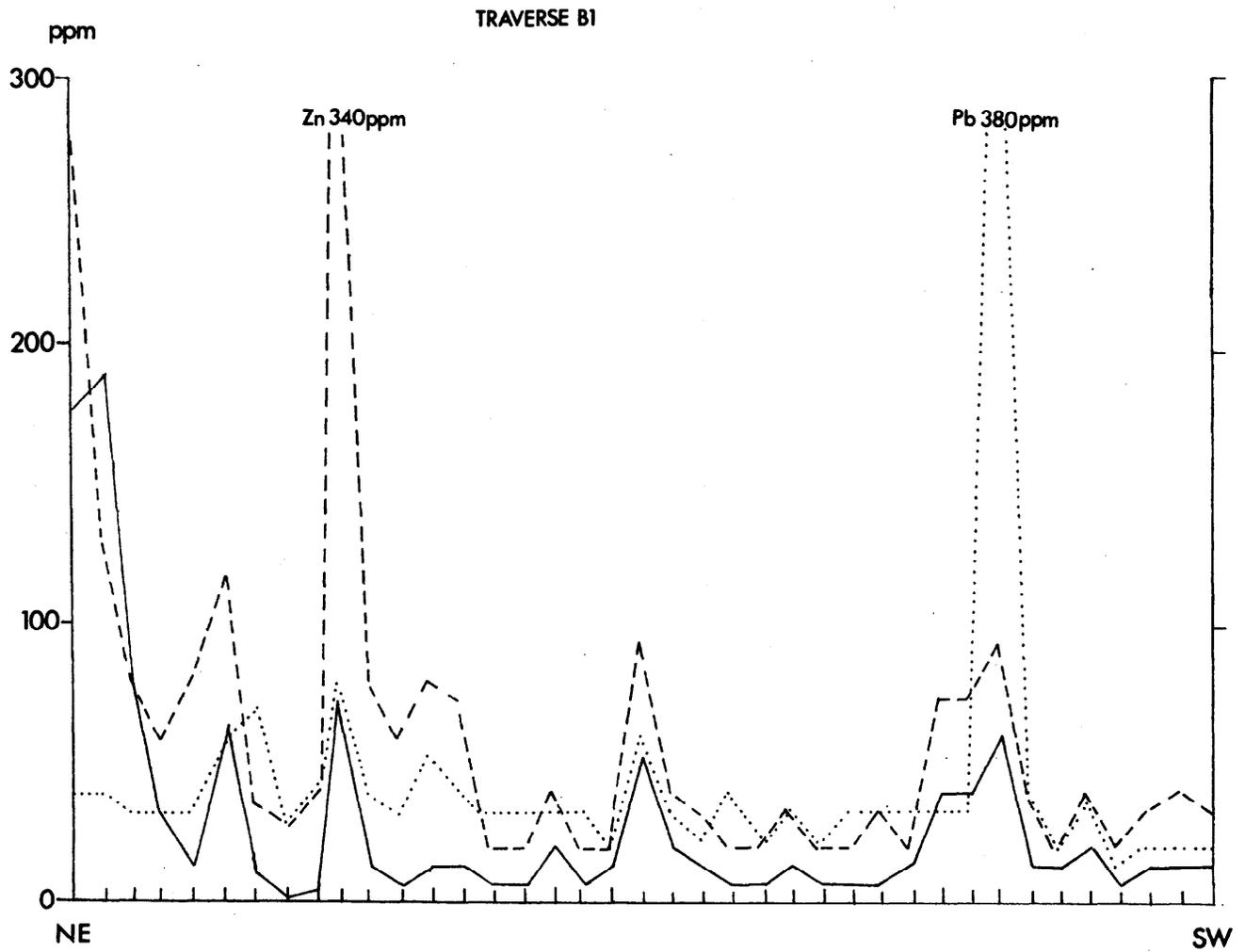
Fig.36F Dol Haidd; copper, lead and zinc in soil samples collected along traverse lines B1 and B3 shown in Fig.35

TRAVERSE B2
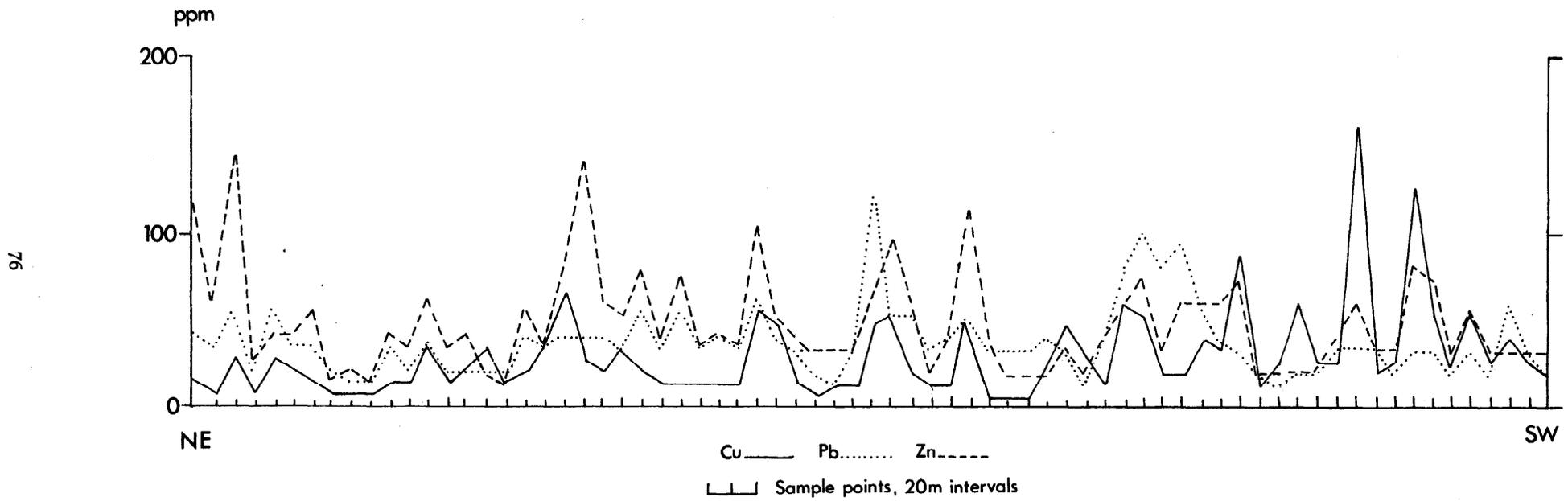
Fig.36G   Dol Haidd; copper, lead and zinc in soil samples collected along traverse line   B2 shown in Fig.35
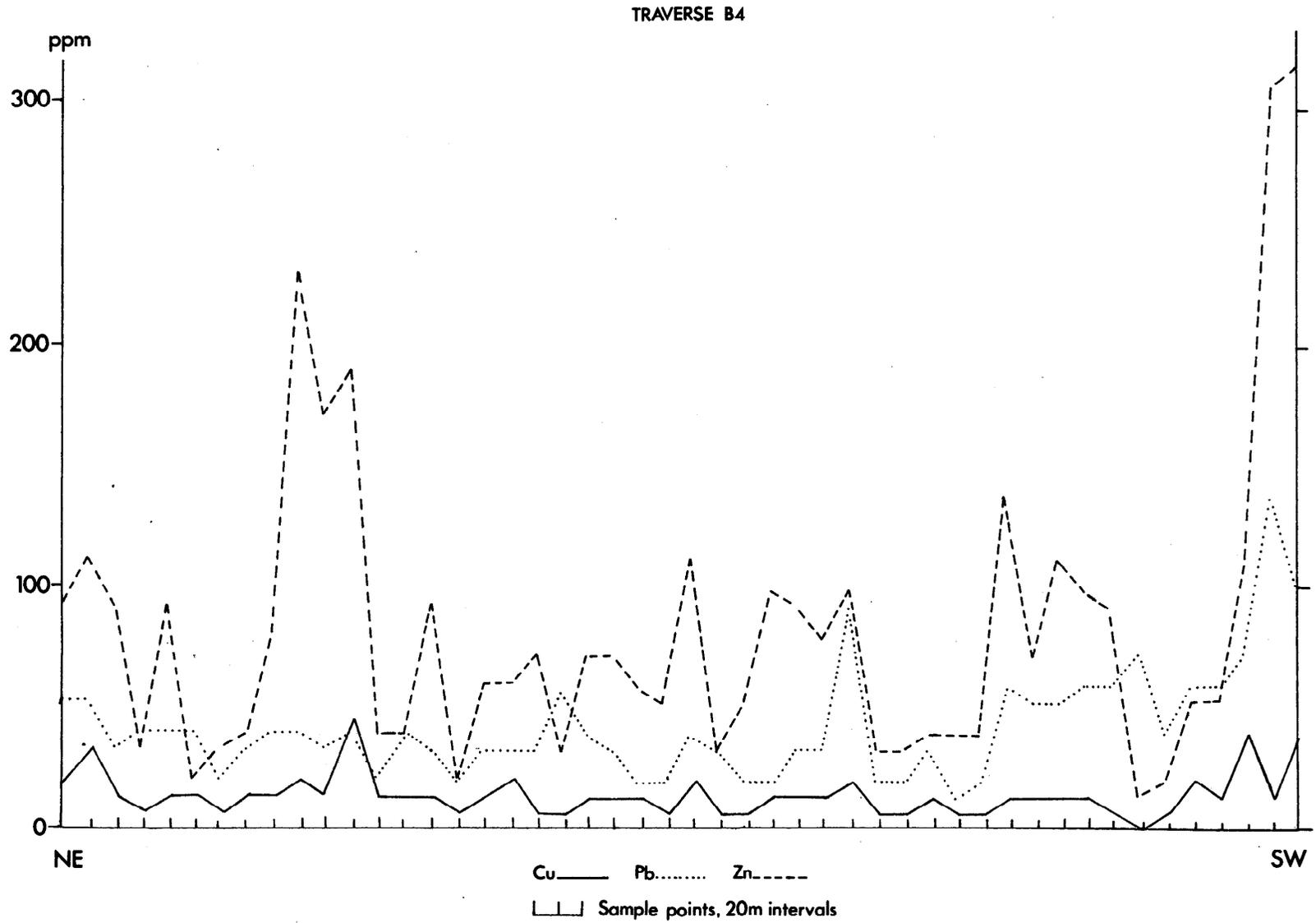
TRAVERSE B4

Fig.36H Dol Haidd; copper, lead and zinc in soil samples collected along traverse line B4 shown in Fig.35

TRAVERSE B5
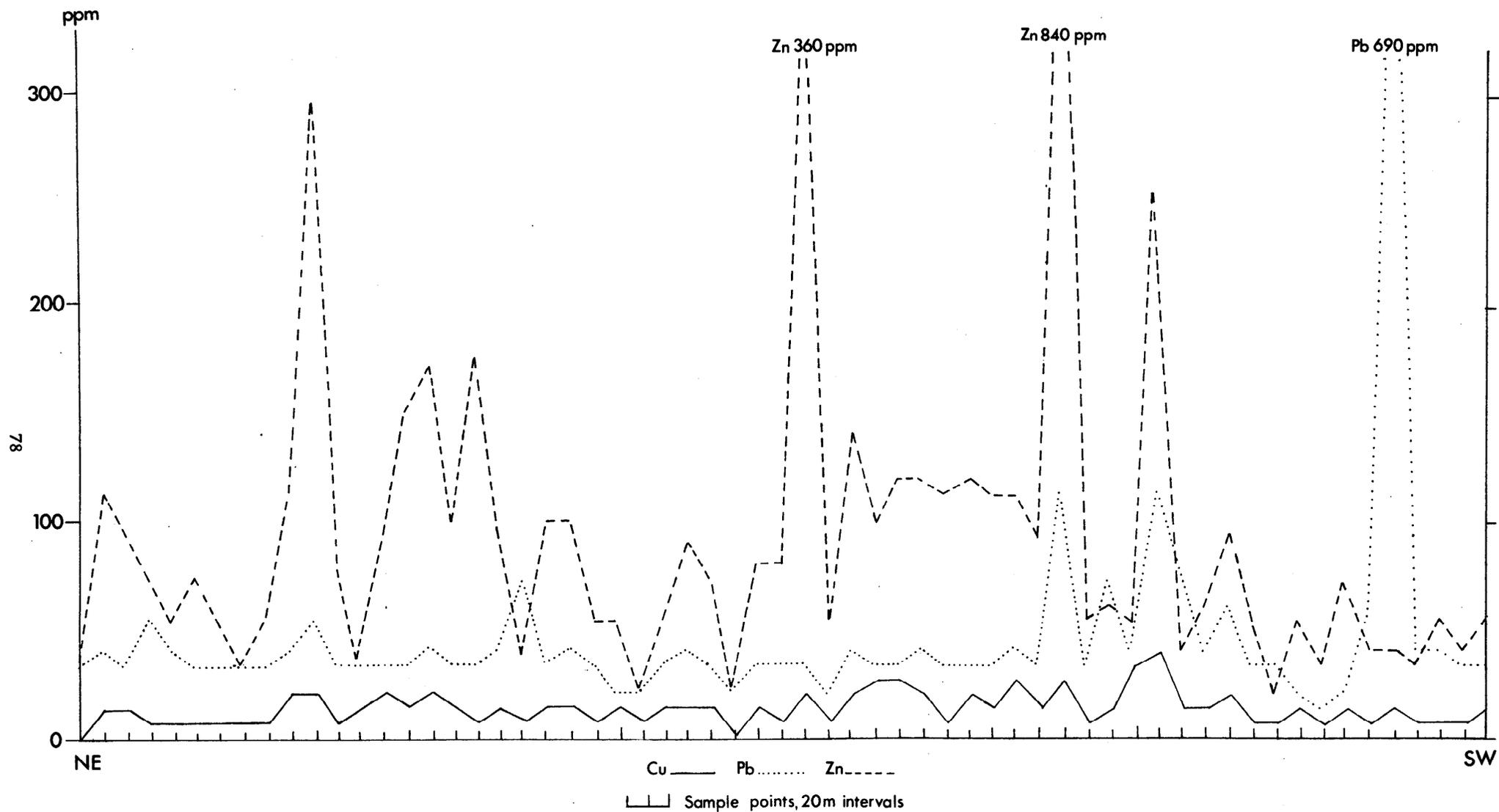
Fig.36J DolHaidd; copper, lead and zinc in soil samples collected along traverse line B5 shown in Fig.35

TRAVERSE B6

Cu
Pb
Zn
Sample points, 20m intervals
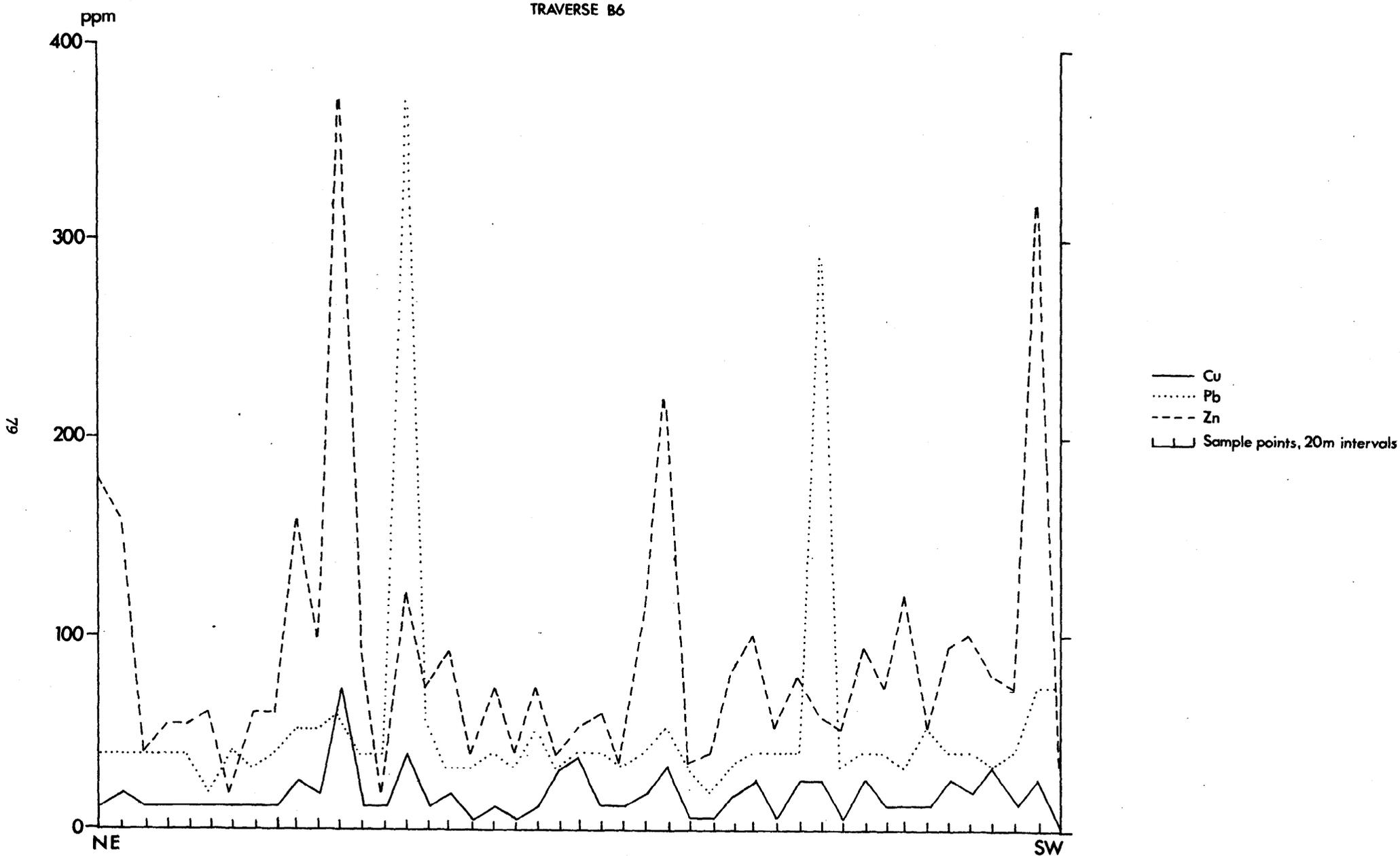
Fig.36K   Dol Haidd; copper, lead and zinc in soil samples collected along traverse line B6 shown in Fig.35
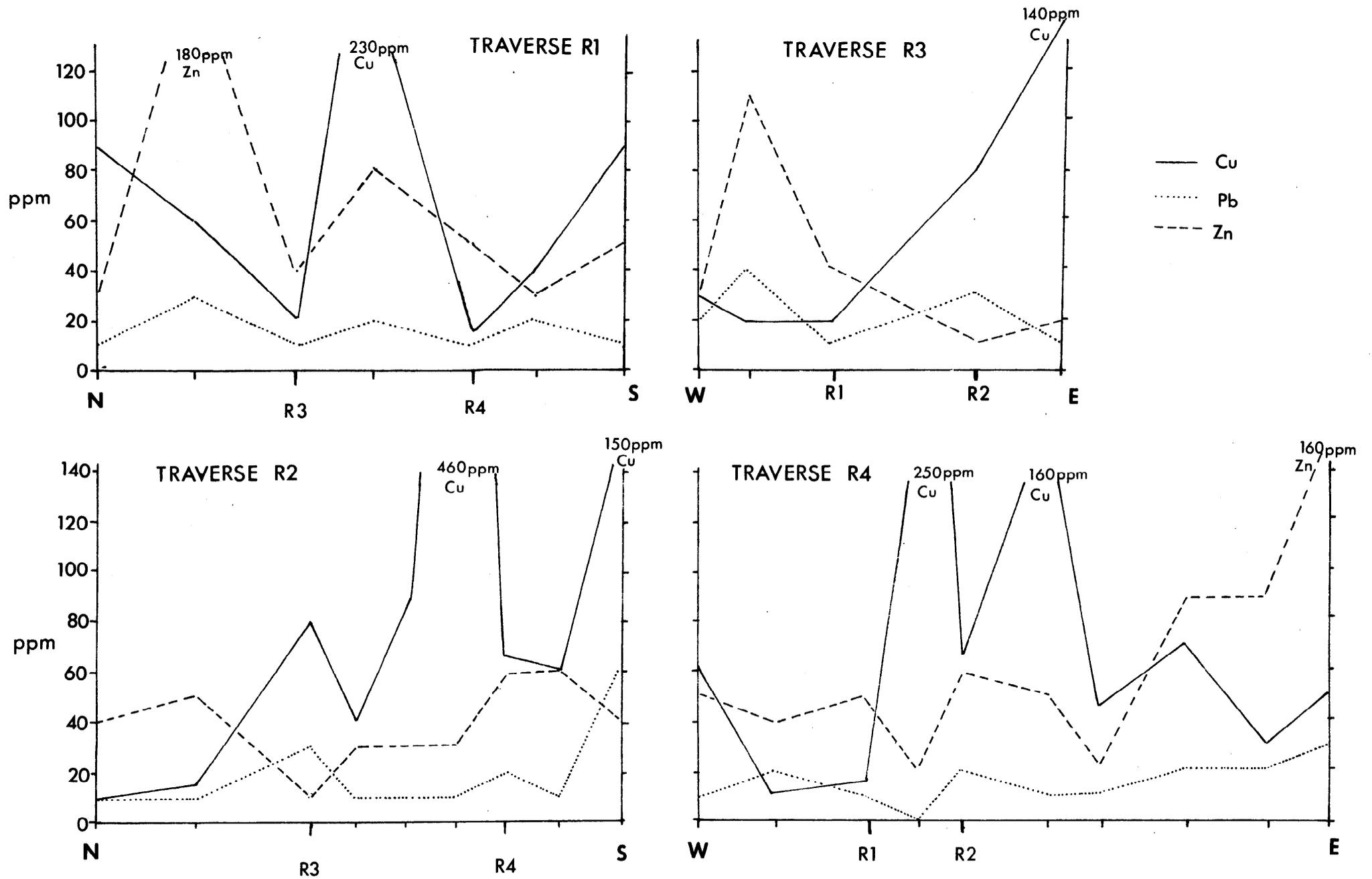
Fig.36L Dol Haidd; copper, lead and zinc in rock samples collected along traverse lines R1 — R4 shown in Fig.35

the lead anomalies on the same traverse at
SH 7715 3566 and SH 7735 3581, along strike from
quartz veining observed at surface, are probably
directly related to mineralisation. None of the
north-west-trending structures are picked up on
consecutive traverses, which suggests that any
mineralisation is of very limited extent.

Traverses B2, B3 and B4 coincide in position
with IP traverses (Fig. 34) but a comparison of
results shows few relationships except perhaps
on B2 where three zones of low resistivity and high
chargeability coincide with soil anomalies. The
most promising of these coincidences is at
SH 773 367 which can be related to the north-west
trending fault and mineralised structures picked
up on traverses to the north-west. The coincident
anomaly at SH 7700 3650 can also be related to a
north-west trending fault. The lack of coincidence
elsewhere suggests the presence of either trans-
ported geochemical anomalies produced by
secondary effects, or mineralisation which is not
detected by the IP method, or coupling effects on
the IP method.

Conclusions

The airborne EM anomaly was not verified on
the ground. Geochemical work, however, defined
three areas of mineralisation: a northern area
of Cu-Pb-Zn mineralisation of vein type, a
western area of weak copper mineralisation which
is probably both disseminated and vein type, and
a south-eastern area of minor vein mineralisation.
The northern area of vein mineralisation produces
the largest anomalies, but it is doubtful if this
warrants further investigation. There is some
coincidence between soil and IP results. The
value of these anomalies is difficult to assess
since the peaty upland environment can produce
false IP anomalies and transported geochemical
anomalies. It does not appear, however, that
visible mineralisation, or geophysical or geo-
chemical results warrant further study.

FFRIDD BRYN-COCH
Centre point: SH 705 290
6-inch sheet SH 72 NW

Geology

This area has a thick cover of boulder clay
which, at the edge of the alluvium along the Afon
Crawcwellt, forms cliffs 6-7 m high. The
alluvium itself is bouldery and in places is
cemented by black manganese minerals. Exposure
of solid is limited to the river bed. At SH 7085
2893, below the waterfall, purple slates of the
Llanbedr Formation overlie the Dolwen
Formation, which is exposed in an eastward-
dipping succession at intervals along the river
bed up to 1 km west of the waterfall (Fig. 37).

The Dolwen Formation consists of grey and
green siltstone with thin beds of fine-grained
sandstone developed in parts. Both are massive
and laminated in places. Some sandstone beds
are cross-bedded; some show complex slump
structures. Pyrite is present locally, but 1 cm

thick ferruginous bands and thinner seams
containing magnetite occur in some sandstone beds.
Magnetite was also recorded forming lens shaped
patches in thickly bedded coarse-grained sandstone
at SH 7059 2893.

Geophysics

A north-east-trending aeromagnetic anomaly
about 1 km long, apparently conformable with the
geological strike, but which appears to be the
extension of a larger feature, was investigated by
4 ground magnetometer traverses (Fig. 38).

Each traverse detected the anomaly with a
prominent peak aligned with the airborne peak.
Some field susceptibility measurements at
SH 7077 2889, on strata dipping 30° E showed the
strong value of 80×10^{-3} SI units from a fine-
grained sandstone sample containing thin bands of
abundant magnetite with minor pyrrhotite. A
small aeromagnetic high is present at this point,
which is not apparent on the simplified results
shown in Fig. 38. There is no exposure within
the area of the major aeromagnetic feature, so
an interpretation was attempted using suscepti-
bility values obtained near the much smaller
anomaly.

Any interpretation based on susceptibility
measurements, which are so variable, is not
completely reliable. In this case the best fit to
the results on Traverse A (Fig. 39) was from a
body 25 m thick dipping north-west at 30°, which
is opposite to the bedding and may result from
the combination of a complicated distribution of
magnetite in the rocks and the difficulty in deter-
mining an appropriate local regional field.

Conclusions

Despite the difficulty in producing an inter-
pretation which conforms with the geological dip,
it is suggested that the magnetic anomalies are
the result of detrital magnetite in the Dolwen
Formation, and, therefore, have no significance
in terms of mineralisation.

FFRIDD DOL-Y-MOCH
Centre point: SH 768 343
6-inch sheet SH 73 SE

Geology

On the western side of Foel Boeth this area
overlaps the edge of an extensive spread of thick
boulder clay in the upper part of the Afon Gain
valley. There is a patchy development of peat on
the boulder clay. Exposure is mostly in stream
beds, but on the hillside in the eastern part of the
area there are isolated small exposures between
thin patches of head.

The Maentwrog Formation consists of grey
laminated mudstone with laminae and thin beds of
sandstone developed locally. Intruded into the
sedimentary rocks are a sill of microdiorite in
the south of the area, a sill of microtonalite,
mostly obscured by drift in the north-east, and a
large laccolith, the Ranges Intrusion, of

DRIFT

Quaternary ⎰ ṁ Peat
          ⎱ ᵔ Alluvium, undivided
          ⎣ ᵥ Boulder Clay

SOLID

Cambrian ⎡ Ldr Llanbedr Formation ⎤ Harlech
         ⎣ Dr Dolwen   „   ⎦ Grits
                                    Group

⟋ Geological boundary, solid
⋯⋯ „ „ , drift
40⟍ Inclined strata, dip in degrees
⟋ Fault, crossmark indicates
         downthrow side
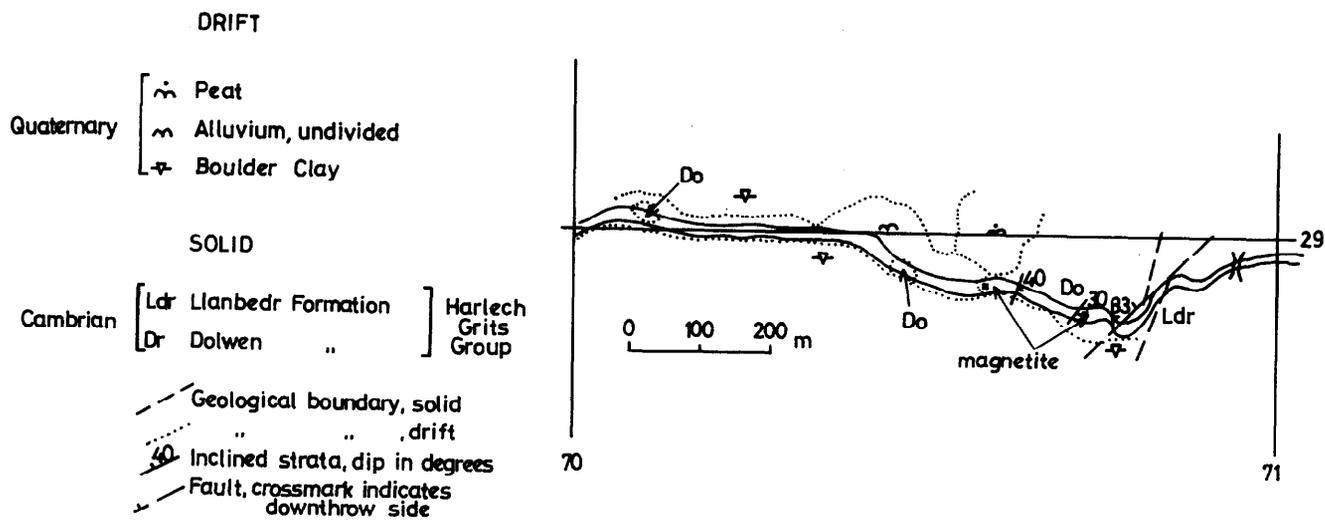
FIG. 37. GEOLOGICAL DATA FOR FFRIDD BRYN COCH AREA
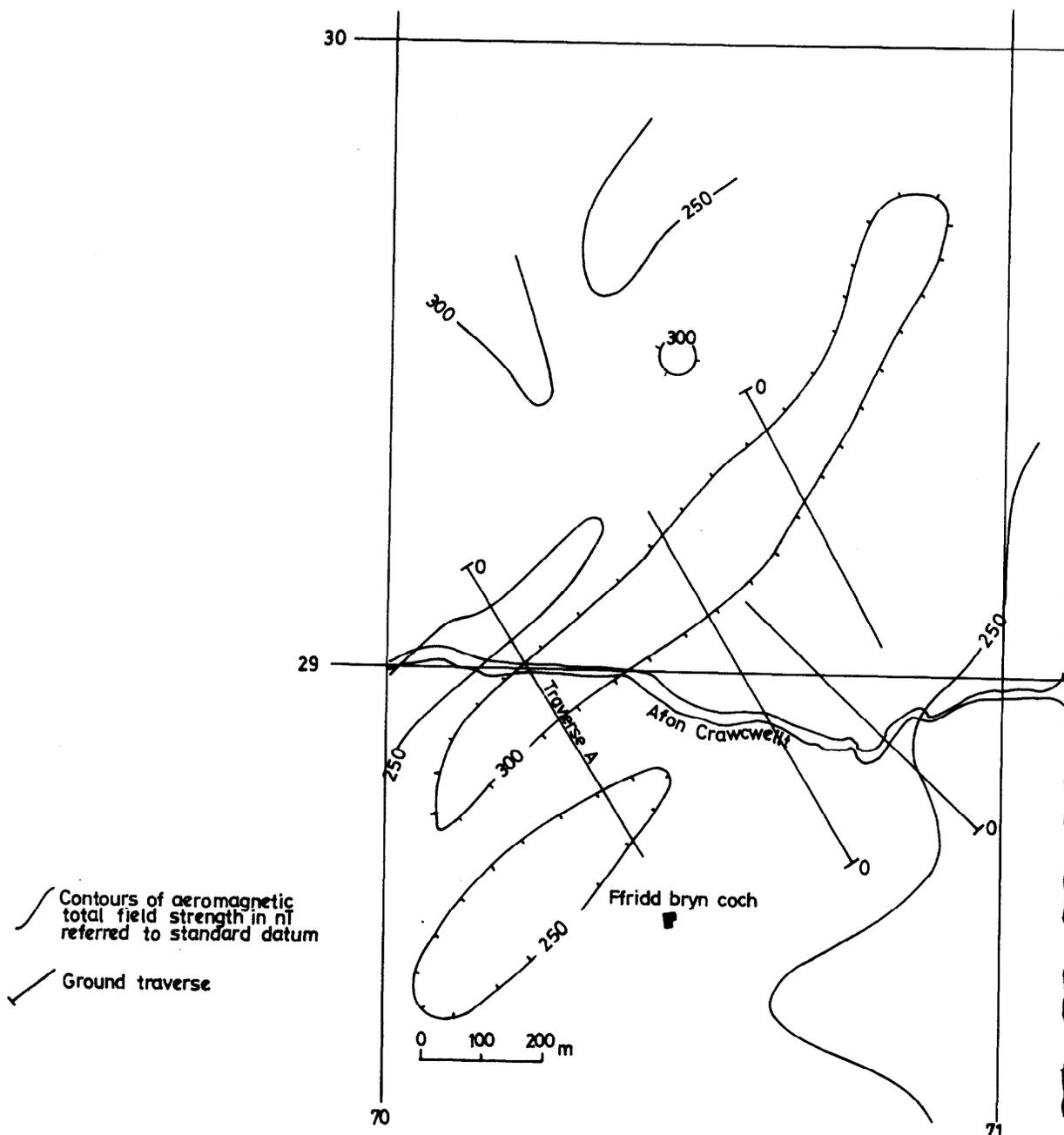
FIG. 38. GEOPHYSICAL DATA FOR FFRIDD BRYN COCH AREA

Contours of aeromagnetic
total field strength in nT
referred to standard datum

Ground traverse
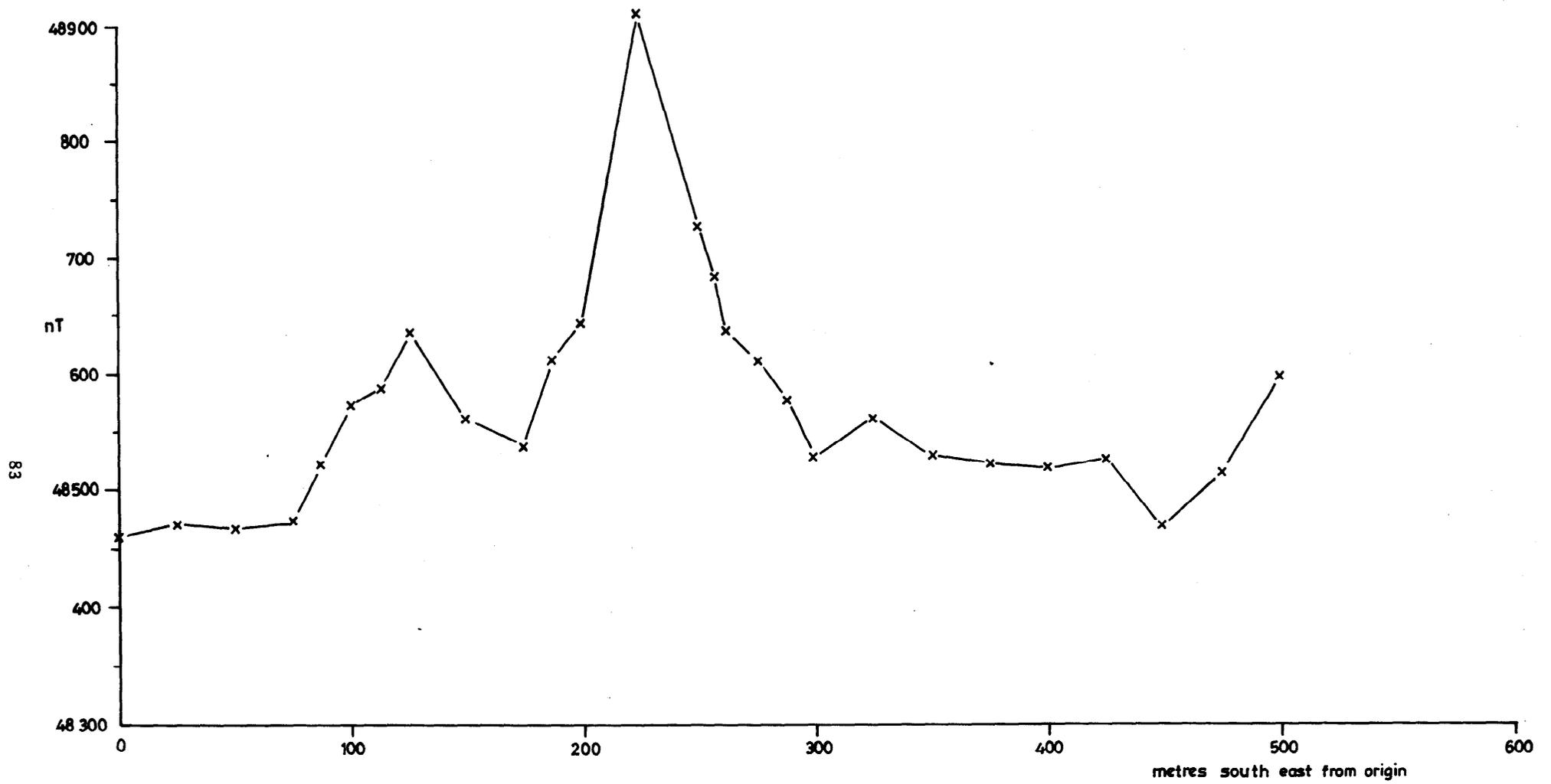
FIG. 39. MAGNETIC RESULTS ALONG TRAVERSE 'A' IN FFRIDD BRYN COCH AREA

83
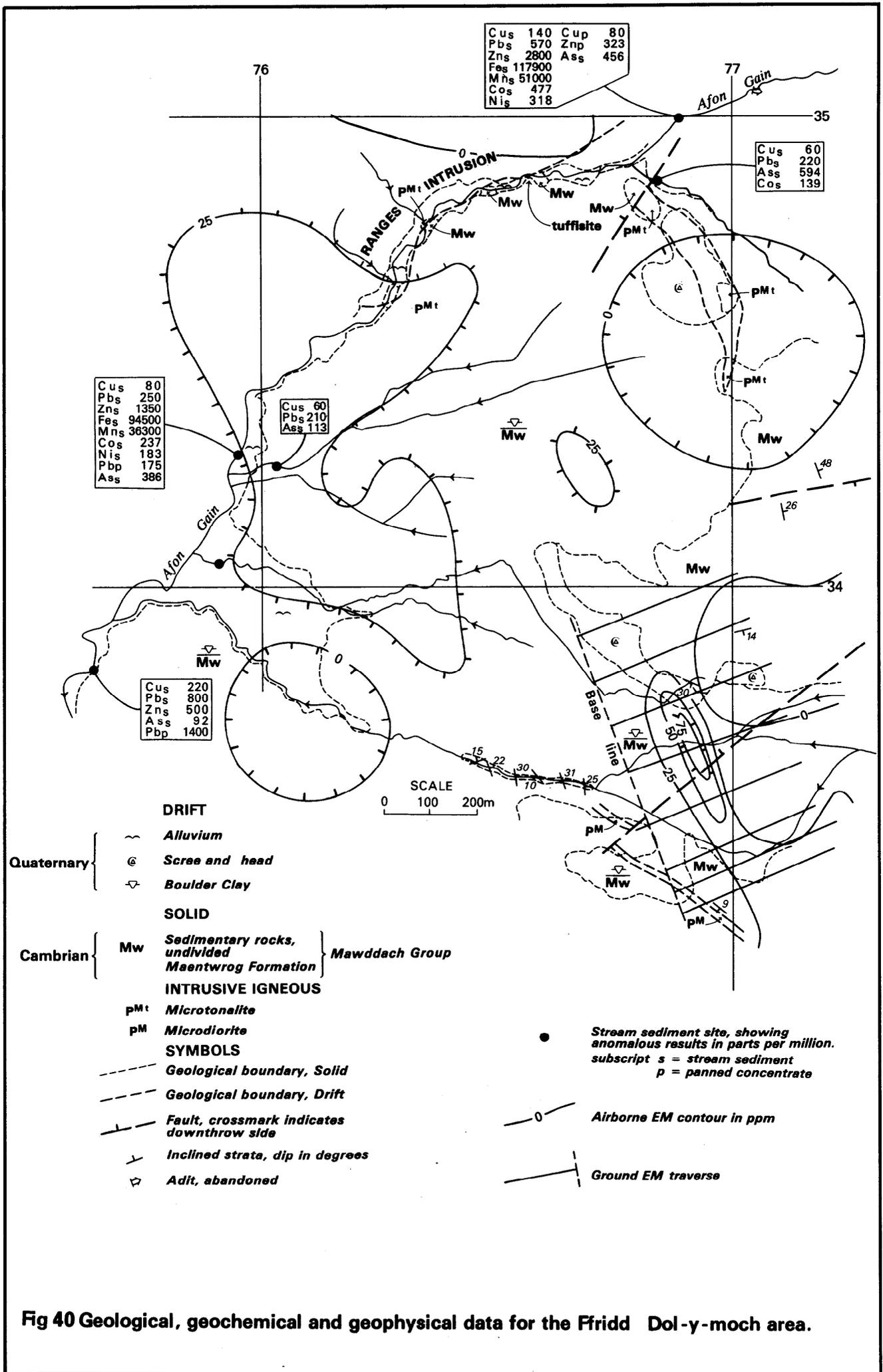
Fig 40 Geological, geochemical and geophysical data for the Ffridd   Dol-y-moch area.

Cus 140 Cup 80
Pbs 570 Znp 323
Zns 2800 Ass 456
Fes 117900
Mns 51000
Cos 477
Nis 318

Cus 60
Pbs 220
Ass 594
Cos 139

Cus 80
Pbs 250
Zns 1350
Fes 94500
Mns 36300
Cos 237
Nis 183
Pbp 175
Ass 386

Cus 60
Pbs 210
Ass 113

Cus 220
Pbs 800
Zns 500
Ass 92
Pbp 1400

SCALE
0   100   200m

DRIFT

Quaternary
~   Alluvium
@   Scree and head
▽   Boulder Clay

SOLID

Cambrian
Mw   Sedimentary rocks,
undivided   } Mawddach Group
Maentwrog Formation

INTRUSIVE IGNEOUS

pMt   Microtonalite
pM   Microdiorite

SYMBOLS
_ · _ · _   Geological boundary, Solid
_ _ _ _   Geological boundary, Drift
_⊥_·_   Fault, crossmark indicates
downthrow side
⅄   Inclined strata, dip in degrees
▽   Adit, abandoned

●   Stream sediment site, showing
anomalous results in parts per million.
subscript s = stream sediment
p = panned concentrate

_0_   Airborne EM contour in ppm

⊥   Ground EM traverse

microtonalite in the north. At the contact with this intrusion at SH 7658 3488 there is a small tuffisite intrusion, which, because of the surrounding drift cover, is of unknown size and shape (Fig. 40).

Structurally, the area is complex and interpretation is not helped by the poor exposure. In most places the mudstones show either an incipient cleavage or a fracture cleavage and in the stream sections there is evidence that the area is crossed by a zone of north-trending minor folds. The main faults trend between north-east and east-north-east.

Mineralisation

Trial workings in a quartz vein have been recorded north-east of this area at SH 7705 3505 and small amounts of secondary copper minerals have been observed staining joints in the outcrops along the south-western margin of the Ranges Intrusion. The tip by the trial working contains quartz with pyrite, abundant sphalerite, some chalcopyrite and rare galena.

Geophysics

Eight east-north-east-trending traverses were measured over an airborne EM anomaly of 75 ppm as shown in Fig. 40.

The ground and airborne anomalies closely correspond in direction and extent. The trend is roughly parallel to the geological strike (Fig. 40) but a reliable dip has not been determined. A small fault which cuts the area of the anomaly does not displace the EM results, probably because the throw is small compared to the resolution of the EM method. The cause of the anomalies appears to lie within the Maentwrog Formation, but because of the lack of exposure in the area it cannot be identified.

Geochemistry

The reconnaissance drainage survey indicated that the upper part of the Afon Gain contains anomalous amounts of a wide range of elements compared with thresholds for the Harlech Dome as a whole. However, the presence of extensive drift deposits, from which virtually all the stream sediment is derived, coupled with the presence of Fe and/or Mn hydrous oxide precipitates, makes it difficult to identify the source of the anomalies. The main stream, which runs along the north-west margin of the area, contains anomalous amounts of Cu, Pb, Zn, Fe, Mn, Co and As in stream sediment, whilst the sampled tributaries which drain the area of the geophysical anomaly generally only contain background or slightly elevated amounts of these elements (Fig. 40). The main exception to this pattern is the record of 594 ppm As in the sediment sample collected from SH 7685 3486 in the north of the area. High metal values in panned concentrates are only recorded in the main stream and these are generally much lower than the values in the equivalent sediment samples. It is clear that the source of these panned concentrate anomalies is primarily the small working in the upper reaches of the Afon Gain around SH 7705 3505. However, the dispersion train for such a small working, even taking into account possible hydrous oxide precipitation effects, seems unusually large; this, coupled with the elevated metal values in the tributaries, suggests that some additional mineralisation may well be present under the drift cover, which is entering the superficial environment and regenerating the stream anomalies.

Conclusions

The ground geophysics confirmed the presence of a conductor under drift in the Maentwrog Formation, but the cause of the conducting property has not been determined. By analogy with other areas it may be due to either pyritic or carbonaceous bands in the mudstone.

The stream geochemistry suggests that there is a source of metal enrichment additional to the known trial working in the upper part of the Afon Gain. This may be mineralisation concealed under drift, or the source may be in the drift itself. An artificial cause cannot be ruled out in this area, which was once part of an artillery firing range. The weak indications of a disseminated copper mineralisation in the Ranges Intrusion were not confirmed by geochemistry.

Because the possibility of mineralisation, most probably of vein-type, cannot be ruled out for this area it is suggested that a programme of detailed stream sampling and reconnaissance geophysics is justifiable as the next stage in this investigation.

FOEL BOETH
Centre point: SH 785 344
6-inch sheet SH 73 SE

Introduction

In this area a strong aeromagnetic anomaly coincides with a large laccolithic dolerite intrusion. As magnetic intrusions of this size are uncommon in the Harlech Dome it was decided to carry out limited ground geophysics and geochemistry over the area in order to assess their mineralisation potential.

Geology

Much of the area, which is on the eastern flanks of Foel Boeth, is covered with drift deposits. On the north-east and east the boulder clay, which is locally thick, is at the edge of an extensive spread of drift in the valley to the north-east. There is a large area of thick peat in the south-east.

The area is underlain mostly by sedimentary rocks of the Ffestiniog Flags Formation and a large dolerite intrusion (Fig. 41). The edge of a large intrusion of microtonalite is exposed on the eastern margin of the area. The sedimentary rocks are thinly interbedded grey silty mudstone and sandstone, the latter showing characteristics of deposition in shallow, turbulent water. The

DRIFT

Quaternary

∼	*Peat*
⋏	*Hillwash*
ℓ	*Head and scree*
▽	*Boulder Clay*

SOLID

Cambrian — **Ff** — *Interbedded sandstone and silty mudstone* } *Ffestiniog Flags Formation* } *Mawddach Group*

INTRUSIVE IGNEOUS

D — *Dolerite*

pMt — *Microtonalite*

SYMBOLS

Geological boundary, Solid

Geological boundary, Drift

Fault, crossmark indicates downthrow side

29 — *Inclined strata, dip in degrees*

✗ — *Vertical strata*

SCALE
0   100   200m
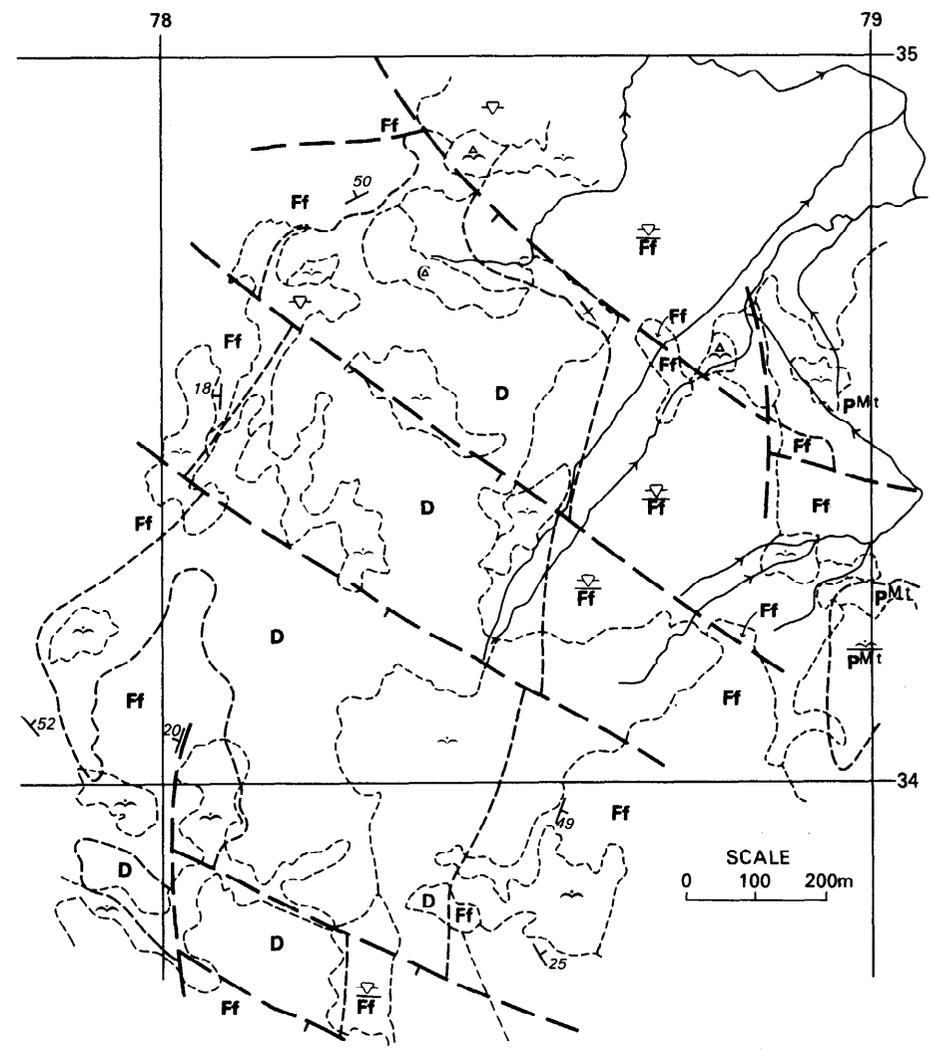
Fig41 Geological map of Foel Boeth area.

Fig 42 Geophysical data for Foel Boeth area.

Fig 43 Geochemical data for Foel Boeth area.
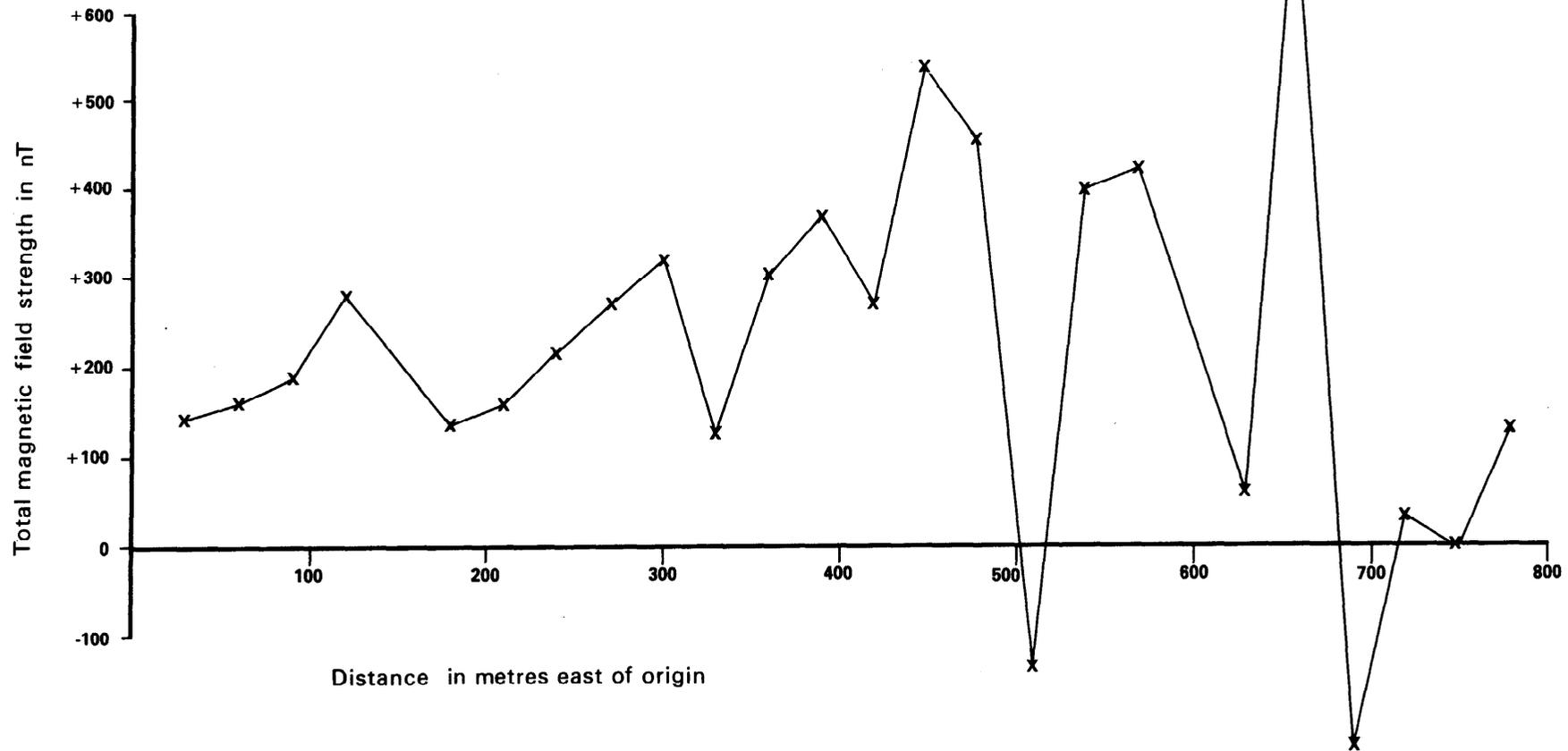
Fig 44 Magnetic data for traverse A, Foel Boeth area.
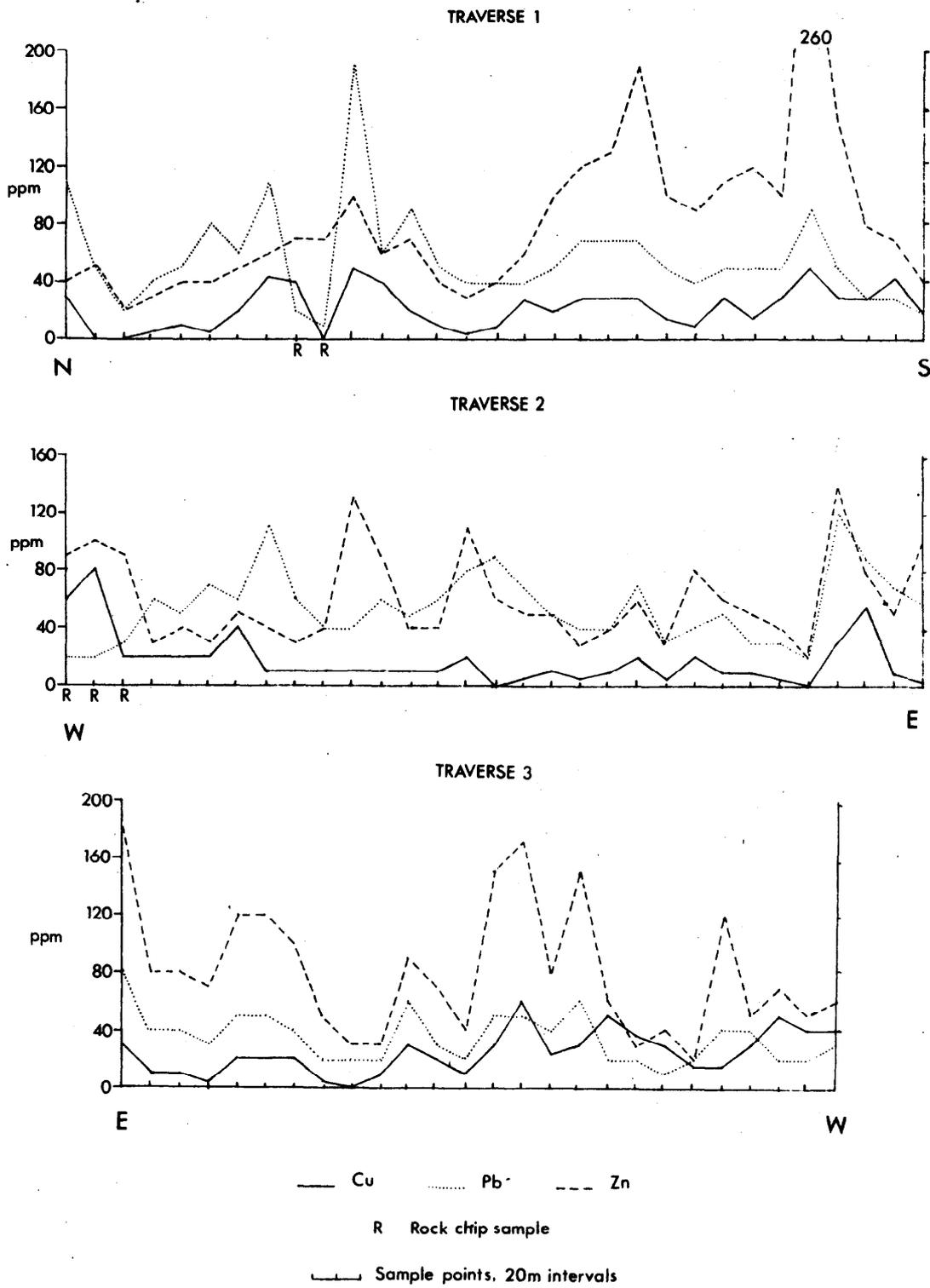
Fig.45 Foel Boeth; copper, lead and zinc in soil and rock chip samples collected along the traverse
lines shown in Fig.43

Table 14. Summary of analytical results in ppm for 83 soil and 5 rock chip samples from Foel Boeth

	Arithmetic mean	Standard deviation	Mean+ 2 x std. dev.	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Cu	22	16.2	54.5	15	41	114	80	<3
Pb	50	28.4	107	43	75	131	190	10
Zn	74	44.0	162	63	111	195	260	20

regional dip of the bedding is to the east, but the dolerite intrusion appears either to have domed the strata above it, or to be situated along the axis of an anticline on the east of the north-trending, shallow Foel Boeth Syncline. The dolerite, which is intensely altered in the marginal parts, forms a slightly discordant intrusion and it is possible that only the top is exposed. The main rock type is sparsely porphyritic, medium-grained and contains intergrown laths of albite, probably metasomatic in origin, tremolite, chlorite and rare epidote with accessory pyrite, ilmenite, magnetite, apatite and sphene. Vesicles are infilled with epidote and quartz or chlorite, or chlorite, epidote and sphene.

Geophysics

Six east-west magnetic traverses were measured, using a fluxgate magnetometer, across a sub-circular aeromagnetic anomaly of 200 nT amplitude (Fig. 42).

The ground traverses each show anomalies corresponding in position with the main airborne peaks. However the anomalies are of greater frequency on the ground, as can be seen in Traverse A, (Fig. 44) suggesting an origin very near surface. The airborne features correspond closely to the large dolerite body and this is clearly the cause; it is not however possible to relate individual ground anomalies to specific origins, since they occur both over the dolerite and over the unexposed contact area with the Ffestiniog Flags Formation. It is possible that the eastern contact of the intrusion is not located exactly or that the Ffestiniog Flags Formation contains contact-metasomatised magnetic minerals.

Geochemistry

One reconnaissance drainage survey site covered this area (Fig. 43). In contrast to the panned concentrate and water sample which show only background values the sediment sample contains distinctly anomalous amounts of zinc (1200 ppm) and manganese (5.8%), as well as high values for cobalt (147 ppm), nickel (104 ppm), arsenic (88 ppm) and iron (8.8%). With the exception of nickel, these anomalies are likely in the first instance to be largely the product of precipitation effects brought about by Eh and pH variations in the ground and stream water. All the anomalies with the exception of arsenic can

be related to a high background produced by the dolerite country rock rather than to any hidden mineralisation.

Soil samples were collected at 20 m intervals along two east-west traverses across the margin of the altered basic intrusion and along a third traverse roughly parallel to and over the marginal area of the intrusion. The samples consist mainly of boulder clay from beneath peat, but many samples contain some peat. At five sites there was no soil cover and rock chips of altered dolerite were taken. A summary of results is given in Table 14. The individual values are plotted in Fig. 45. The rock chip results were not treated separately as they formed such a small group.

Copper results show.a normal distribution whilst lead and zinc were lognormal. Values greater than mean + two standard deviations for copper, and greater than geometric mean + two geometric deviations for lead and zinc were arbitrarily chosen as threshold levels and the values greater than these levels are shown on Fig. 43.

Compared with other areas in the Harlech Dome none of these results are highly anomalous. Two of the highest copper results are from rock chips and they fall well within the background range for basaltic rocks (Prinz, 1968). The high copper results at the eastern end of traverse 2 which are adjacent to relatively high lead and zinc results and situated over microtonalite may reflect a weak seepage-related secondary concentration. The highest zinc value (which is accompanied by small rises in the lead and copper results), a weak copper anomaly with an associated zinc peak on traverse 3, and the highest lead value are all in samples sited close to the margin of the basic intrusion, but it is considered that they are mainly the product of background lithology, groundwater movement and local concentrations (absorption and/or precipitation) in the peaty environment, rather than mineralisation.

Conclusions

The aeromagnetic anomaly is caused by an intrusion of dolerite. The sediment and soil anomalies are most likely to be the products of background lithology and secondary concentrations in the peaty environment. There are no indications of any significant base metal mineralisation associated with this magnetic anomaly.
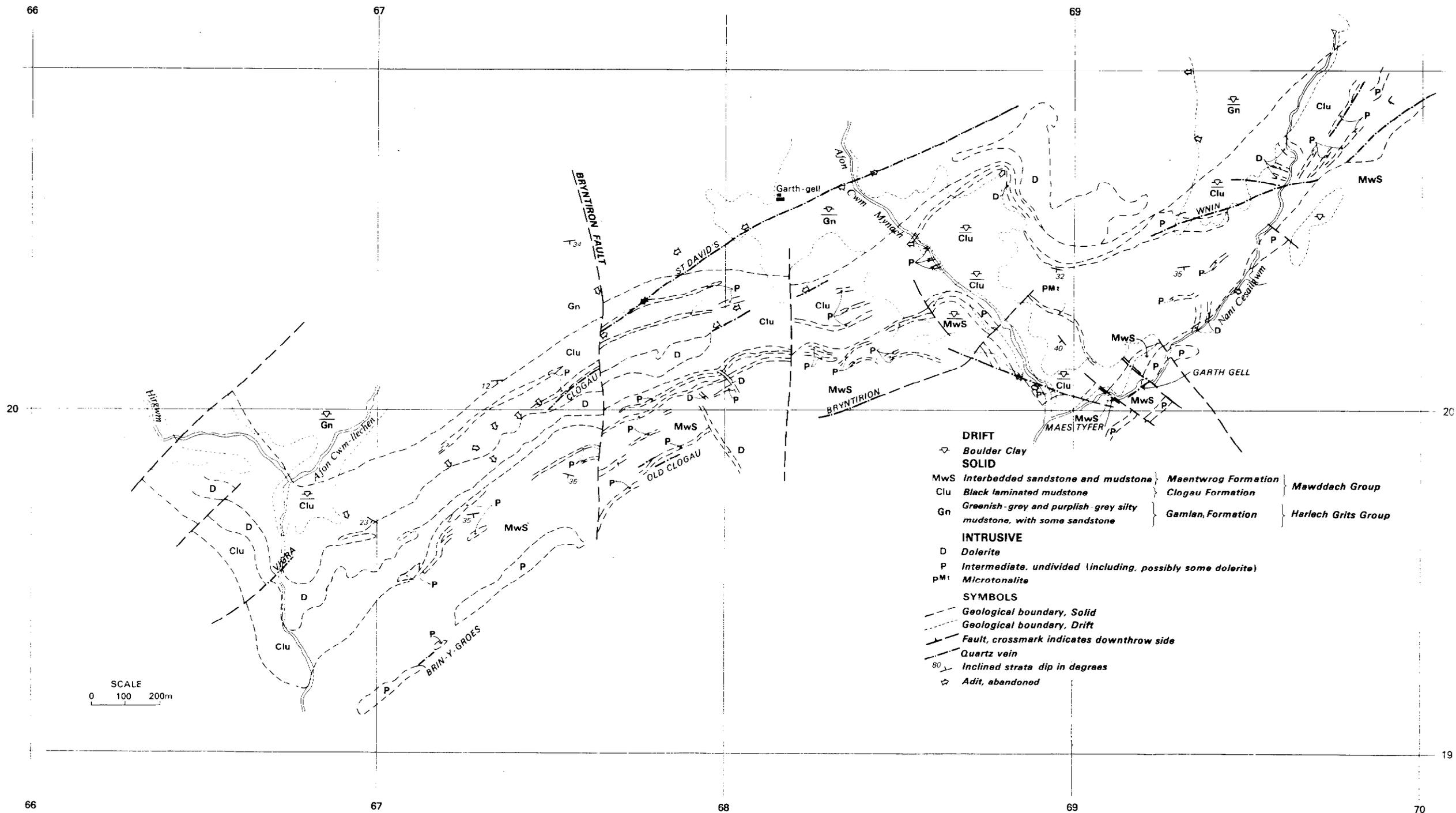
Fig 46 Geological map of Garth Gell Area.

GARTH GELL
Centre point: SH 680 201
6-inch sheets SH 61 NE, 62 SE

Introduction

The investigation of this area was one of the most important to be carried out in the early stages of the exploration project, because of the coincidence of high EM and magnetic anomalies with the Clogau Formation in an area containing numerous intrusions and the most productive gold-quartz veins in the Gold-belt.

The area, which is covered by oak forest with lowland and upland pasture, is on the generally south-facing slopes of the southern part of the Harlech Dome and is cut by the steep valleys of the southward-flowing rivers Hirgwm, Cwm-llechen, Nant Cesailgwm and Cwm-mynach.

Geology

Apart from boulder clay in the valleys there is little drift in the area.

The Gamlan, Clogau and lower part of the Maentwrog formations are the main stratigraphic units (Fig. 46). The pale grey and greenish-grey siltstone and, in the upper part, interbedded coarse-grained sandstone of the Gamlan Formation pass sharply into the dark grey and black laminated mudstone of the Clogau Formation. As elsewhere, in addition to organic-rich bands, the mudstone contains abundant sulphide minerals, including pyrite cubes up to 7 mm square, in disseminations and lenses parallel to the bedding and in veinlets.

The Maentwrog Formation consists of thinly interbedded grey silty mudstone, dark grey mudstone and fine-grained quartzose sandstone, which contains abundant finely divided sulphide in places.

There are sills of dolerite and less common microtonalite in all three formations. All the recorded dykes are altered dolerite.

The bedding dips at about 30° south to south-eastwards. In the area around the confluence of Afon Cwm-mynach and Nant Cesailgwm the bedding is bent around a large south-plunging anticline and syncline. Minor folds with similar trending axes have been recorded in other parts of the Clogau Formation. There is a weak cleavage throughout this formation. Faults, nearly always at right angles to the strike, trend north, north-west and north-east. One of them, named the Bryntirion Fault by Andrew (1910), bisects the quartz vein worked in the Clogau/St David's mines.

Mineralisation

There are many mineralised quartz veins in this area, the majority trending roughly north-east, and most have been either worked or tried. The greatest thickness of any veins is about 6 m.

Among the mines, Clogau Gold Mine was the most productive in Merioneth. It produced over 78,000 oz gold between 1862 and 1911 at an average yield of 0.45 oz per ton. The lode was a north-east-trending system of branching, anasto-mosing and parallel quartz veins linked by cross-veins and stringers. Besides the Clogau/St David's Lode, the north-east end of the Vigra Lode, where it crosses the Hirgwin, was worked in the West Clogau Mine. Old Clogau worked the middle part of the Bryntirion - Bryn-y-groes vein system. North-east extensions of the St David's Lode were tried on Garth Gell and Caemabseifion properties, the Garth Gell Mine incorporating workings of smaller veins, called Meastyfer and Garth Gell by Andrew (1910) in the lower part of the Nant Cesailgwm. The Cesailgwm Mine worked part of the Wnin Lode, though on the same property some trials were driven into the St David Lode at its easternmost extension.

The principal gangue minerals in the veins are quartz, calcite and ferroan calcite, sericite and chlorite. The dominant sulphides are pyrite, pyrrhotite and chalcopyrite with lesser sphalerite, galena and arsenopyrite. The mineral usually called tetradymite, which also is present in minor quantities, has been re-identified by Kingsbury (1965) as tellurbismuth. The Clogau Mine is the only one in the Gold-belt at which gold telluride has been recorded.

Rocks of the three sedimentary formations contain locally abundant sulphides. In the Clogau Formation the lenses and disseminations of sulphide consist of pyrite and minor pyrrhotite, both of which appear to show local concentrations along the cleavage. Pyrophanite prisms are commonly scattered through the rocks. In samples from the Clogau Mine pyrrhotite and traces of chalcopyrite are present in strongly cleaved crenulated mudstone. The sulphides occur in association with quartz, chlorite and carbonate in pods and lenses parallel to bedding and as veinlets. In most cases there is evidence to show that these minerals post-date the deformation of the mud-stone. This is also possibly true of the dissemi-nated sulphides, which tend not to show any signs of strain. Evidence of an earlier generation of sulphide, however, is present in a patch of pyrrhotite and chlorite which, in keeping with the sedimentary banding, has been displaced by cleavage.

Geophysics

This investigation covers part of the north-east-trending belt of airborne magnetic anomalies with amplitudes of up to 500 nT, stretching from near Barmouth to the north of Ganllwyd. It is closely associated with airborne EM anomalies of up to 300 ppm.

Initially 3 traverses were surveyed in the south-west to confirm the presence on the ground of both magnetic and EM anomalies. Further work, undertaken to relate the magnetic anomalies to the geology, involved measuring 19 traverses at 200 m intervals across the anomalous zone using a proton precession magnetometer. On all profiles very sharp local anomalies are seen, in places with extreme gradients of 3000 nT in 30 m. An example is shown in Fig. 47 (traverse C of Fig. 48). Locally the magnetometer did not

91
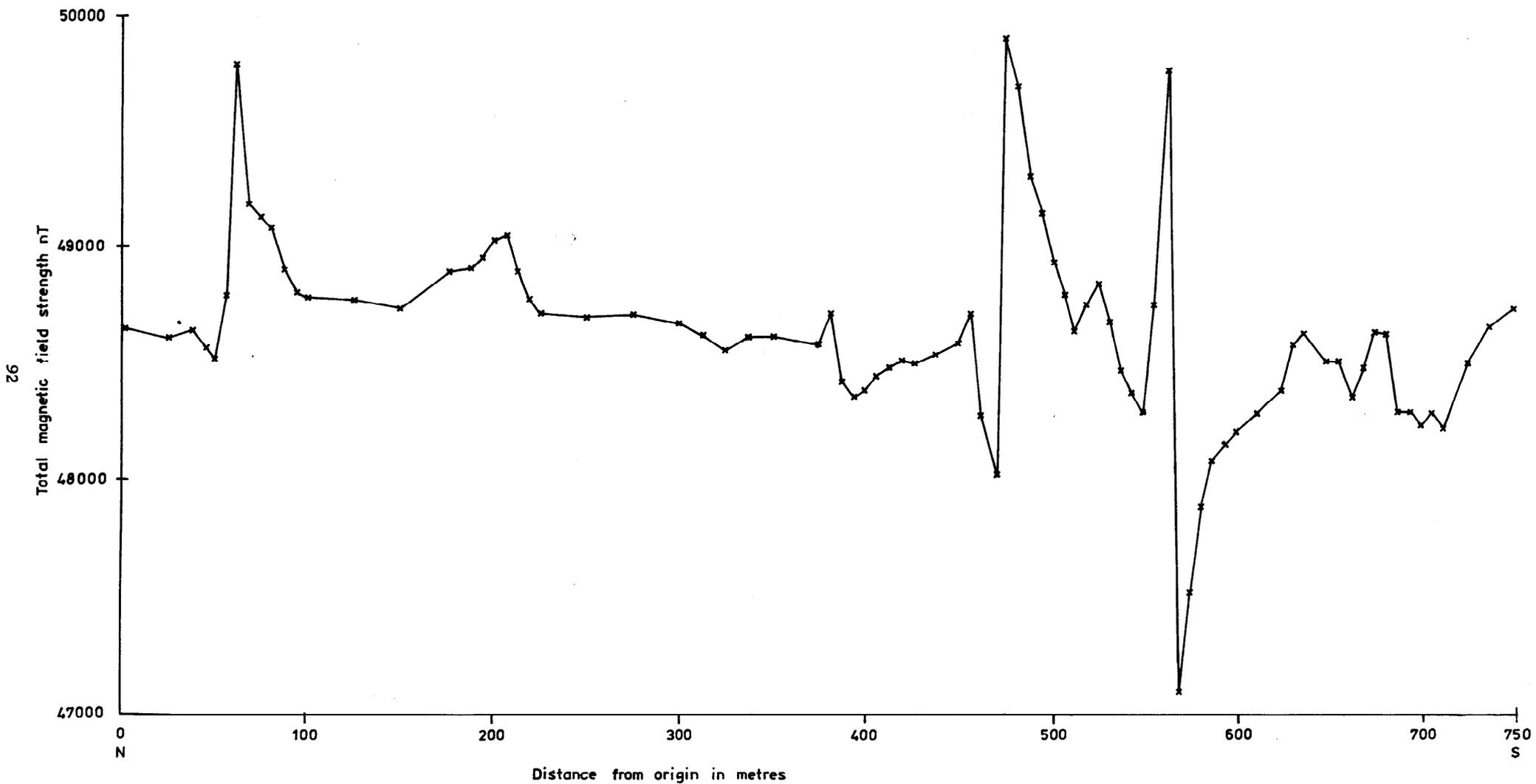
FIG. 47.   TOTAL MAGNETIC FIELD STRENGTH ON TRAVERSE C AT GARTH GELL
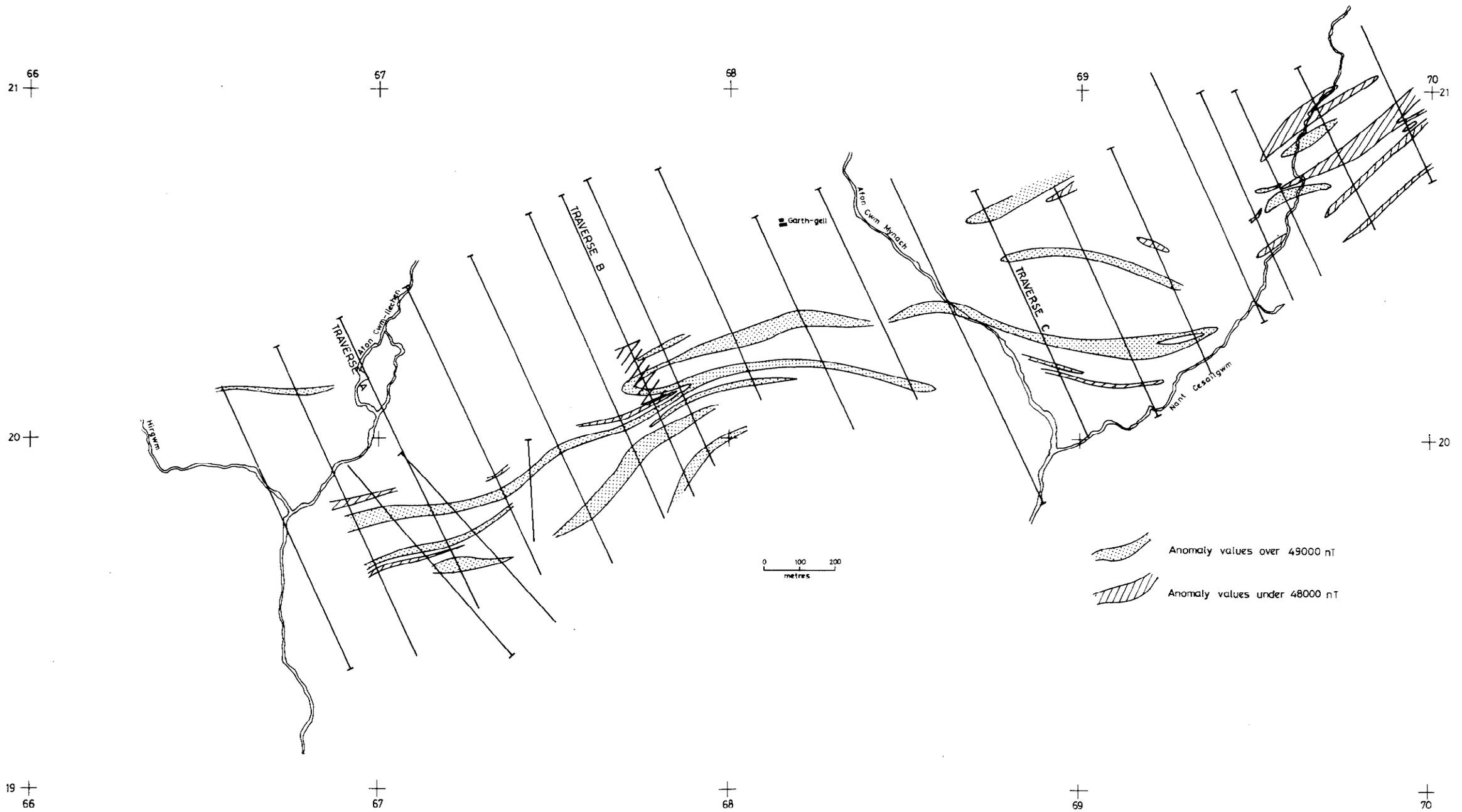
FIG. 48.   MAGNETIC PROFILES FOR GARTH GELL AREA

EM was measured on Traverse B and hatched area shows area of In-phase component <100% thus
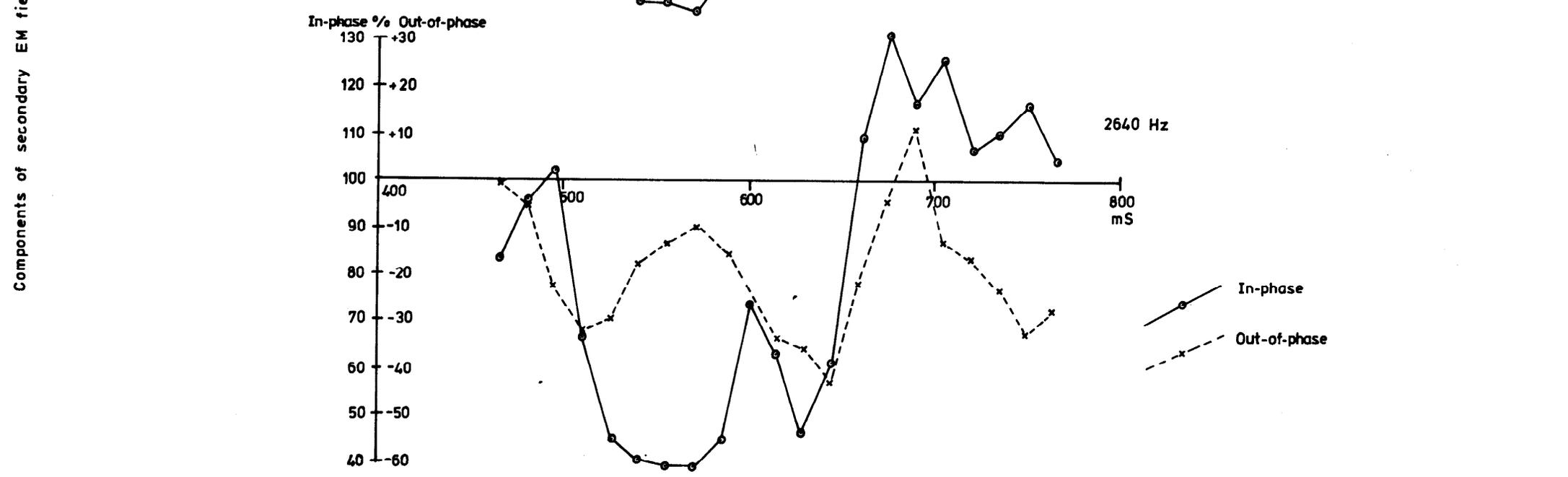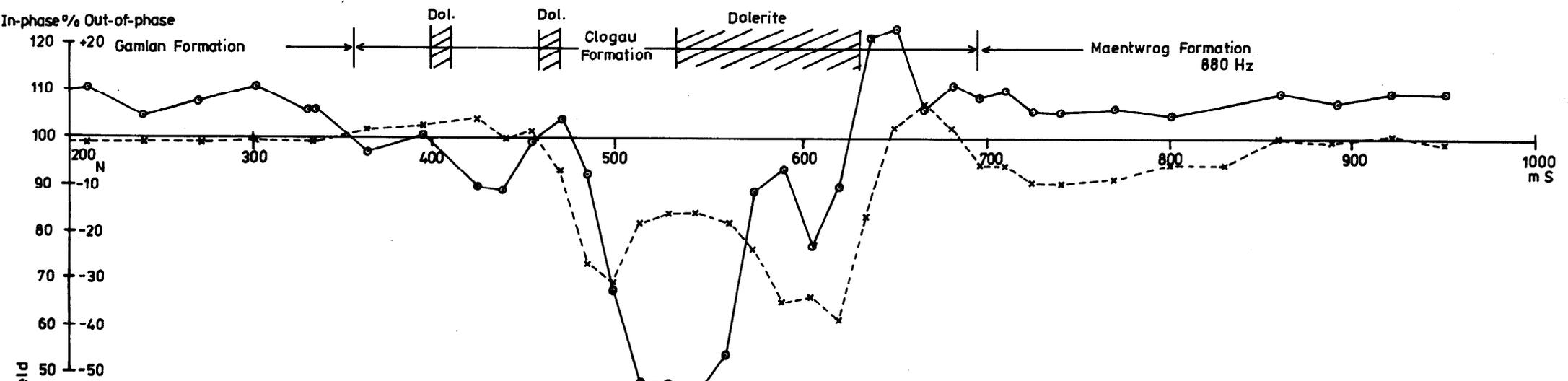
FIG. 49.   SLINGRAM EM DATA FOR TRAVERSE B AT GARTH GELL

Table 15. Physical properties of rocks in the Garth Gell area

Rock type	Susceptibility		Magnetisation	
	Field	Laboratory	Equivalent induced	remanent
Clogau mudstone	2.5 0.4 (2)	0.48	23	0.16 (st. var. = 0.14 (2)) azimuth 200°, dip 73° up
Intrusives	1.2 0.5 0.4	1.28	61	1.93 (st. var. = 1.0 (2)) azimuth 290°, dip 63° down

Units of susceptibility are SI x 10^{-3}, and of magnetisation nT.
Figures in parenthesis are number of samples. Field and laboratory measurement were taken on different samples.

function because the local gradient was too steep. On traverse A (Fig. 48) interference from a power line prevented the collection of useful data.

A contour map prepared from the data is shown in simplified form as Fig. 48. This shows a band, some 0.5 km in width, of intense magnetic anomalies with amplitudes greater than 1000 nT, which stretches across the area. This does not appear on the aero-magnetic map which shows a series of disconnected features, produced by insufficient data to allow contouring. The anomaly pattern mainly coincides with the outcrop of the Clogau Formation, although anomalies are found outside its outcrop. Individual anomalies correlate with outcrops of dolerite, microtonalite and mudstone. Two explanations for this confused pattern are initially apparent:

a) The contours were produced on an objective basis, correlating similar-shaped anomalies on adjacent profiles and this may lead to some mismatching between geology and anomaly.

b) The survey was not detailed enough to allow correlations to be made in an area of such complex geology, and variable magnetic properties.

In order to test these, further work both in the laboratory on two oriented samples (see Table 15) and using a susceptibility meter in the field, was carried out and it demonstrated that both the intrusives and the mudstone show strong susceptibilities.

The table also shows the equivalent induced magnetisation obtained from susceptibility and magnetic field strength assuming a magnetic field of 48,000 nT; it is clear that the remanent component is not important in determining the shape of the magnetic anomalies. Despite the simplification of interpretation that this allows, it is not possible to fit a precisely defined body to the anomaly curves. This is best done by comparing the anomalies with model curves and it can be seen that most anomalies are best fitted by a series of sub-vertical bodies at or very near the surface; a few fit with bodies dipping at low angles to the south.

An EM traverse, measured across the St David's Lode (Fig. 48), shows a complex anomaly pattern coincident with the airborne anomaly and the outcrop of the Clogau Formation (Fig. 49). Most of the thickness of the Clogau Formation is conductive, but the variations of the ratio of in-phase to out-of-phase components show that the conductivity varies locally across the outcrop. The anomaly values decrease where sills occur. The conductive body may be interpreted as dipping at 30° to the south-east, corresponding to the geological dip in the area.

Conclusions

Mineralogical examinations here show that pyrrhotite is present in all rock types; that most of it post-dates the cleavage and that its concentration increases adjacent to the gold-bearing quartz veins. There is, therefore, a possibility that the pyrrhotite was introduced into the country rock at the same time as the quartz veins.

Apart from the possibility of some magnetite in the intrusive rocks, pyrrhotite almost certainly causes most of the magnetic anomalies and the postulated late introduction of it, mostly along cleavage and joint planes, fits well the geophysical interpretation of the anomalies being caused mainly by thin, irregular, sub-vertical magnetic bodies at or near the surface. The few bodies which dip shallowly to the south can be explained by the fact that some pyrrhotite is demonstrably pre-cleavage and in stratiform concentrations. The tendency for some pyrrhotite to occur in local, irregularly distributed veinlets could account for the large variation in field measurements of susceptibility and in the standard variation of remanent magnetisation shown in Table 14.

The EM traverses show a complex anomaly pattern, which is probably explicable by varying degrees of conductivity within the mudstones of the Clogau Formation due to the irregular distribution of sulphide minerals (including pyrrhotite) and organic matter (see Part 1). As indicated in Part 1 the sulphide concentrations are unlikely to have an economic significance except where they indicate the proximity of mineralised quartz veins.

Fig 50 Geological map and soil sample traverse lines for the Glan llafar area.
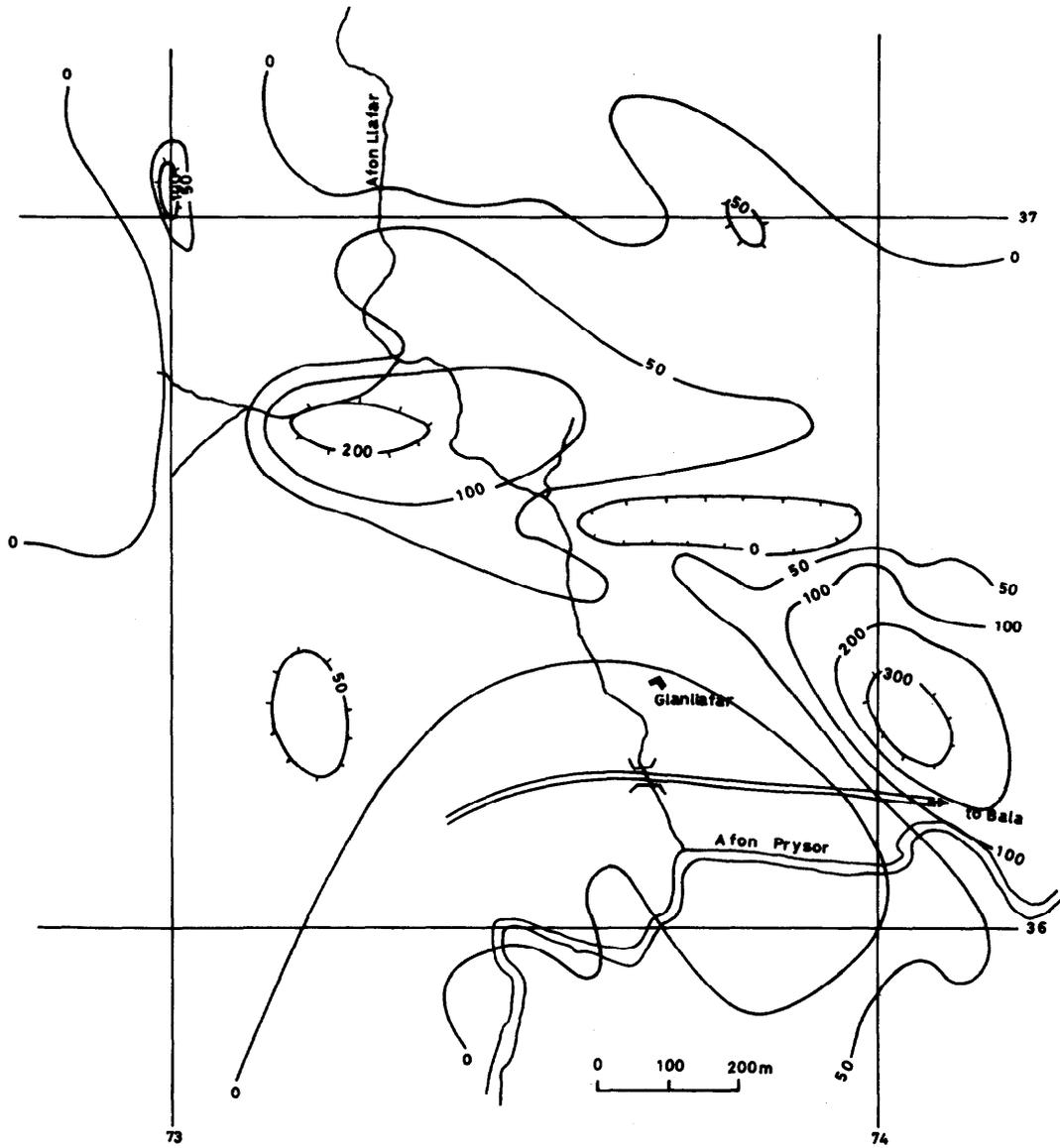
FIG. 51. CONTOUR MAP OF AIRBORNE EM FOR THE GLANLLAFAR AREA
SHOWING IN-PHASE COMPONENT IN p.p.m.
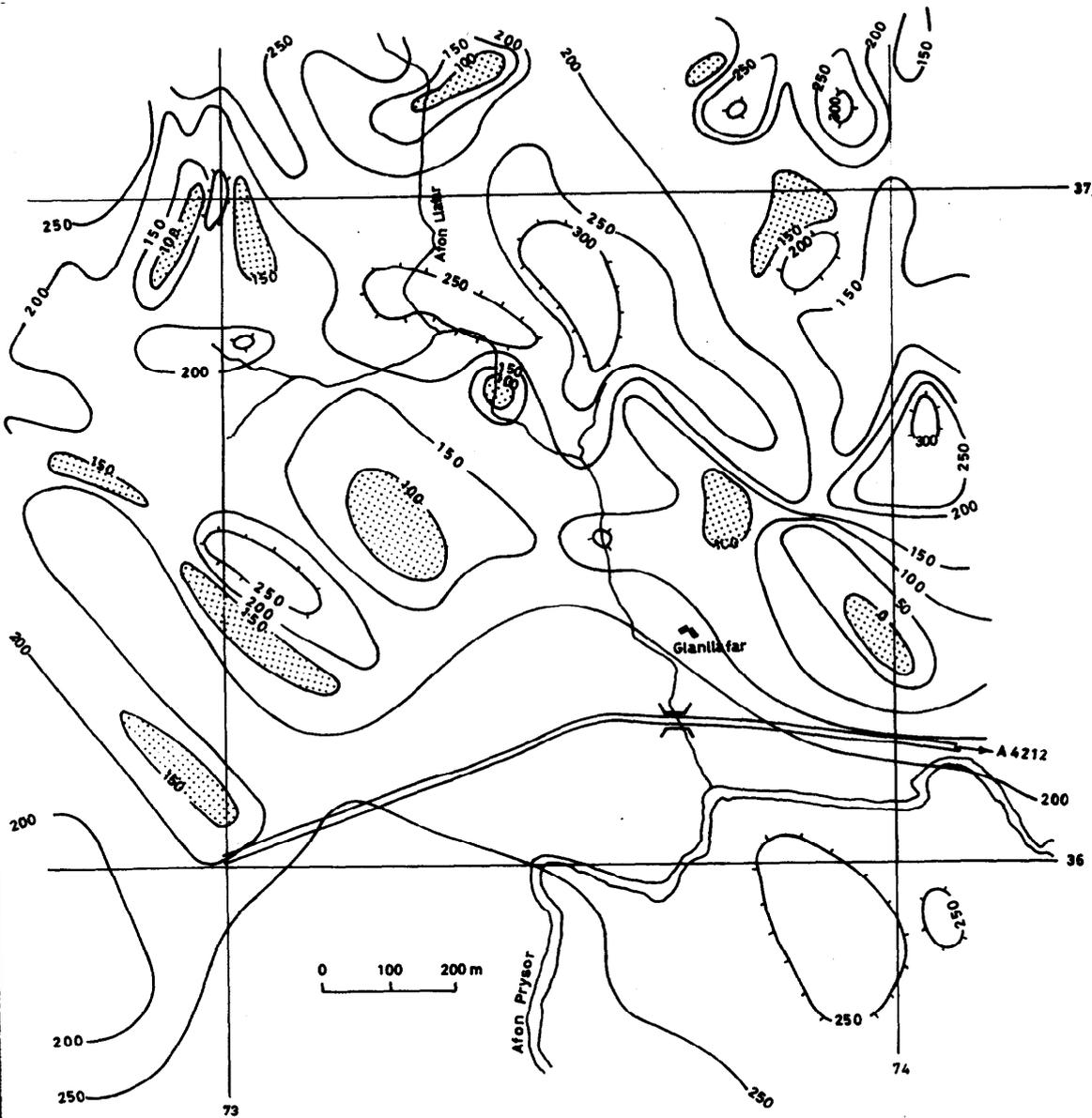
INDICATES LOW

FIG.52.

CONTOUR MAP OF TOTAL MAGNETIC FIELD STRENGTH
FOR GLANLLAFAR AREA
CONTOUR INTERVAL 50 n.T.
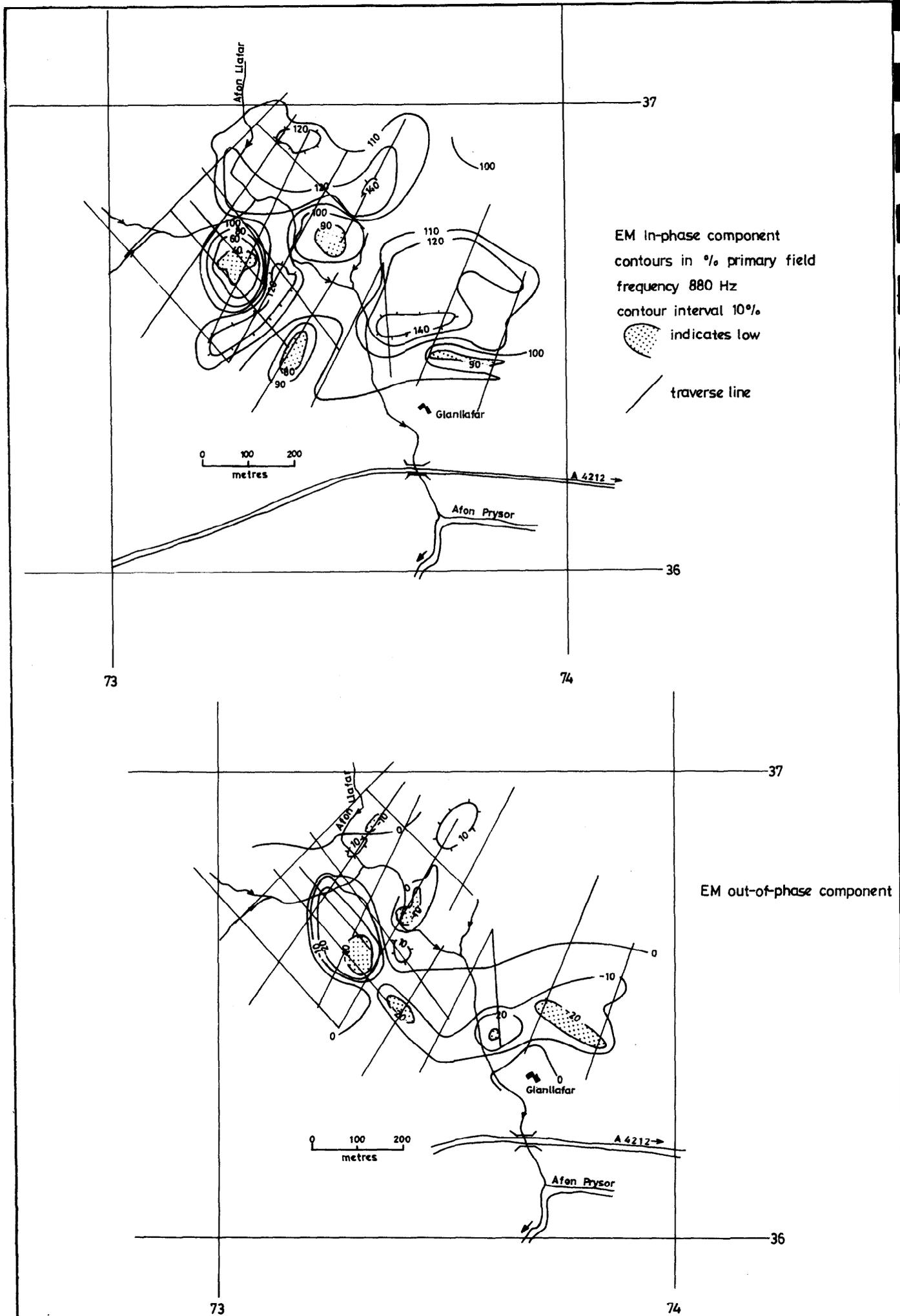
FIG. 53. RESULTS OF GROUND EM SURVEY AT GLANLLAFAR

GLANLLAFAR
Centre point: SH 735 366
6-inch sheet SH 73 NW

Introduction

This, one of the first areas to be investigated, was regarded as a type area for the Clogau Formation. Ground geophysics was followed by geochemical sampling and detailed mineralogical examination of the mudstones in an attempt to determine whether or not the EM anomalies, which characterise this formation, indicated the possible presence of commercially useful sulphide deposits.

Geology

The area is on the north side of the Prysor valley. It rises gently northwards and is mostly rough pasture used for sheep grazing. Drainage is poor and much of the ground has a cover of thin boulder clay.

Stratigraphically, the lowest unit is the Gamlan Formation (Fig. 50) which consists of purple banded mudstone, interbedded with thin beds of greywacke overlain by thickly-bedded coarse sandstone with thin beds of grey silty mudstone. The Clogau Formation, which is about 90 m thick, consists of black and dark grey laminated silty mudstone. There are rare sandy laminae in the lower parts.

The lower part of the Maentwrog Formation consists of fine-grained sandstone beds up to 45 cm thick interbedded with grey mudstone. The sandstone is usually laminated and may display cross-bedding, slump structures and load casts. Upwards the sandstone-dominated succession passes abruptly into grey mudstone with rare thin beds and laminae of sandstone.

There are many sills, up to several metres thick, of altered dolerite, microdiorite and microtonalite intruding the Maentwrog Formation. They are less common in the underlying formations. Dykes of altered dolerite are relatively uncommon.

The whole succession in this area is folded into an anticline with an axis plunging gently northwards. The principal faults trend north-north-west. There is a weak cleavage in the Clogau Formation mudstone.

Mineralisation

Several roughly north-west-trending quartz veins are present in the western part of the area and a level and shafts have been driven into one of them at SH 7299 3664. A sample from the tip contains macroscopic pyrite, chalcopyrite, pyrrhotite and minor sphalerite. Analysis of another tip sample showed 1.7% Cu, 0.1% Pb, 1.0% Zn, 17 ppm Ag and 20 ppm As, which suggests in addition that minor amounts of argentiferous galena are also present.

Lenses of pyrrhotite with minor chalcopyrite and sphalerite are common in the lower half of the Clogau Formation, often accompanied by disseminated pyrite and clots of marcasite.

Geophysics

The airborne EM results show a north-west-trending pattern of anomalies with an amplitude of up to 300 ppm roughly coincident with the outcrop of the Clogau Formation (Fig. 51). The area also shows intense aeromagnetic anomalies with a similar trend and an amplitude of over 200 nT (Fig. 52).

Ground follow-up work consisted of EM slingram traverses, magnetometer traverses and resistivity expansions, totalling about 8 km.

The ground EM survey confirmed the presence of strong, discontinuous anomalies, shown in Fig. 53, which overlie the Clogau Formation. The discontinuous nature is probably due to faulting and locally thick patches of conductive overburden, preventing penetration of the primary EM signal into the underlying rock. The ground magnetic results cannot be contoured because different instruments were used during the survey; however strong negative anomalies are seen over the conductive parts of the Clogau Formation, probably attributable to pyrrhotite, and over the Maentwrog Formation where they may have a similar cause or be due to dolerite intrusions. Resistivity probes using the Wenner configuration were measured over areas of conductive Clogau Formation and proved apparent resistivity values ranging from 0 - 10 Ωm. The value of 0 Ωm was obtained when the resistivity was too low to be precisely determined by the method.

Geochemistry

Three north-south traverses supplemented by three short east-west traverses over EM anomalies were sampled at 20 m intervals (Fig. 50). Yellow-brown clay with rock fragments developed below topsoil was the most commonly sampled medium; however where drift cover was absent the organic rich topsoil or bedrock was sampled. The 11 rock samples collected were divided into 8 sedimentary rocks (shales and siltstones) and 3 intrusions (intermediate to basic). To the latter group were added 2 samples collected for another study. The analytical results for both groups of rocks and the 150 soil samples collected are summarised in Table 16 and shown on traverse diagrams in Fig. 54.

The distribution of all three elements in soils is near normal and no distinct, anomalous group of results could be defined. Values greater than mean plus two standard deviations were taken to be anomalous. The broad pattern of results shown by traverses one and two is very similar, and it is believed that variations on all traverses reflect stratigraphic variations, for even the maximum levels recorded are unexceptional compared with threshold levels determined for some other areas in the Harlech Dome. Anomalous copper results in the southern parts of traverses one and two probably reflect a sulphide-bearing mudstone horizon. Anomalous and other high values of all three elements in the northern part of traverses one, two and three are probably related in the

TRAVERSE 1

TRAVERSE 2

TRAVERSE 3

Zn 220 ppm

TRAVERSE 4

TRAVERSE 5
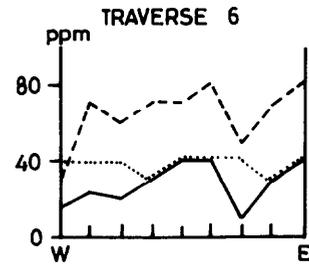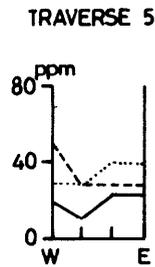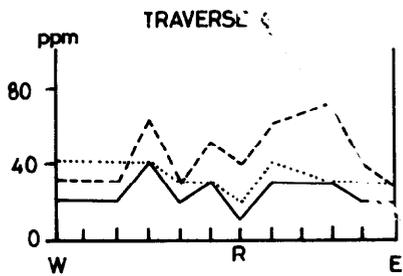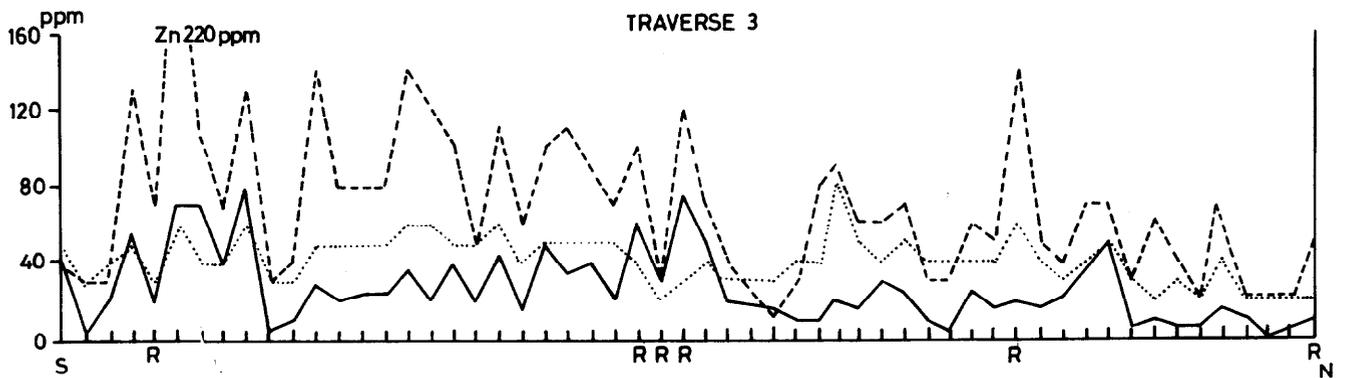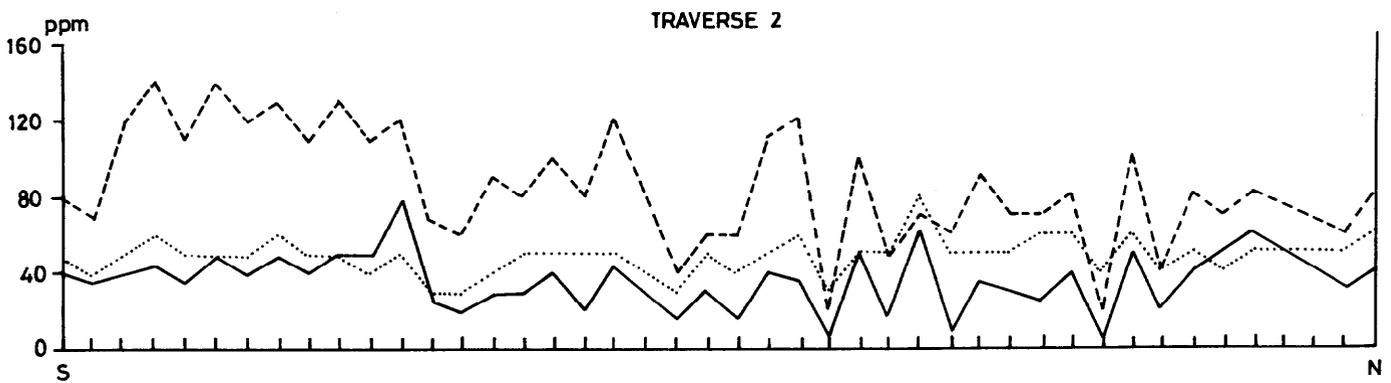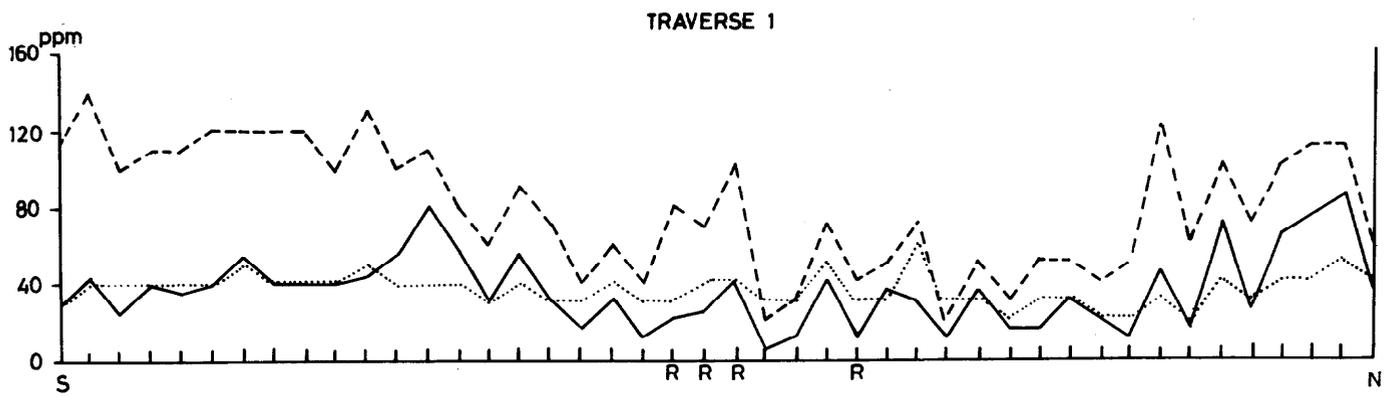
TRAVERSE 6

—— Cu   ········ Pb   ――― Zn

⊥⊥ Sample points   R   Rock chip sample

Fig. 54 Ghanllafar; copper, lead and zinc in soil and rock chip samples collected along the traverse lines shown in Fig. 50

Table 16. Summary of analytical results in ppm for soil and rock samples from Glanllafar

	Median	Arithmetic mean	Standard deviation	Maximum	Minimum	Mean+ 2 x std. dev.
Soils (150)						
Cu	30.0	31.2	18.0	85	<3	67.2
Pb	40.0	41.6	11.4	80	20	64.4
Zn	70.0	74.6	35.8	220	10	146.2
Siltstones and Shales (8)						
Cu	27.5	33.7	23.4	75	10	-
Pb	30.0	30.0	9.3	40	20	-
Zn	70.0	73.8	31.1	120	30	-
Intermediate and Basic Intrusives (5)						
Cu	15.0	19.0	12.4	40	10	-
Pb	20.0	18.0	13.0	30	>5	-
Zn	40.0	50.0	17.3 ·	80	40	-

first instance to secondary concentrations. The source of the metals is unknown. Anomalous copper and zinc values at the south end of traverse three either indicate mineralisation related to a microtonalite intrusion or a fault or precipitation of metals from groundwater moving along the fault. High zinc values from the southern part of traverses 1, 2 and 3 occur in the lower grass-covered slopes of the area and may be the result of groundwater movement off the higher, peaty ground through the sulphide bearing Clogau Formation.

Element concentrations in the intrusions and sediments (Table 16) are similar to or lower than averages quoted for these lithologies (Turekian and Wedepohl, 1961; Vinogradov, 1962; Prinz, 1968). However, rock samples were only taken when there was no soil cover, resulting in small, incomplete sample populations biased in favour of resistant rocks. For example, no samples were collected from the lower part of the Clogau Formation where minor sphalerite and chalco-pyrite were noted in the rocks. The rock sample with the highest copper and zinc content is a pyritiferous mudstone collected about half way along traverse 3 close to the margin of an intrusion. The relatively high values may be related to syngenetic concentrations in the mudstone or some enrichment marginal to the intrusion.

Conclusions

The geophysical results demonstrate the strong, but often intermittent, conductivity and magnetic nature of the Clogau Formation. In one area only (SH 738 365) there is an approximate coincidence of the EM, magnetic and geochemical anomalies (Cu 80 ppm). The geochemical anomalies are weak compared with levels recorded elsewhere in the Harlech Dome and are related to groundwater movement, possible weak mineralisation marginal to intrusions and along faults, and sulphide-

bearing mudstone. The small size and scattered nature of the geochemical anomalies suggests that the amount of economic mineralisation here is insignificant.

As in other areas both the EM and magnetic anomalies in the Clogau Formation are largely the result of pyrrhotite/pyrite concentrations with only minor amounts of chalcopyrite. A general conclusion that might be drawn from the work at Glanllafar, therefore, is that where EM and magnetic anomalies coincide over the Clogau Formation the chance of them indicating significant copper mineralisation is small.

GORWYR
Centre point: SH 783 187
6-inch sheet SH 71 NE

Geology

About 1 km east of Brithdir this area of relatively low relief is extensively covered with boulder clay. Exposure is limited to small "islands" rising out of the drift. The area contains almost a complete section across the Aran Volcanic Group. In the north-west is coarse-grained, massive and cross-stratified volcanic sandstone of the Allt Lwyd Formation. This is succeeded by acid ash-flow tuff which has been correlated with the Offrwm Volcanic Formation. Above this, acid ash-flow tuff intercalated with rhyolite in places, and correlated with the Brithion Formation is sandwiched between units of black silty mudstone. The Benglog Volcanic Formation contains crystal tuff interbedded with basaltic lava. Exposure is poor east of this, but there are two small exposures of acid ash-flow tuff probably belonging to the Craig-y-Ffynnon Formation (Fig. 55).

There are three dolerite intrusions: the biggest in the north-west is gabbroic in places, and

Quaternary

DRIFT

~~ Peat

▽ Boulder clay

Ordovician

SOLID

Z^R Acid tuff } Craig-y-Ffynnon Formation [CF]

ZB Tuff and basalt, undivided } Benglog Volcanic Formation

AVG Sedimentary rocks,

Z^R Acid tuff } Brithion Formation

AVG Sedimentary rocks, undivided

Z^B Acid tuff } Offrwm Volcanic Formation

S^V Volcanic sandstone } Allt Lŵyd Formation

Aran Volcanic Group

INTRUSIVE IGNEOUS

D Dolerite

SYMBOLS

--- Geological boundary, Solid

----- Geological boundary, Drift

⌐_ _ Fault, crossmark indicates downthrow side

63
⤹ Inclined strata, dip in degrees

✗ Vertical strata

SCALE
0 100 200m

Fig 55 Geology of the area around Gorwyr.

Traverse A

B

Gorwyr

SCALE
0 100 200m

/ Contours of airborne magnetics in nT, referred to standard datum

↗ Ground magnetic traverses
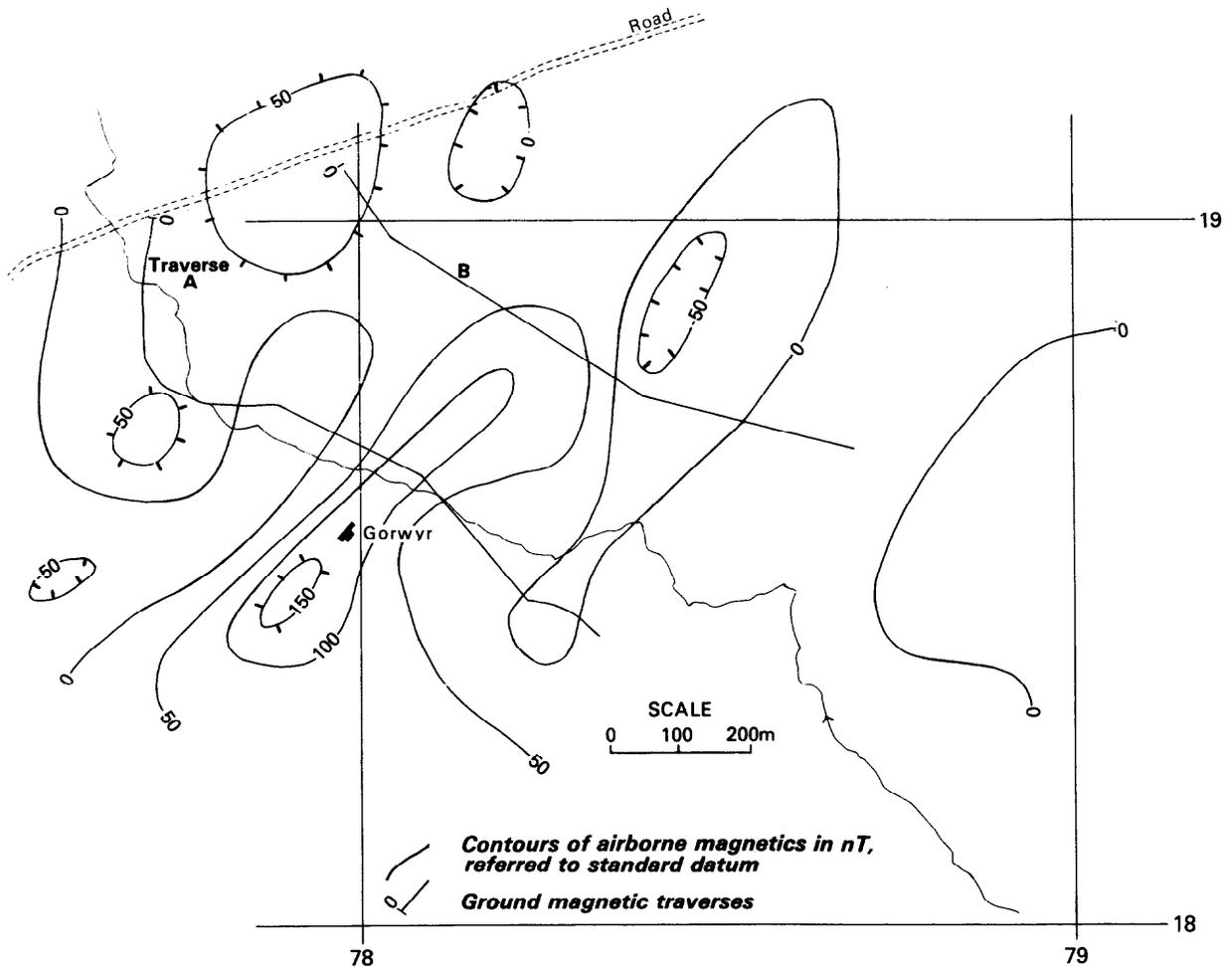
Fig 56 Geophysical data for the area around Gorwyr.

102
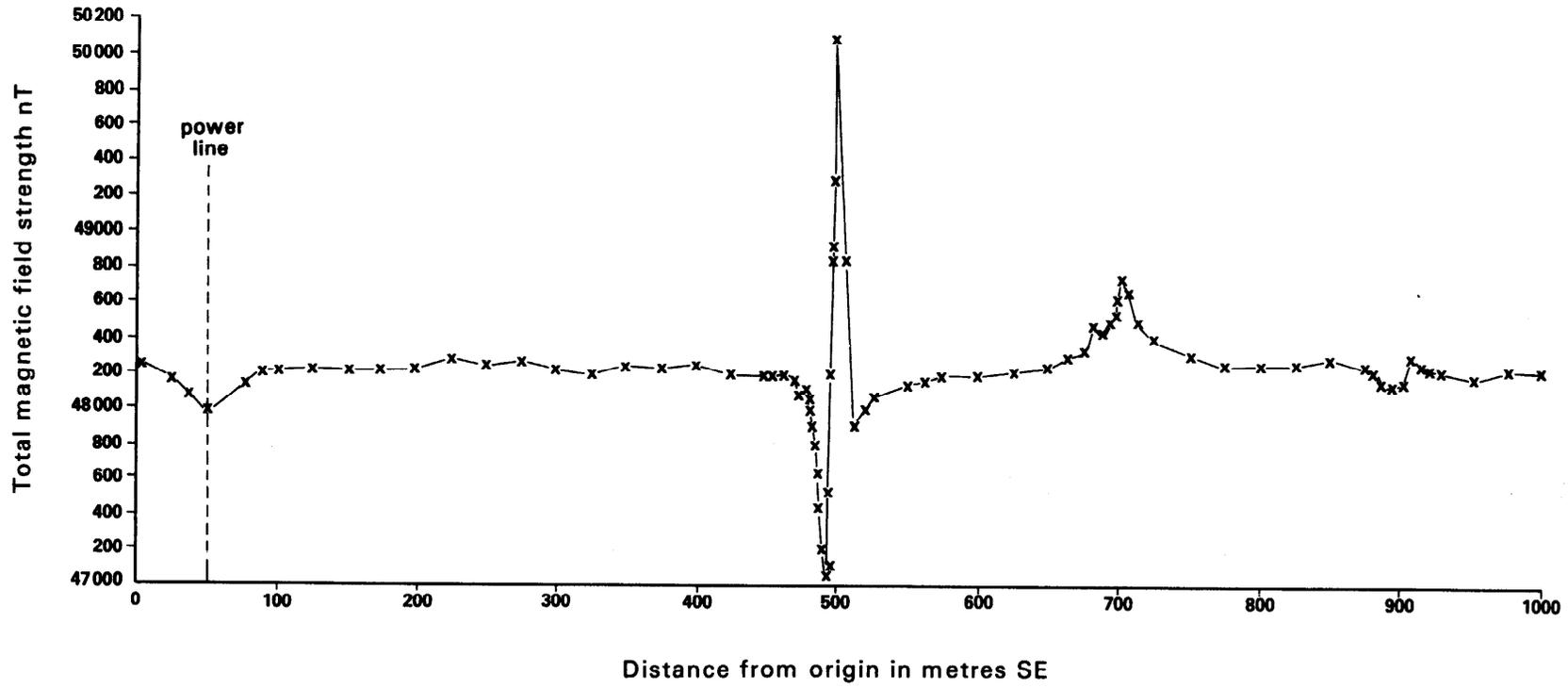
Fig. 57 The total magnetic field strength on traverse A. at Gorwyr.

contains abundant titano-magnetite.

The succession youngs to the south-east, but most measurements on bedding in this immediate area show a north-westward dip. In the absence of criteria for determining way up it is not certain whether this is explained by overturning or tight local folding. The Bala Fault passes through the south-eastern corner of the area.

Geophysics

Airborne magnetic anomalies of 200 nT elongated in a north-east direction were checked on the ground by two proton magnetometer traverses (Fig. 56).

The most prominent feature has a very short wavelength and high amplitude as for example at 500 m SE on traverse A (Fig. 57). This is due to a near surface or, more likely, man-made source, such as a pipe. A power line causes a minor anomaly at 50 m SE. The more subdued anomalies, which correspond with the airborne data, for example at 700 m SE on traverse A (Fig. 57) show a strong correlation with the edges of the mapped outcrops of dolerite and they conform to the local strike.

Conclusions

Because of the extensive drift cover it is difficult to identify the exact cause of the magnetic anomalies, but from considerations of the overall mineralogy of the dolerite intrusions in this area the most probable cause is the content of titano-magnetite in this rock, unrelated to mineralisation.

HAFOD-FRAITH
Centre point: SH 747 277
6-inch sheets SH 72 NW & NE

Geology

Much of this afforested area on the northern slopes of Moel Hafod Owen is covered with boulder clay. Peat is thick in a depression near Hafod-Fraith while scree and head obscure outcrop on all the steep slopes. The Maentwrog and Ffestiniog Flags formations (Fig. 58) dip at moderate angles east-south-eastwards. As elsewhere the Maentwrog Formation consists of thick beds of sandstone interbedded with grey mudstone in the lower part, overlain by mudstone. Above this, sandstone beds reappear, thinly interbedded with light and medium grey siltstone, in the Ffestiniog Flags Formation.

One large, sill-like, body of microtonalite intrudes the Ffestiniog Flags Formation. The rock is medium-grained and sparsely porphyritic. Plagioclase, mostly altered to sericite, with interstitial quartz, chlorite and epidote are the main constituents. There is a richly porphyritic phase near the base in the northern part of the intrusion. In addition a number of thin sills and rare dykes of microtonalite and other intermediate rocks intrude all parts of both sedimentary formations.

The dominant fault direction is north-north-west. The easternmost fault in the area is the Craiglaseithin Fault, which can be traced northwards for several kilometres. The other two faults shown on Fig. 58 are part of a set of strong faults which merge with the Trawsfynydd Fault in the Capel Hermon area.

Minor folds have been observed only in conjunction with faults. A fracture cleavage is visible in places in the mudstones of the Maentwrog Formation.

Mineralisation

The north-western part of this area contains the Cwmheisian East and Princess Marina gold mines. It was at the former that gold was first found in this part of Merioneth. This mine is situated at the intersection of two sets of quartz veins. The workings are mainly in the roughly east-west vein exposed in the river bed nearby. The north-south 'vein' appears to be a zone of minor veins. The Princess Marina or Bedd-y-Coedwr Mine consists of a number of workings in a set of east-west veins in both sides of a major fault in which there is also quartz veining. In the worked veins pyrite, sphalerite and galena occur with minor chalcopyrite. At locations south-east of the mines quartz, usually only with pyrite, occurs in veins along the faults and in places there are small trial diggings in them.

Pyrite is common in parts of the Maentwrog Formation, usually as sparsely disseminated cubes parallel to bedding or as smears along joints, but veins up to 1 cm thick trending 010° and 055° in mudstone are exposed in the Afon Mawddach at SH 7445 2811. To the south of this area in the upper part of a stream at SH 7435 2726 mudstone of the Maentwrog Formation contains abundant quartz-chlorite veinlets with chalcopyrite, pyrite, marcasite and sphalerite.

In common with most other intrusions the large microtonalite sill is pyritic and contains quartz veinlets. In places, notably the southern part at SH 7492 2755, malachite staining on joints indicates the possible presence of chalcopyrite in the rock.

Geophysics

The airborne survey shows a discrete EM anomaly of 200 ppm associated with an area of intense aeromagnetic anomalies of 200 nT peak-to-peak (Fig. 59). Six traverses using slingram and fluxgate magnetometer equipment were measured in a general east-west direction across the anomalous zone, encountering difficult operating conditions on the steep terrain.

Only on traverse B (Figs 59, 60) was a well-defined EM anomaly found. This confirmed the presence of the airborne anomaly and correlated closely with it in position. The interpretation suggests that it is caused by a double conductor dipping to the east at 30°. Traverses A and D show weak features of uncertain significance and only roughly correlate with the airborne results. Two pieces of evidence suggest that the anomalies are not due to vein-type mineralisation; firstly no response was seen where the airborne EM survey crossed the rich sulphide-bearing vein

DRIFT

Quaternary	~	Peat
	G	Scree and Head
	᠊ᠣ᠊	Boulder Clay

SOLID

Cambrian	Ff	Thinly interbedded sandstone and siltstone	Ffestiniog Flags Formation
	Mw	Grey mudstone	Maentwrog Formation
	MwS	Interbedded sandstone and mudstone	

INTRUSIVE IGNEOUS

| pMt | Microtonalite |
| P | Intermediate, undivided |

SYMBOLS

- Geological boundary, Solid
- Geological boundary, Drift
- Fault, crossmark indicates downthrow side
- Quartz vein
- 40 Inclined strata, dip in degrees
- ᠊ᠣ᠊ Adit, abandoned
- ⊕ Shaft, abandoned

Fig 58 Geological map of Hafod Fraith area.

105

Fig 59 Geophysical data for Hafod Fraith area.

Gwynfyndd
Gold Mine   No.6
            Level

Contours of airborne
E.M. in ppm

Contours of aero-
magnetic survey in n T,
referred to standard
datum

Ground survey traverses
with areas of <100%
in-phase

SCALE
0   100   200m

**Fig 61 Geochemical data
for Hafod Fraith
area.**

SCALE
0   100   200m

Stream sample site

Soil traverse showing anomalous
values in parts per million

106

FIG. 60.   SLINGRAM EM DATA FOR TRAVERSE B AT HAFOD FRAITH

TRAVERSE 1

TRAVERSE 2

TRAVERSE 3

TRAVERSE 4

Cu
.... Pb
Zn

∟__l__⊐ Sample points,
20m intervals
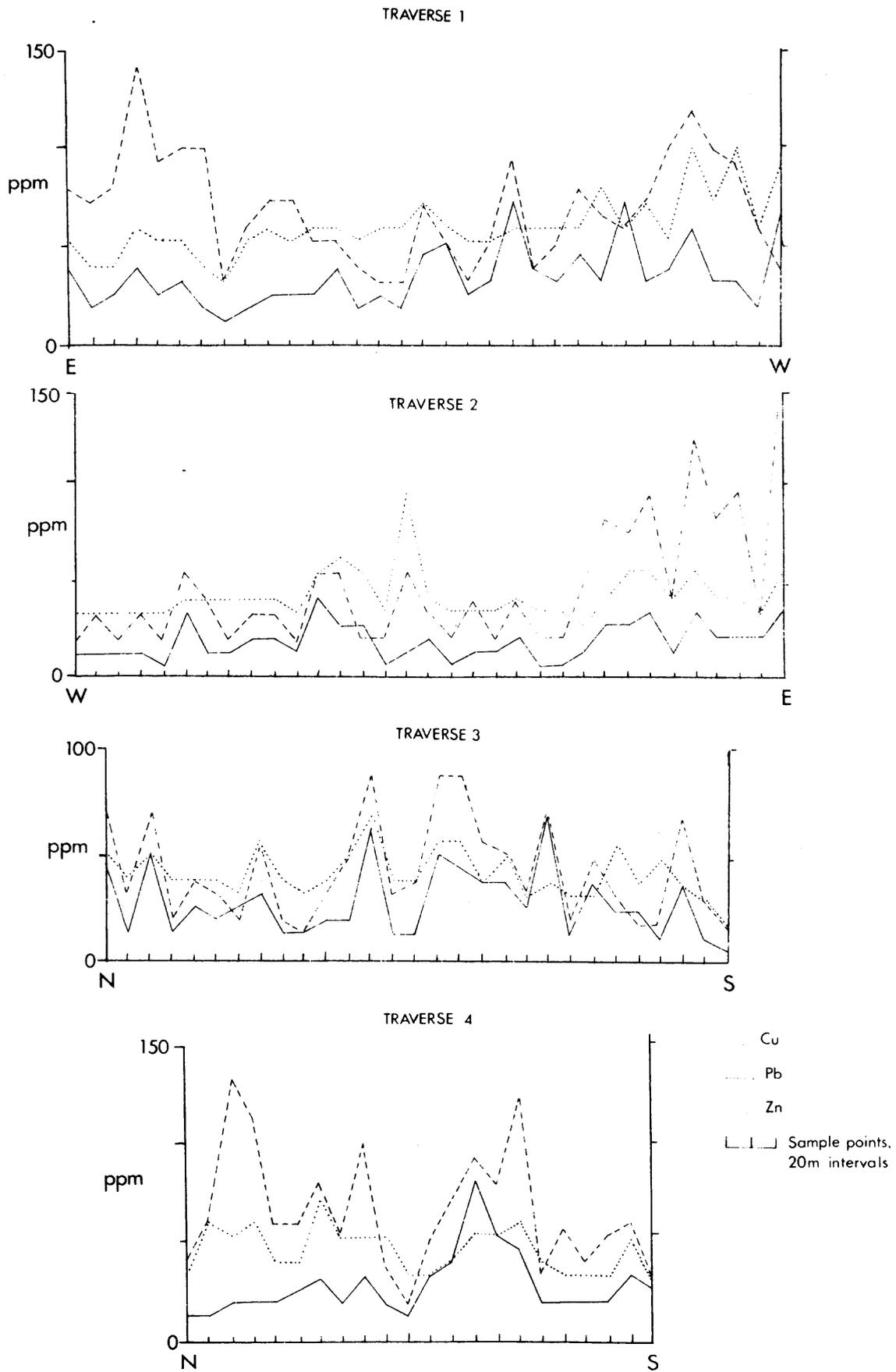
Fig. 62A, Hafod Fraith; copper, lead and zinc in soil samples collected along traverse lines 1 — 4 shown in Fig.61
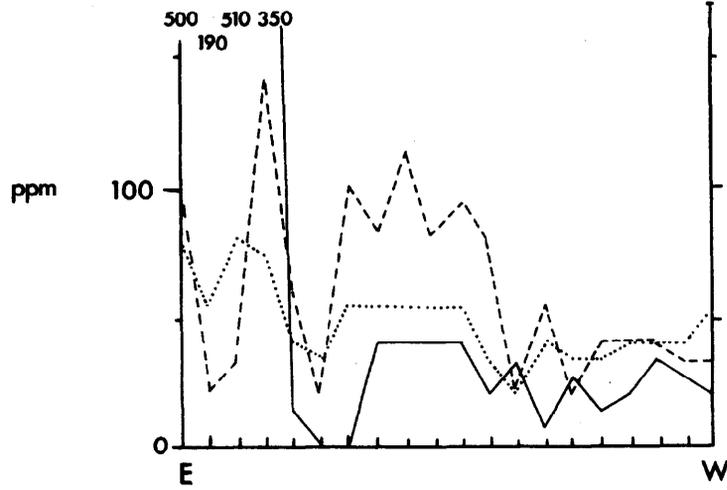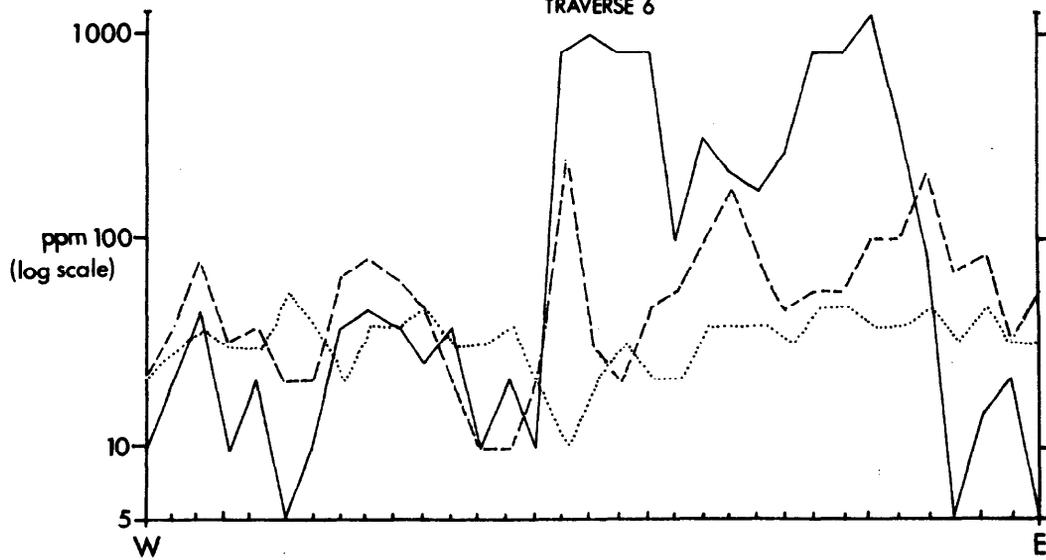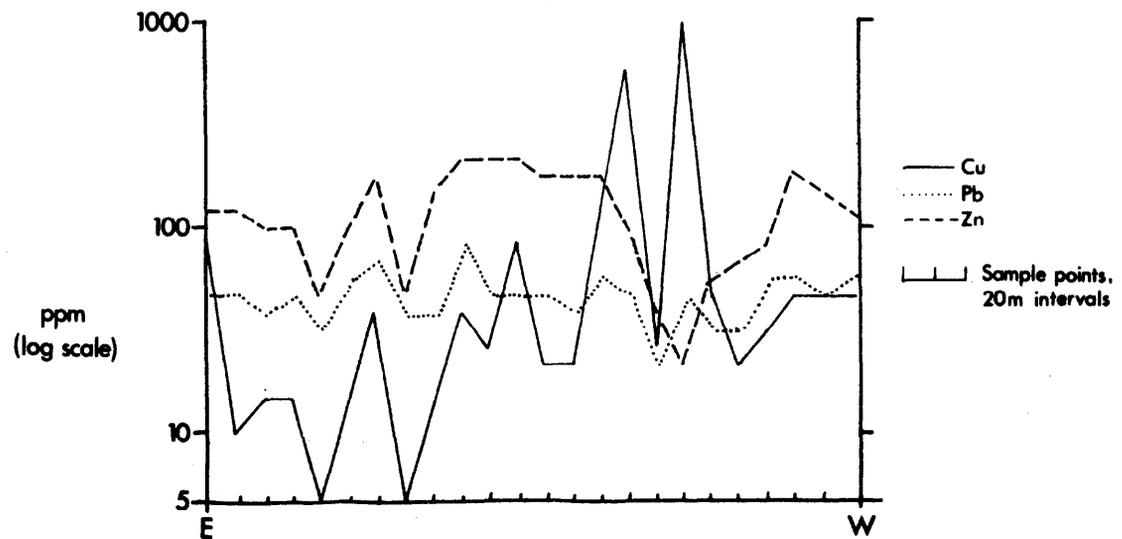
Fig. 62B. Hafod Fraith; copper, lead and zinc in soil samples collected along traverse lines 5 — 7 shown in Fig.61

TRAVERSE 8

TRAVERSE 9

—— Cu ········ Pb ─ ─ ─ ─ Zn

⌐_⌐_⌐ Sample points, 20m intervals
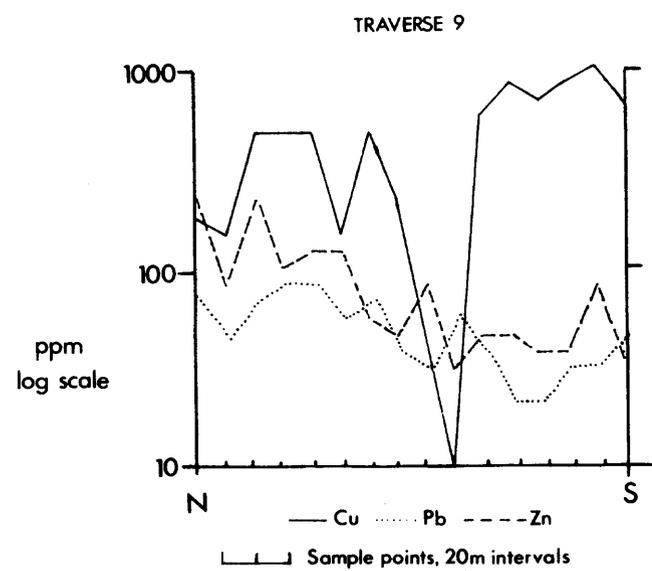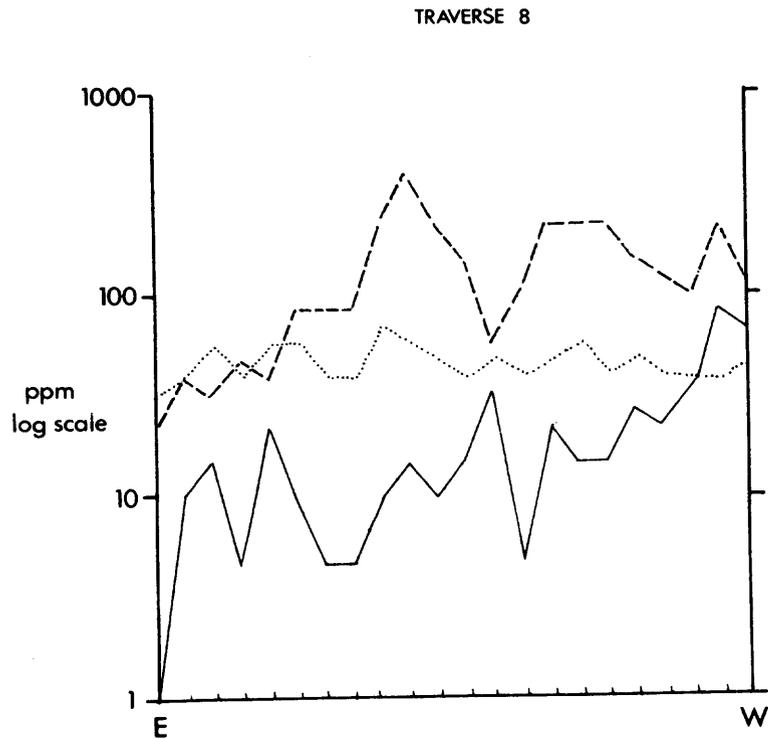
Fig. 62C, Hafod Fraith; copper, lead and zinc in soil samples collected along traverse lines 8 and 9 shown in Fig. 61

Table 17. Summary of analytical results in ppm for 232 soil samples from Hafod Fraith

	Mean	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Cu	23	100	216	32	120	453	1250	<3
Pb	37	45	15.4	43	61	86	100	10
Zn	50	74	56.2	57	117	239	410	10

exposed in the river at SH 7405 2820; and secondly three traverses near the main lode at the Gwynfynydd Mine failed to show a systematic anomaly, suggesting that either all the conductive material has been removed, or if any still remains it does not give a significant EM response.

In the area of the EM anomaly (traverse B) grey mudstone of the Maentwrog Formation dips at 45° to the east which crudely correlates with the geophysical interpretation. This formation, however, does not show consistent conductivity on all traverses and it must, therefore, only tentatively be regarded as the origin of the anomaly.

The ground magnetics show sharp variations superimposed upon broader variations, which in general confirm the pattern indicated by the airborne survey. The anomalies overlie an area of faulted Maentwrog Formation and Ffestiniog Flags. Elsewhere the Maentwrog Formation has been found to be magnetic (e.g. at Mynydd Penrhos) and this is the probable origin for the anomaly. It is also possible that some of the sharp anomalies may result from mine debris.

Geochemistry

Two sites were sampled in the area during the reconnaissance drainage survey (Fig. 61). At SH 7473 2805, the only anomalous value, 74 ppm tin in panned concentrate, is considered to be due to contamination from the farm upstream. At SH 7477 2754, above the farm, anomalous results for copper (130 ppm) and zinc (800 ppm) are present in stream sediment.

Soil samples were collected at 20 m intervals first along traverses over the EM anomaly (traverses 1-5) and then, following the discovery of highly anomalous results at the eastern end of traverse five, to the south-east of the anomaly (traverses 6-9). The majority of samples were taken from head and boulder clay underlying organic-rich topsoil or peat, but a few samples on traverses 6, 7 and 9 consists solely of peat where this layer was greater than 120 cm deep. A summary of the analytical results is given in Table 17 and the detailed results are plotted on traverses in Fig. 62.

The distribution of lead and zinc is nearly lognormal but copper shows a more complex form. Analysis of the copper distribution (Parslow, 1974) defined two populations, an upper group with a median of 270 ppm and a lower group with a median of 23 ppm. The threshold level for copper was set at 80 ppm. At this level 99% of the upper population would be described as anomalous as

well as 7% of the lower population. For lead and zinc the threshold was set at the 97.5 percentile of the population, theoretically corresponding to the geometric mean + 2 geometric deviations, but as the distributions were not perfect the threshold levels were 85 ppm for lead and 220 ppm for zinc. Anomalous results are shown in Fig. 61.

The correlation matrix indicates a highly significant (99%) positive correlation between lead and zinc but only a weak relationship between these elements and copper. This lead-zinc relationship must be formed in the background samples; for the anomalous results show no close relationship.

The majority of the lead anomalies, all of which are very weak, occur on traverses 1 and 2 (Fig. 61) and overlie the assumed position of a north-north-west trending fault which passes through Princess Marina Mine. The soils over these anomalies are well drained and not peaty; thus anomalies may well indicate the presence of weak lead mineralisation along the fault structure. The isolated, weak copper anomaly on traverse 4 is adjacent to a known vein.

All the other copper anomalies occur in a group which roughly coincides in position with a peat-filled depresssion on the gently sloping hillside. Some of the anomalous samples are of peat, but the majority consist of the underlying boulder clay. Some of the anomalies, notably from the south east end of traverse six and the north end of traverse 9, are outside the peaty depression. The latter is underlain by the Ffestiniog Flags Formation and a microtonalite intrusion and the copper anomalies may reflect mineralisation associated with these rocks. It is considered more likely, however, in this environment that the area of copper enrichment represents a transported anomaly, of a similar type to the turf copper deposit, with the copper being leached from bedrock and/or boulder clay in the catchment to the south-east and deposited in the depression.

Some zinc anomalies occur with the high copper values, but the highest zinc values and several near threshold values are found on traverses 7 and 8 in thin drift over microtonalite. It is not clear whether these values are indicative of mineralisation or simply reflect high local background levels, perhaps coupled with some secondary enrichment.

Conclusions

There is no obvious relationship between any of the soil anomalies and the EM anomalies, which

possibly relate to conductive horizons within the Maentwrog Formation.

The independent behaviour of lead, zinc and copper anomalies in this area is believed to reflect different sources. Weak lead anomalies probably indicate patchy local vein mineralisation. Zinc anomalies which are generally weak may either indicate a high background associated with a microtonalite intrusion or weak secondary concentrations in drift. It is uncertain whether the copper enrichment in the peat-filled depression represents a transported anomaly or disseminated mineralisation underlying the depression. The former is considered more likely.

It is recommended that further sampling is undertaken, both of soil and bedrock to try and establish the source of the Hafod Fraith copper anomaly.

HAFOD-Y-FEDW
Centre point: SH 722 221
6-inch sheet SH 72 SW

Introduction

The coincidence of airborne EM and magnetic anomalies in this relatively well exposed area, plus the presence of an old mine adjacent to it, suggested that it was a good place to investigate the causes of the geophysical anomalies. Thus, in addition to the routine ground follow-up some geophysical orientation studies were carried out.

Geology

Apart from one or two small patches of peat there is little mappable drift in this area, though most of the hollows between the ridges of exposed rock contain a thin filling of boulder clay.

In the west of the area the Maentwrog Formation consists of thinly interbedded white, fine-grained sandstone and grey siltstone. In places the sandstone occurs only in laminae and thin beds; elsewhere beds several centimetres thick dominate the succession. Separated from this arenaceous succession by a north-east-trending fault, the upper part of the formation consists of light and medium grey siltstone and silty mudstone with occasional laminae and thin beds of sandstone (Fig. 63).

Intruded into the sedimentary rocks are a considerable number of sills, some less than a metre thick. The majority of them are highly altered. In some there are chlorite pseudomorphs after amphibole phenocrysts and white mica pseudomorphs after feldspar. The groundmass is microcrystalline quartz, feldspar, chlorite, sericite and leucoxenized opaque. In others there is intense alteration to carbonate. Pyrite, present often as cubes several millimetres wide, and possibly pyrrhotite, occur in most intrusions. Their composition is difficult to determine, but it seems to vary from microdiorite to dolerite.

The large intrusion on the eastern side of the area has been named the Hafod-y-fedw Complex. Adjacent to its western margin the country rock has been brecciated, and in the marginal parts of the complex there are rafts and large xenoliths of country rock, which suggest repeated intrusion rather than incorporation of country rock. The main rock is altered quartz-dolerite containing interlocking saussuritised plagioclase and chlorite pseudomorphs after ferromagnesian minerals. Near Cae Mawr Mine this rock is totally altered to clinozoisite, albite and chlorite. There are porphyritic varieties containing pseudomorphs after and relicts of brown hornblende and some rocks are veined by chlorite and brecciated. Ilmenite and pyrite are present in all rocks and chalcopyrite has been observed in one specimen. In many parts of the complex there are abundant quartz veins.

The succession dips steeply eastwards and is cut by strike and dip faults. Both the mudstone and the dolerite in the Hafod-y-fedw Complex are cleaved.

Mineralisation

At SH 7252 2263 there are two closely spaced fenced-off adits, one above the other, which follow a 1.2 m thick, roughly north-trending quartz vein. In addition to quartz, calcite and chlorite gangue minerals, only pyrite was found in this vein. At SH 7259 2248 there is a flooded adit trending 240°. There are a number of thin quartz veins in the country rock, including a thin horizontal one, but again the only sulphide found is pyrite. At Cae Mawr Mine, SH 7251 2247, a quartz vein trending 295° and dipping at 46° to the south-west has been open stoped. Among the spoil there is abundant quartz, epidote, calcite and chlorite associated with pyrite and chalcopyrite. All three of these workings are in the Hafod-y-fedw Complex, which is locally richly veined by quartz. Gilbey (1969) regarded this mineralisation as a separate event from that which produced the Gold-belt veins.

There is some mineralisation in the Maentwrog Formation. At SH 7230 2241 an outcrop of light grey silty mudstone in a stream bed contains 2-3% sulphide by volume. Small amounts of pyrrhotite with minor chalcopyrite and marcasite occur in lenticular, slightly buckled, disseminated bodies almost parallel to the bedding. In addition, pyrrhotite occurs, often corroded and associated with pyrite and minor marcasite, in small fractures which are oblique to the bedding and this may represent a later, possibly post-cleavage, mineralisation.

Geophysics

This area, in which EM and magnetic activity is intense, has an airborne EM anomaly of 300 ppm coincident with a negative aeromagnetic anomaly of 500 nT in amplitude. To define these on the ground 7 traverses using slingram and total field magnetometer were measured (Fig. 64).

The airborne and ground magnetic anomalies coincide reasonably in position (Figs. 64 and 65) but the ground survey showed that the aeromagnetic low feature consists of a zone of intense variations. The simpler features to the east are, however, similar, with values gradually decreasing

112
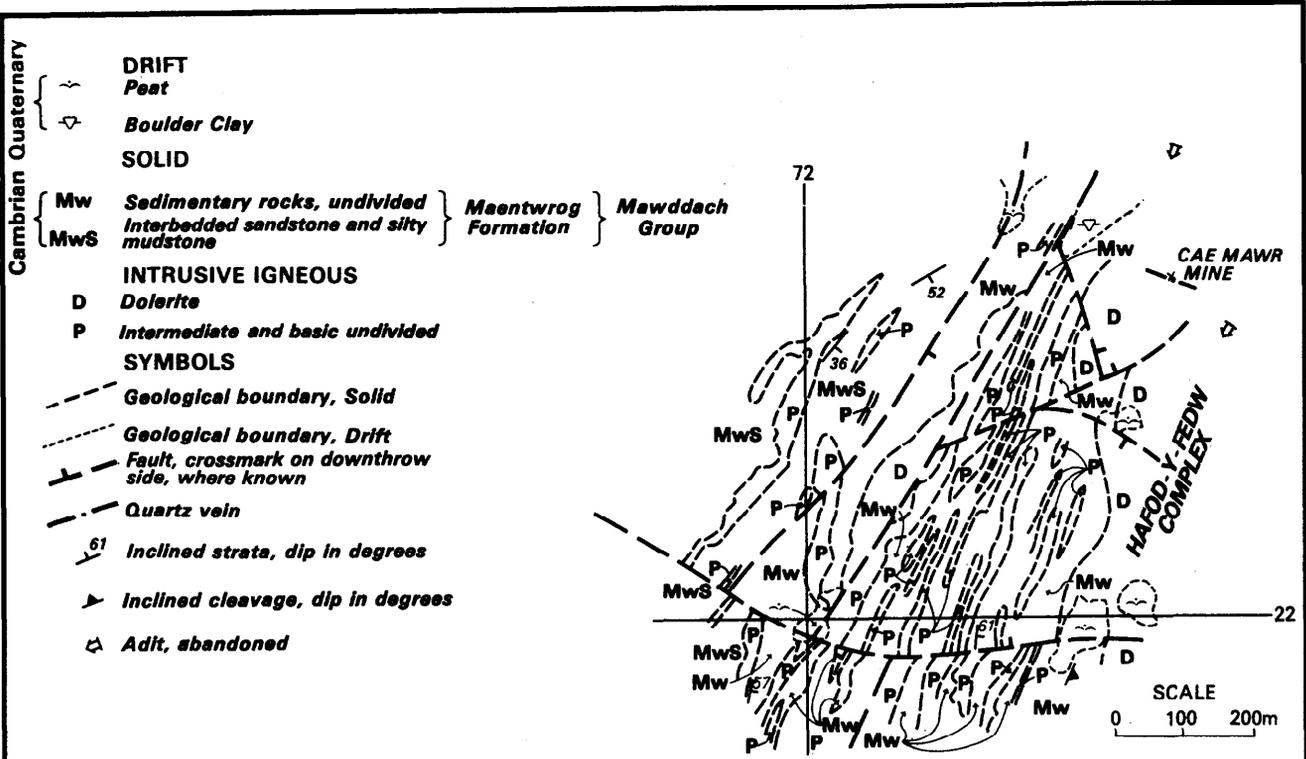
Fig. 63 Geological map of Hafod - y -fedw area.

Legend

Cambrian Quaternary

DRIFT
- ~ Peat
- ▽ Boulder Clay

SOLID
- **Mw** Sedimentary rocks, undivided ⎱ Maentwrog ⎱ Mawddach
- **MwS** Interbedded sandstone and silty mudstone ⎰ Formation ⎰ Group

INTRUSIVE IGNEOUS
- **D** Dolerite
- **P** Intermediate and basic undivided

SYMBOLS
- Geological boundary, Solid
- Geological boundary, Drift
- Fault, crossmark on downthrow side, where known
- Quartz vein
- ⟋⁶¹ Inclined strata, dip in degrees
- ⟋ Inclined cleavage, dip in degrees
- ⋄ Adit, abandoned

Fig. 65 Contour map of total magnetic field strength, contour interval 1000 nT.

Areas of <100% in phase EM anomaly shown by ⋉⋉⋉⋉⋉⋉

Aeromagnetic contours in nT referred to standard datum.

In phase contours of airborne E. M. in ppm.

Ground magnetic and E. M. traverses.

TRAVERSE A

Hafod-y-fedw

Fig. 64 Airborne geophysical data for Hafod-y-fedw area.
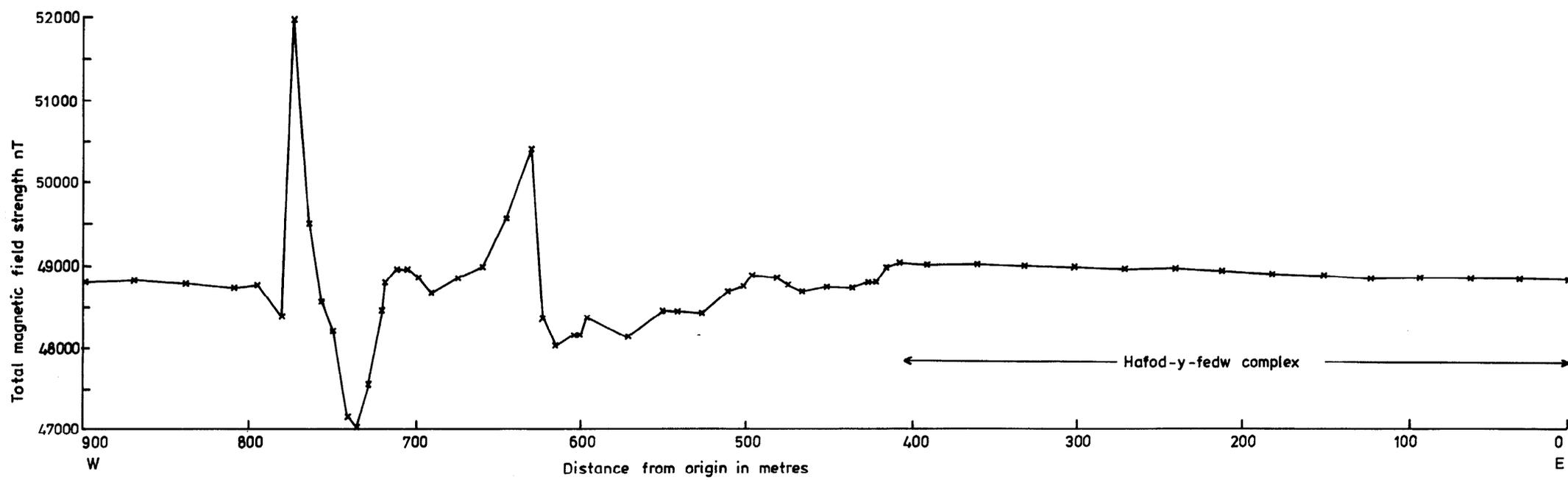
FIG. 66.   THE TOTAL MAGNETIC FIELD STRENGTH ON TRAVERSE A AT HAFOD-Y-FEDW

to the east. This is clearly seen in traverse A (Fig. 66).

The airborne and ground EM anomalies are rather different in shape - the one proved on the ground apparently extending further to the north than is suggested by the airborne data.

Further detailed ground measurements using a field susceptibility meter and a small slingram 'metal detector', were carried out to identify the rocks causing the anomalies. Some of the minor intrusions have a susceptibility of about 3×10^{-3} SI units presumably caused by magnetite and pyrrhotite. The large Hafod-y-fedw Complex is non-magnetic.

Using the 'metal detector' it was demonstrated that the conductive rocks in the Maentwrog Formation form discontinuous bands, typically 40 m long, less than 1 m thick and roughly parallel to the strike. A sample taken from one such band contains 2-3% sulphide, in laminae parallel to bedding and in oblique fractures, which is apparently sufficient to produce a large enough bulk conductivity to cause the EM anomalies.

Conclusions

The EM anomalies are apparently caused by roughly 2-3% of sulphide minerals in lenticular disseminations parallel to bedding and in fractures oblique to the bedding in the Maentwrog Formation. There is no carbonaceous material in any of the rocks examined. Pyrrhotite and magnetite in the intrusive rocks and pyrrhotite in the sedimentary rocks account for the magnetic anomalies.

The sulphides, which are in part at least post-cleavage in age, include pyrite, pyrrhotite, marcasite and minor chalcopyrite. Similar assemblages, which are of no commercial value, have been recorded elsewhere in the Maentwrog, Clogau and Gamlan formations not always in association with EM anomalies. It is believed that at Hafod-y-fedw the critical factor is the presence of sulphides in fractures crossing bands of disseminated sulphides and, therefore, setting up a continuous network of conducting minerals.

HENGWRT UCHAF
Centre point: SH 7990 2215
6-inch sheets SH 72 SE, 82 SW

Geology

Thin boulder clay covers the whole of the area under investigation, which is arable farmland. Exposure is limited, in the main, to streams, which in places cut down deeply to form steep-sided gorges.

The principal rock units (Fig. 67) are lower Ordovician volcanic formations which dip east to the south-east. At the base, the Allt Lwyd Formation consists of a lower division of black and white banded siltstone, silty mudstone and sandstone. It is overlain by an upper division of coarse, often pebbly, volcanic sandstone. Overlying the Allt Lwyd Formation, the Melau Tuff is a thick unit of bedded basic tuff, lapilli tuff and breccia. There is no exposure either of the over-

lying mudstone or of the Benglog Formation.

Mineralisation

Thin veins of calcite have been found in basic tuffs of the Melau Formation. Disseminated pyrite is present in the tuffs and the underlying volcanic sandstone, which also contains disseminated pyrrhotite. This is present in both the matrix and clastic fragments and, therefore, is unlikely to be clastic in origin (PTS 2778 in Lab. No. 1619; Min. Unit Rpt. 214). A small amount of disseminated galena has been observed in one tuff sample.

Geophysics

A discrete oval airborne EM anomaly of 150 ppm elongated 500 m to the north-east is centred on SH 779 221 (Fig. 68). It was traversed at 3 points using the ABEM Demigun slingram equipment.

A strong anomaly was found on each traverse, only slightly to the north of the airborne feature. As an example traverse A on Fig. 68 is shown in Fig. 69.

The anomaly may be interpreted as being caused by a body approximately 20 m thick dipping to the south-east at about 30°. This is consistent with the local stratigraphy and may be correlated with the black mudstone horizon, which elsewhere is exposed above the Melau Tuff.

Although pyrrhotite has been found in the area it does not appear to cause a significant magnetic anomaly.

Geochemistry

Soil samples were collected at 20 m intervals at depths of 30-50 cm along three traverse lines over the EM anomaly (Fig. 70). Most samples consist of boulder clay from beneath the organic-rich topsoil; some may have come from the drift-bedrock interface. The results for copper, lead and zinc on the 56 samples collected are summarised in Table 18 and shown in Fig. 71.

Copper results show a near normal distribution whilst lead and zinc are near lognormal in form. No distinct breaks or groups of high values are discernible in the distributions and meaningful threshold levels are difficult to establish because of the small number of samples and, for lead and zinc, the clustering of results.

The top 5% of values for each element (Cu > 45 ppm, Pb > 180 ppm and Zn ∼ 270 ppm) are shown on Fig. 70, but inspection of the traverse diagrams (Fig. 71) indicates that some lower results form distinct peaks which may also be significant. Copper levels are generally low but some of the small peaks coincide with high lead and zinc values. Samples rich in lead and zinc were not necessarily from low-lying ground and there were no organic-rich or water-logged samples to suggest that secondary enrichment processes were operative. Some of the element variability probably reflects changes in background geology, especially as traverse 2, which shows the most variable results, runs close to the

Fig 67 Geological sketch map of the Hengwrt Uchaf area.

Legend (Fig 67):

Quaternary

DRIFT
~ Peat
▽ Boulder clay

SOLID

Ordovician

Bgl Volcanic rocks, undivided } Benglog Volcanic Formation

AVG Sedimentary rocks, undivided

Z^B Basic tuff } Melau Tuff

Zz^B Basic tuffite

S^V Volcanic sandstone } Allt Lwyd Formation

All Banded siltstone, sandstone

Aran Volcanic Group

INTRUSIVE IGNEOUS
D Dolerite

SYMBOLS
------- Geological boundary, Drift
----- Geological boundary, Solid
-+-- Fault, crossmark indicates downthrow side
⌐⌐ 48 Inclined strata, dip in degrees

SCALE
0   100   200m

Fig 68 Geophysical data for Hengwrt Uchaf Area.

Legend (Fig 68):

⌐100 Contour of In phase component of airborne EM (in ppm)

▦ Area of >100% In phase component ground EM.

⌐ EM traverse line, bar indicates the beginning.

SCALE
0   100   200m

Fig 70 Geochemical data for Hengwrt Uchaf area.

Legend (Fig 70):

⌐ Cu 50 Soil sample traverse line, showing location of highest copper, lead and zinc values in ppm.

SCALE
0   100   200m

FIG.69. SLINGRAM EM DATA FROM TRAVERSE A AT HENGWRT UCHAF

117
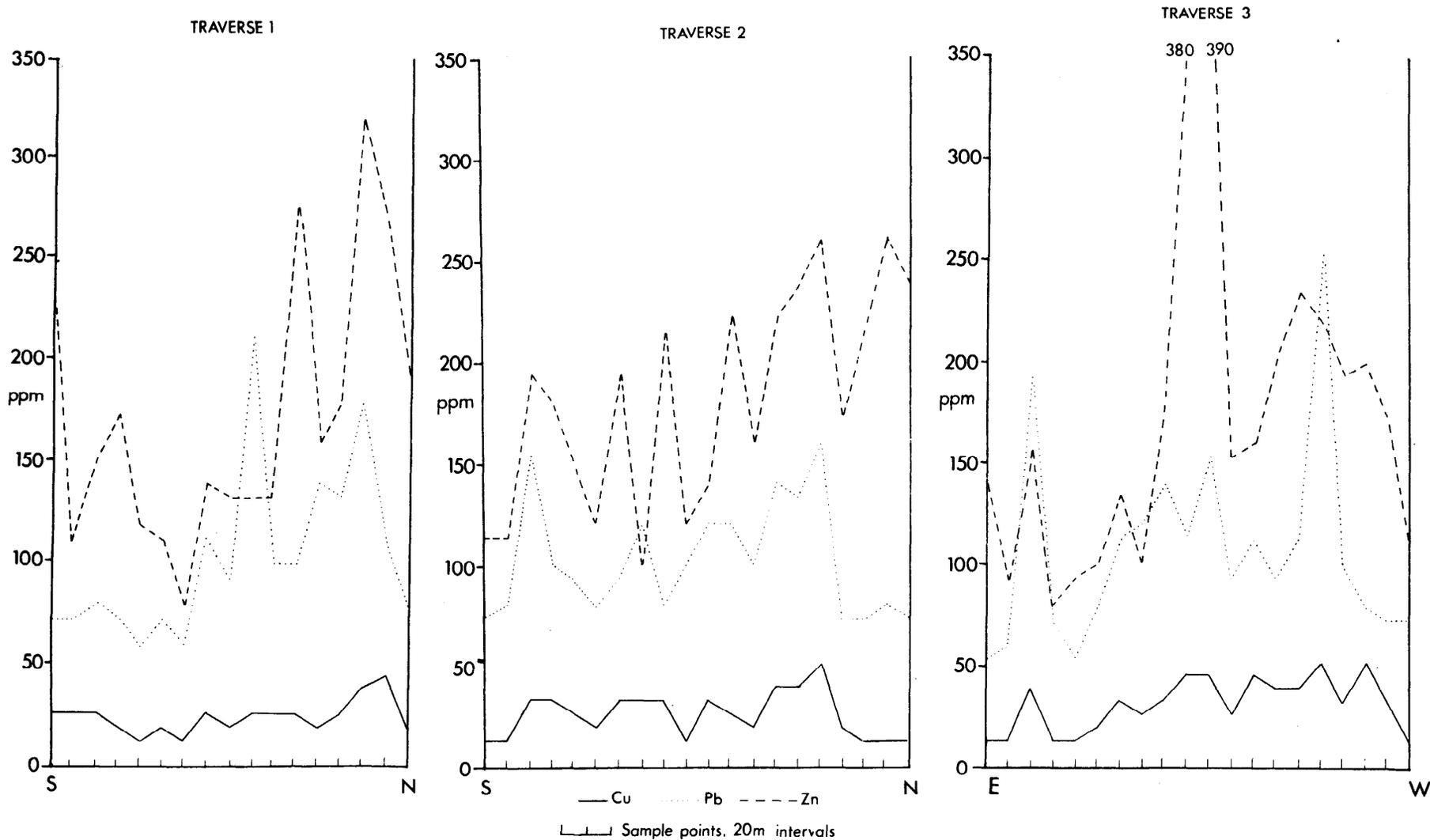
Fig.71 Hengwrt Uchaf; copper, lead and zinc in soil samples collected along the traverse lines shown in Fig.70

	Median	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Cu	25	27	11	25	39	61	50	10
Pb	100	103	40	97	138	196	250	50
Zn	160	175	69	164	238	345	390	80

predicted junction of mudstone with basic tuffs and crosses a fault. There may also be some weak enrichment associated with groundwater movement along structural breaks. However, it is suspected that the most prominent peaks, at least, indicate some form of lead-zinc mineralisation.

Conclusions

The EM anomaly is most likely to be explained by the black mudstone horizon above the Melau Tuff and is not necessarily connected with any mineralisation. The absence of a magnetic anomaly in the area suggests that the pyrrhotite is confined to small, local concentrations. The soil geochemistry, however, indicates the possibility of a weak bedrock mineralisation, but there is no strong evidence to suggest of what type.

It is concluded that further investigation is justifiable and should include, initially, rock geochemistry of the bedrock exposed in the Nant Goch accompanied by further soil sampling to determine the shape of the anomalies.

LLANFACHRETH
Centre point: SH 762 225
6-inch sheet SH 72 SE

Geology

This is an area of subdued hills covered in boulder clay, and in many parts exposure is limited to small craggy outcrops rising above the drift.

The main rock units are the Ordovician Allt Lwyd Formation which rests unconformably on the Rhobell Ganol Formation of the Rhobell Volcanic Group (Fig. 72). At the base of the Allt Lwyd Formation is the coarse-grained quartzose sandstone of the Garth Grit Member. This is overlain by thinly interbedded siltstone and volcanic sandstone, in parts bioturbated. The southern part of the area consists of massive volcanic sandstone. The Rhobell Ganol Formation consists of basaltic lavas.

The bedding generally dips south-west at moderate angles, but there is a zone of faults trending north-east to east-north-east which bring a succession of slices of Garth Grit against the Rhobell Ganol basalts and locally distort the dip and strike. In the north-western part of the area an outlier of Allt Lwyd Formation is folded on a

small scale.

Geophysics

A linear magnetic low of 200 nT amplitude trends north-west for 1 km. It appears mainly on one flight line, although adjacent lines show weaker anomalous values. The validity of the anomaly was tested and proved by 4 ground traverses with a proton precession magnetometer (Fig. 73).

Fig. 74 shows traverse B. An attempt to interpret this was made but no complete solution was found using a simple model. The best fit was obtained by a near-surface dyke-like body 25 m thick at 525 m from the origin. This body would dip steeply to the north-east. The magnetisation has a value of about 80 nT and is opposed in direction to the present earth's field.

Conclusions

There is no obvious geological explanation for the anomaly, though a line of topographic features has been noted coincident with it. The geophysical parameters, however, are very similar to those exhibited by Tertiary dykes elsewhere in North Wales and weak extensions of this magnetic anomaly may be followed to the north-west and south-east suggesting that the body may extend in these directions. No other Tertiary dykes are known in the Harlech Dome, so this must be a tentative postulate.

MYNYDD BACH
Centre point: SH 738 315
6-inch sheet SH 73 SW

Geology

This area covers part of the Afon Gain valley and the western flanks of Mynydd Bach. Exposure is mostly confined to the river bed and stream courses, there being extensive cover of boulder clay and alluvial deposits elsewhere.

The Gamlan Formation consists mainly of grey banded silty mudstone and siltstone with some pyritic sandy laminae, but in the upper part purplish-grey siltstone predominates, often with thin sandy beds, quartzose nodules and lenses. Sulphides are present locally in nodules, bands and fracture infillings. The overlying Clogau Formation consists of hard, black, banded mudstone
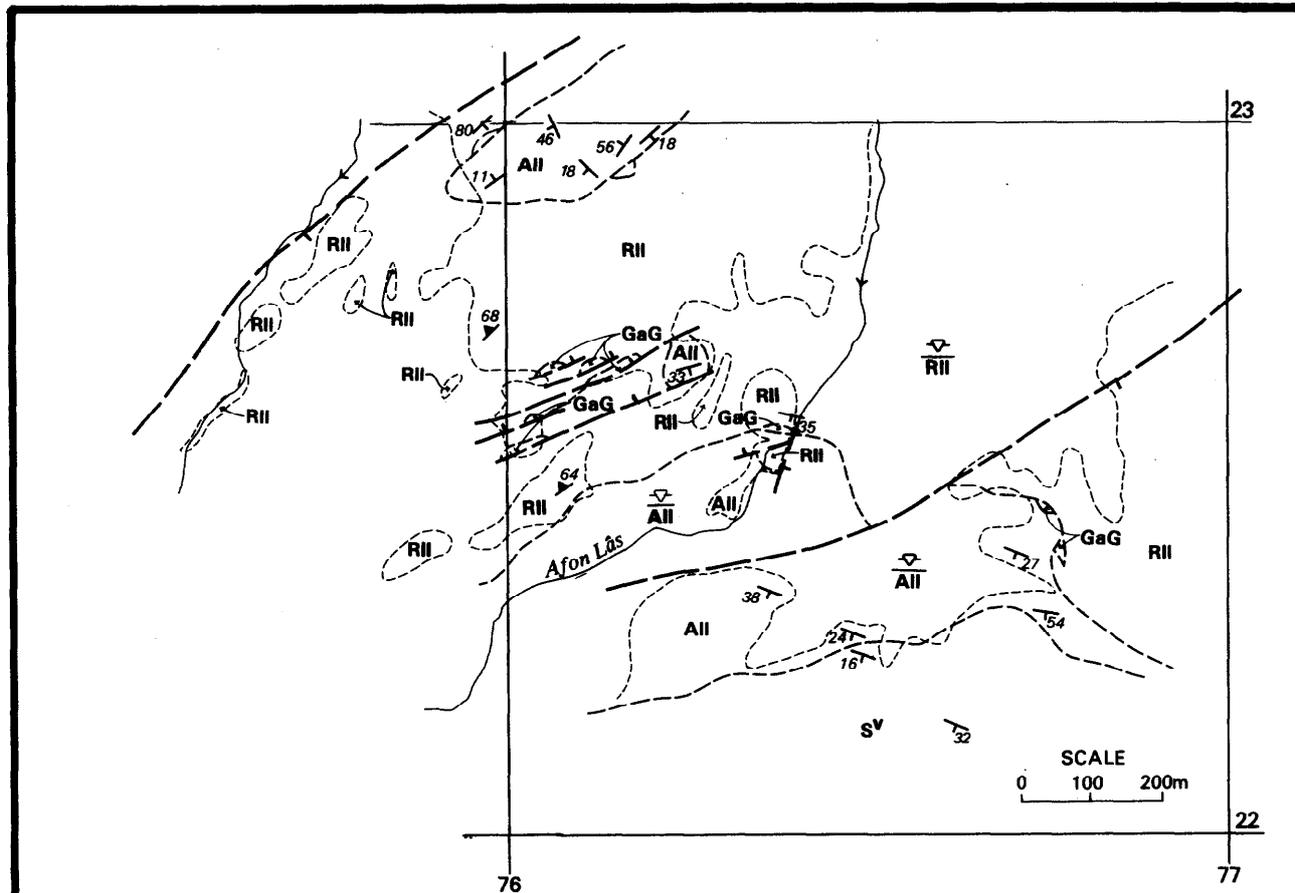
DRIFT
∇ Boulder Clay

SOLID
Ordovician
S^V Volcanic sandstone

Al Interbedded black siltstone and volcanic sandstone

GaG Coarse quartzose sandstone of Garth Grit Member

Allt Lŵyd Formation

Aran Volcanic Group

Cambrian
Rll Basaltic lava of Rhobell Ganol Formation

Rhobell Volcanic Group

SYMBOLS

Geological boundary, Solid

Geological boundary, Drift

ault, crossmark indicates downthrow side

19 Inclined strata, dip in degrees

47 Inclined cleavage, dip in degrees

Fig72 Geological map of Llanfachreth area from mapping by B.P.Kokelaar.

Fig 73 Geophysical data for the Llanfachreth area.

Contours of aeromagnetic survey - earth's field strength in nT referred to standard datum

Ground survey traverses
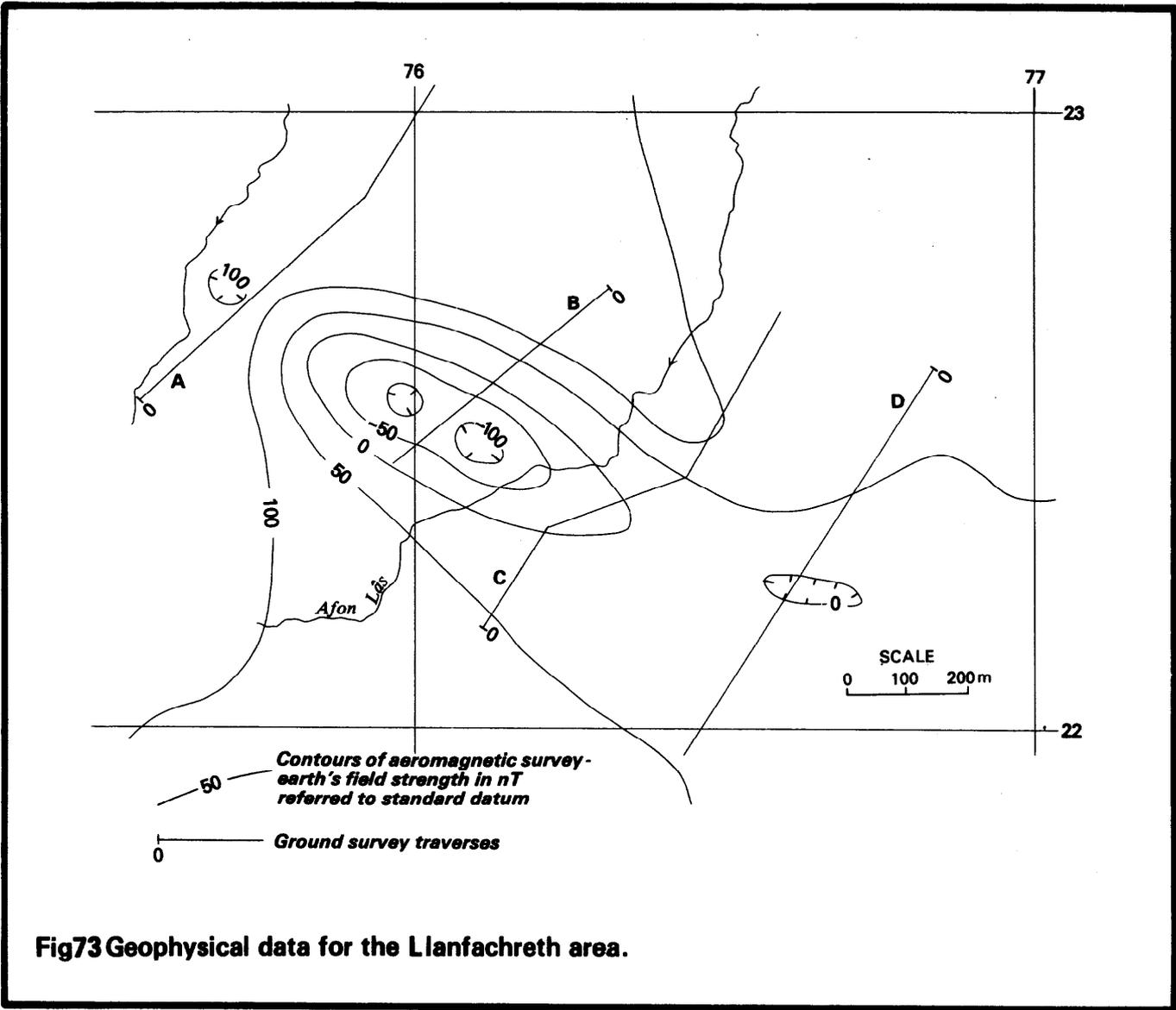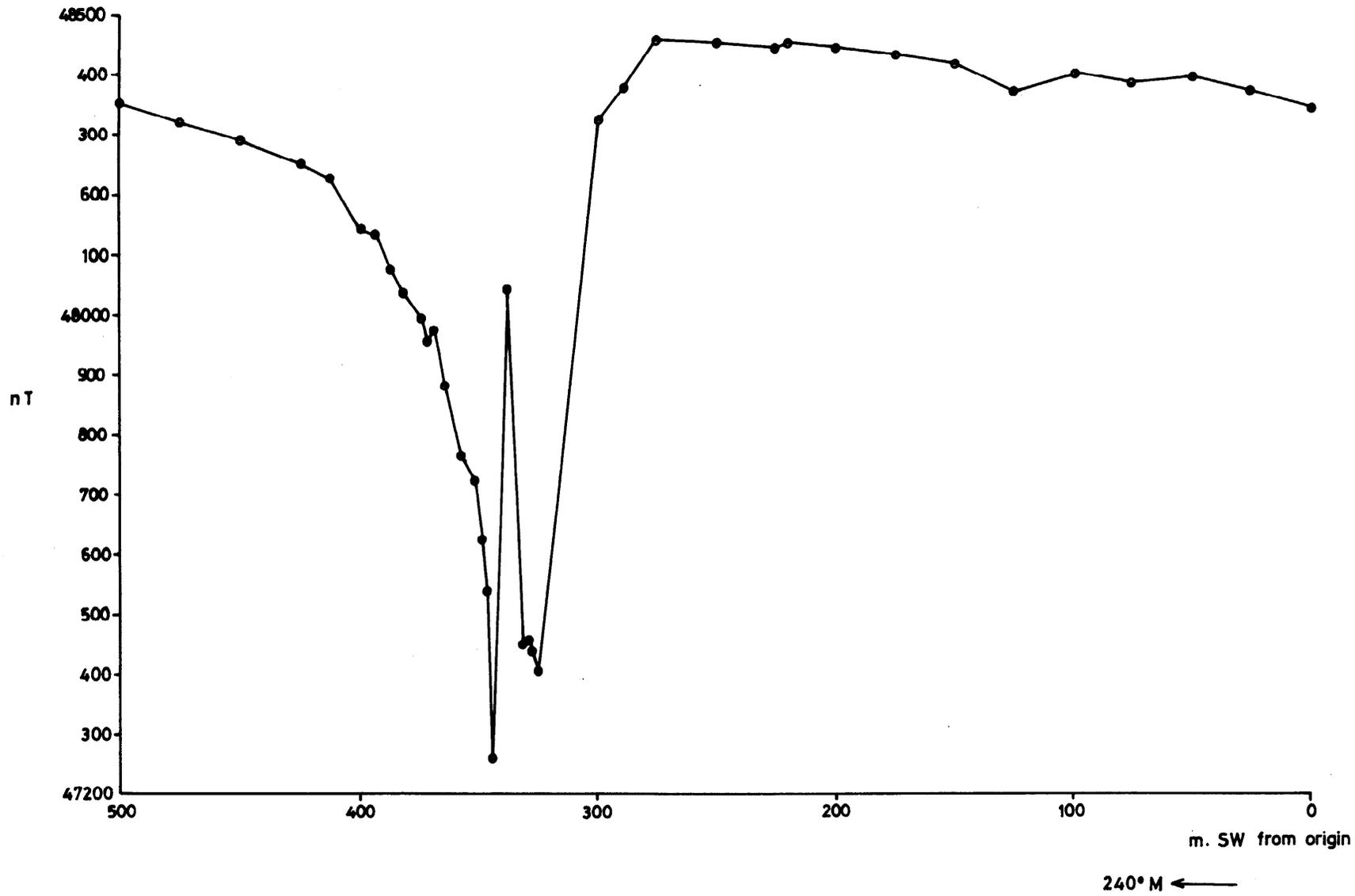
FIG. 74.   MAGNETIC   RESULTS   ON   TRAVERSE 'B' IN LLANFACHRETH AREA

DRIFT

Quaternary

~	Alluvium	
⊍	River terrace deposits, undivided	
⊽	Boulder Clay	

SOLID

Cambrian

MwS	Interbedded sandstone and silty mudstone	} Maentwrog Formation	} Mawddach Group
Clu	Black mudstone	} Clogau Formation	
Gn	Light grey siltstone and silty mudstone	} Gamlan Formation	} Harlech Grits Group

INTRUSIVE IGNEOUS

P   Intermediate, undivided

pMt   Microtonalite

SYMBOLS

_ _ / _	Geological boundary, Solid
-----	Geological boundary, Drift
_|_ / _	Fault, crossmark indicates downthrow side
_._ _	Quartz vein
20 ⤢	Inclined strata, dip in degrees
⤢	Anticlinal axis, minor fold

SCALE
0   100   200m

Fig 75 Geological data for Mynydd Bach.

0.04, 0.01   Zinc and copper values for stream water in ppm. Zinc values underlined

⤙ _ / _   Direction of run-off during flooding

_ 0 _   Contours of airborne EM in ppm

_ 300 _   Contours of airborne magnetics in nT referred to standard datum

AREA USED FOR DRYING PIG BRISTLES

MYNYDD BACH

SCALE
0   100   200m
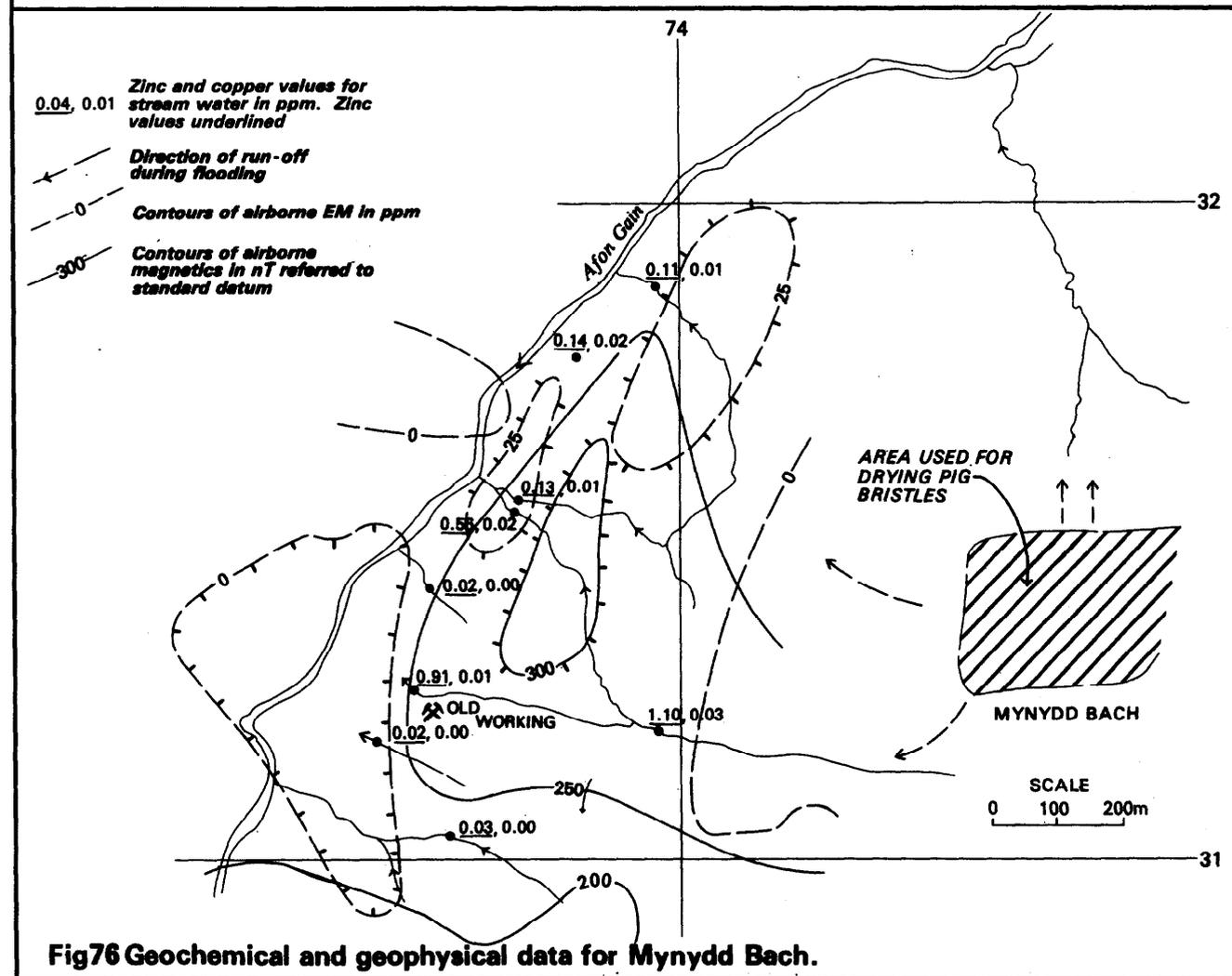
Fig 76 Geochemical and geophysical data for Mynydd Bach.

123

with lenses of sulphide. The Maentwrog Forma-
tion is exposed in only two places, where it
consists of light grey siltstone with laminae of
mudstone and laminae and beds up to 20 cm thick
of fine-grained sandstone (Fig. 75).

There are several sills of microdioritic rocks,
some as little as 1 metre thick, and one thick sill
of porphyritic microtonalite in the Gamlan
Formation. The Craiglaseithin (p. 53) intrusion
of microtonalite lies at the northern edge of the
area and it is possible that the general north-
east strike and moderate to low south-east dip in
this area is a product of the doming effect of this
intrusion on the strata above it. The
Craiglaseithin Fault passes through the west of
the area. Another fault, parallel to it, appears
to pre-date one of the microtonalite intrusions.
An excellent penetrative cleavage is present in
most of the argillaceous rocks.

Mineralisation

A north-east trending quartz vein in the
Maentwrog Formation has been excavated at
SH 7371 3125. Quartz specimens from the tip
contain pyrite, chalcopyrite and abundant sphale-
rite, some in veinlets in the quartz. At Pont
Dol-y-mynach (SH 7335 3119) there are numerous
quartz veins up to 15 cm thick trending from
070° to 105°, some concentrated in a 60 cm-wide
zone in interlaminated siltstone, mudstone and
fine-grained sandstone of the lower part of the
Maentwrog Formation. Some veins contain pyrite,
marcasite and minor sphalerite, but the host
sedimentary rock contains patchy, disseminated
pyrrhotite and rare chalcopyrite and hematite.
Pyrrhotite and quartz have also crystallised along
incipient cleavage planes at angles of 45-50° to
the bedding.

Elsewhere sulphide minerals are abundant in
the sedimentary rocks. Silty mudstone from the
Gamlan Formation at SH 7361 3152 is brecciated
and veined by chlorite and carbonate. Pyrrhotite
and chalcopyrite are present in carbonate veins
developed parallel to an incipient cleavage and
disseminated through the breccia fragments. In
one specimen large patches of pyrrhotite, minor
chalcopyrite and sphalerite associated with
carbonate are sigmoidal in outline, but because
there is no internal distortion of the sulphides it
is likely that the shape represents accommodation
of the minerals to earlier sedimentary structures
rather than a response to a later deformation.
The Clogau Formation from nearby (SH 7324 3154)
contains lenses of coarse-grained pyrrhotite and
marcasite with minor chalcopyrite and sphalerite.
Euhedral pyrrhotite with corroded cores is
disseminated throughout the rock (PTS 2727).

Geophysics

An aeromagnetic anomaly of 100 nT has a
north-north-east trend, roughly parallel to an
airborne EM anomaly of 25 ppm (Fig. 76).

Both anomalies are associated with the Clogau
Formation, although their trends are not parallel
to the strike direction. The rather low amplitude
of the Clogau EM anomaly is due to attenuation of
the primary signal in the boulder clay cover. It
was thought that little useful additional data could
be obtained from ground follow-up in this area.

Geochemistry

A number of water samples were collected
from the small streams which cross this area
and analysed for copper and zinc. Compared with
threshold levels determined for the Harlech Dome
as a whole either large Zn anomalies (>0.10 ppm),
or background Zn (<0.05 ppm) and Cu (<0.02 ppm)
values were recorded in the samples. It is likely
that all the Zn anomalies are the result of conta-
mination from the pig bristle drying area (Fig. 76)
with perhaps a minor contribution from the debris
left on this old artillery range. Both effectively
mask any signs of mineralisation in the bedrock.

Conclusions

Detailed mineralogical examinations of rocks
from the exposures of Maentwrog, Clogau and
Gamlan formations in the Afon Gain revealed two
generations of sulphide minerals both of no direct
economic importance. The first, consisting of
pyrrhotite, chalcopyrite, sphalerite and possibly
pyrite, is syngenetic in origin; the second, which
gave rise to pyrrhotite and chalcopyrite in veinlets
with calcite and quartz and along cleavage planes,
is much younger.

At Garth Gell, where there is a stronger
aeromagnetic anomaly, pyrrhotite was found to
post-date the cleavage in the country rock
adjacent to the quartz vein system which was
worked in the Clogau Gold Mine. This suggests
that the emplacement of the veins was accom-
panied by the introduction of pyrrhotite into the
country rock. Thus, the aeromagnetic anomaly
at Mynydd Bach might be indicative of quartz
veining concealed by drift.

The hydrogeochemical Zn anomalies are at
least in part the product of contamination from
the pig bristle drying area and mask any signs of
zinc mineralisation. The low copper values
suggest that disseminated copper mineralisation
is not present near surface.

MYNYDD FOEL UCHAF
Centre point: SH 711 206
6-inch sheet SH 72 SW

Geology

Topographically this is a strongly featured
area of rough, hill pasture, parkland and conifer-
ous plantations. Except for the south-eastern
part there is very little drift. The ground,
however, tends to be boggy in hollows and drainage
is generally poor.

The Clogau Formation, consisting of black,
laminated mudstone, often with sulphide lenses,
lies on the north-western periphery of the area.
The lowermost part of the Maentwrog Formation
consists of fine-grained sandstone beds up to
60 cm thick and pale grey siltstone and silty
mudstone. There is a gradual upward diminution

DRIFT

Quaternary

€   Scree and head

⊽   Boulder Clay

SOLID

Cambrian

Mw   Sedimentary rocks, undivided

MwS   Interbedded sandstone, siltstone and silty mudstone

} Maent-wrog Formation

Clu   Black banded mudstone

} Clogau Formation

Mawddach Group

INTRUSIVE IGNEOUS

P   Intermediate and basic, undivided

pM   Microdiorite

pMq   Quartz-microdiorite

pMt   Microtonalite

SYMBOLS

---   Geological boundary, Solid

-·-·-   Geological boundary, Drift

—⊥—   Fault, crossmark indicates downthrow side where known

—·—   Quartz vein

37   Inclined strata, dip in degrees

⋩   Adit, abandoned

⊕   Shaft, filled in

GEOCHEMICAL SAMPLING LINE

▲   Rock sample

•   Soil sample

SCALE

0   100   200m

Llyn Tan-y-graig

Afon Whion

Road

Fig 77 Geological map of Mynydd Foel Uchaf area, showing geochemical traverse line.

FIG. 78. GEOPHYSICAL DATA FOR MYNYDD FOEL UCHAF AREA

Track
Contours of total magnetic field strength in nT referred to standard datum
Contours of airborne EM in-phase component in ppm
Ground EM and magnetic traverses
Indicates area of in-phase EM anomaly <100%

126
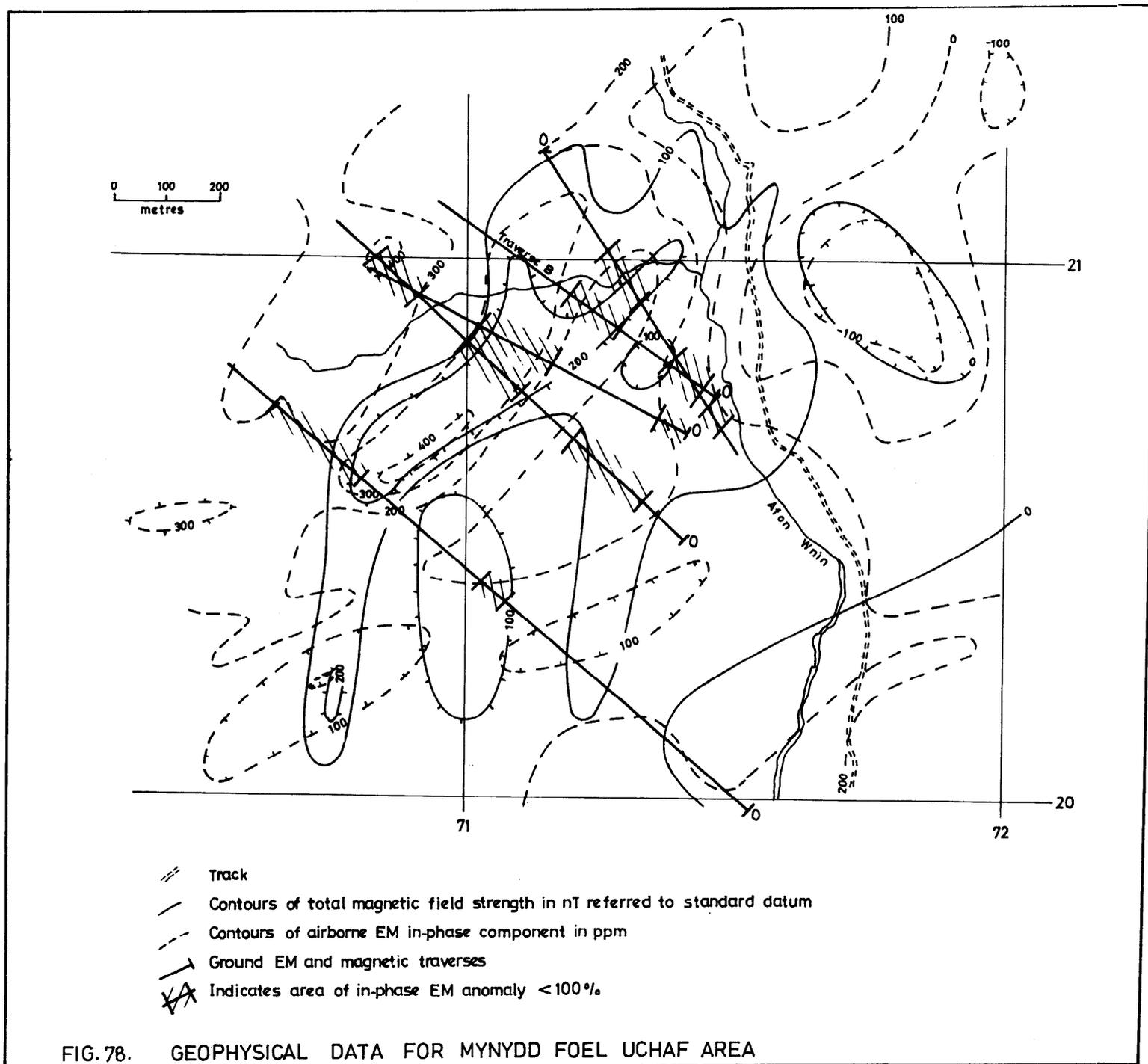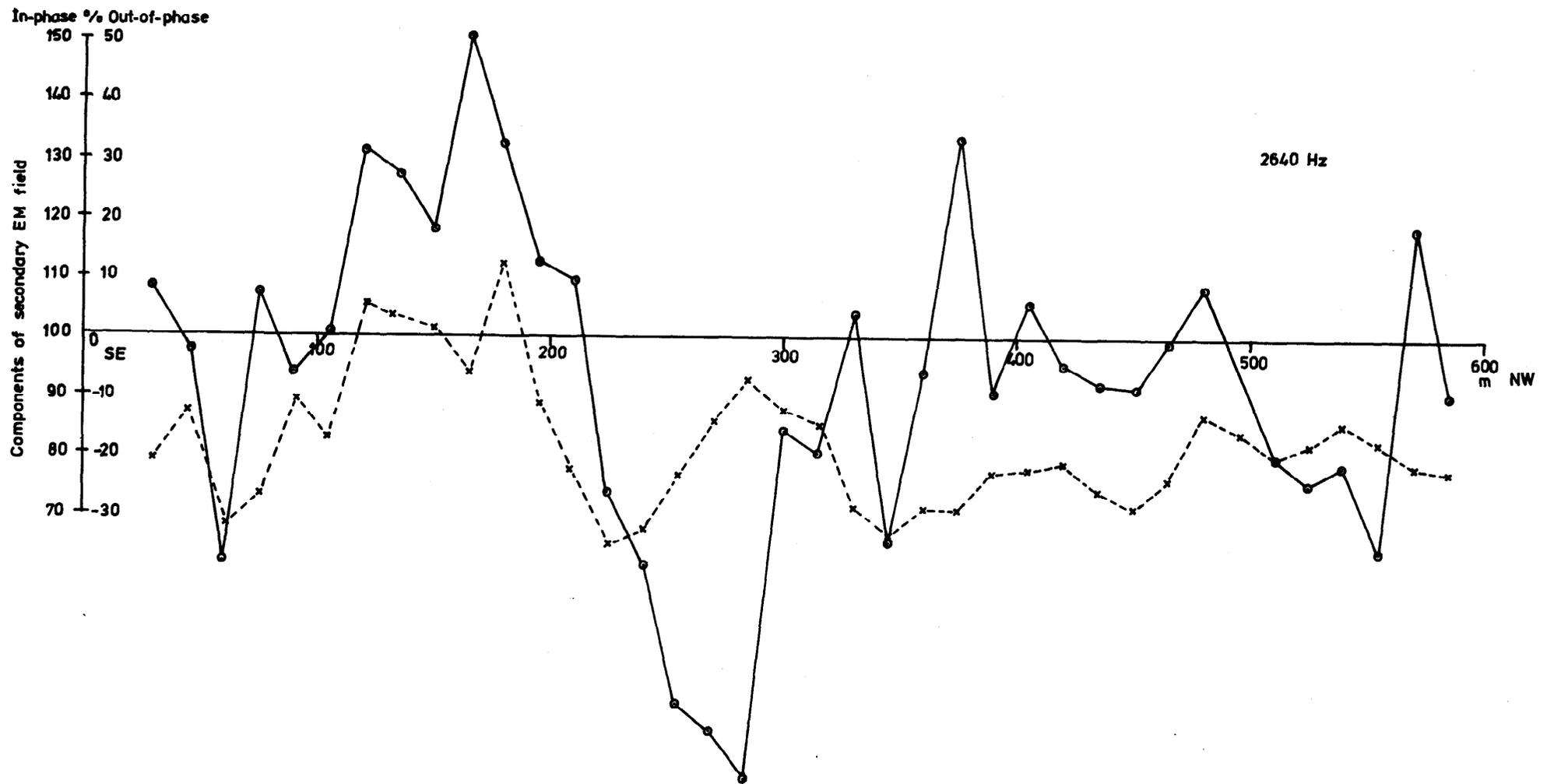
FIG. 79.   SLINGRAM EM DATA ALONG TRAVERSE B AT MYNYDD FOEL UCHAF

FIG.80. TOTAL MAGNETIC FIELD STRENGTH ALONG TRAVERSE B AT MYNYDD FOEL UCHAF

Total magnetic field strength nT

128

in the proportion and thickness of sandstone beds, but they are never absent from the succession. Many of the arenaceous beds are laminated or cross-bedded and some contain slump folds. In most of the formation sandstone is interbedded with dark grey and black mudstone, which in the upper half are the dominant rock types (Fig. 77).

There are a considerable number of sills and slightly discordant intrusions mostly ranging in composition from microdiorite to microtonalite. Most of these are light grey rocks conspicuously rich in pyrite cubes. Porphyritic varieties contain pseudomorphs after amphibole and feldspar phenocrysts, often in a matrix consisting of sericite, calcite, quartz and chlorite, in which there is little sign of the primary texture. A few sills consist of altered dolerite.

The bedding generally dips at about 60° to the east-south-east or south-east, though there are minor folds plunging at moderate angles to the south in some places. There is a strong cleavage in the argillaceous rocks with a similar strike to, but steeper dip than the bedding. There are several prominent north-north-west-trending faults and, in places, small strike faults have been recorded.

Mineralisation

To the south-west of this area there are a number of old workings belonging to the Voel Mines, and north of it, near Ty'n-y-Llwyn (SH 7102 2138) there are several workings belonging to the old Wnin (Wnion) Gold Mine in the Cesailgwm-Wnin Lode. Within the area there is an adit at SH 7150 2109 driven along the contact between a thin sill and the country rock but no tip was found. At SH 7101 2092 there is an old shaft, again with no tip or sign of what was being followed. A tip outside an adit at SH 7061 2095 contains quartz with galena and sphalerite presumably dug from a vein in the adjacent fault. There are more old levels at SH 7118 2062 and SH 7110 2064 which were driven to explore two roughly north-east trending quartz veins. Small diggings in minor quartz veins are present in several other places.

Pyrite is ubiquitous in sandstone and dark mudstone in which disseminated cubes, some several millimetres wide, are present. Pyrrhotite occurs as lenses in the mudstone and associated with pyrite on joints in all rock types. XRF analysis of a sandstone containing pyrrhotite both disseminated and in joints showed abundant Fe, minor Cu and As, and some Zn, indicating the possible presence of other sulphides.

Geophysics

Five ground traverses using slingram and magnetometer were measured over part of this intensely anomalous area (Fig. 78).

All the traverses show strong variations by both methods. The ground EM proves the airborne anomaly, but it may be seen from Fig. 79 that the conductor is complex and consists of several conductive units. Further interpretation is rendered imprecise because of this complexity

but there are indications that the conductor dips to the south-east at about 40° and is within 6 m of the surface.

There is close correlation between the EM anomalies and the dark grey or black mudstone of the Maentwrog Formation.

The ground magnetic anomalies do not correspond in detail with the airborne, as is to be expected from the high frequency and amplitude of the ground anomalies (Fig. 80). However, highly magnetic rocks of several types were identified in the area of the anomalies using a susceptibility meter. These range from the minor intrusions with susceptibility values averaging 2×10^{-3} SI units to sandstones with pyrrhotite-coated joint faces with values up to 7×10^{-3} SI units. The mudstones show a wide range from 0 to 1.5×10^{-3} SI Units.

Geochemistry

The reconnaissance drainage survey did not cover this area effectively. A site sampled in the north of the area, at SH 7137 2128, is contaminated by material from old mine workings, which effectively masks any contribution to the Cu, Pb and Zn anomalies recorded from unknown sources.

A series of rock and soil samples were taken at roughly 20 m intervals along the geophysical survey traverse B (Fig. 77) as an orientation study to examine the relationships between element concentrations in rock and soil and geophysical anomalies. As far as terrain restrictions allowed soil and rock samples were collected alternately along the traverse. At one site an intrusion and shales were exposed in the same outcrop and here two closely spaced rock samples, one of each type, were taken. Soil samples consisted of boulder clay from beneath organic rich topsoil. The samples were analysed for a range of elements by AAS and the results are plotted out in Fig. 81.

A summary of the results is given in Table 19, but because of the small number of samples and variation in rock types no attempt was made to use other statistical methods.

When compared with averages for common rock types the maximum values recorded in these rocks do not suggest any strong enrichment in the metals determined. Cobalt, zinc, iron and especially copper levels are generally higher in the intrusives than the sediments, whilst lead values with one exception are slightly higher in the sediments. The sample from the intrusion at the south-east end of the traverse shows the highest nickel, cobalt, copper, lead and zinc values recorded in the rock samples. None of these values is so high as to rule out a primary magmatic origin, but the combination of elements, and distinct peaks for lead and nickel compared with the other intrusives, does suggest weak sulphide mineralisation.

A comparison of rock and soil results (Fig. 81) shows the much greater variability of soil results, implying either highly variable drift cover or, more likely, variable mobility of some elements under changing physical conditions within the
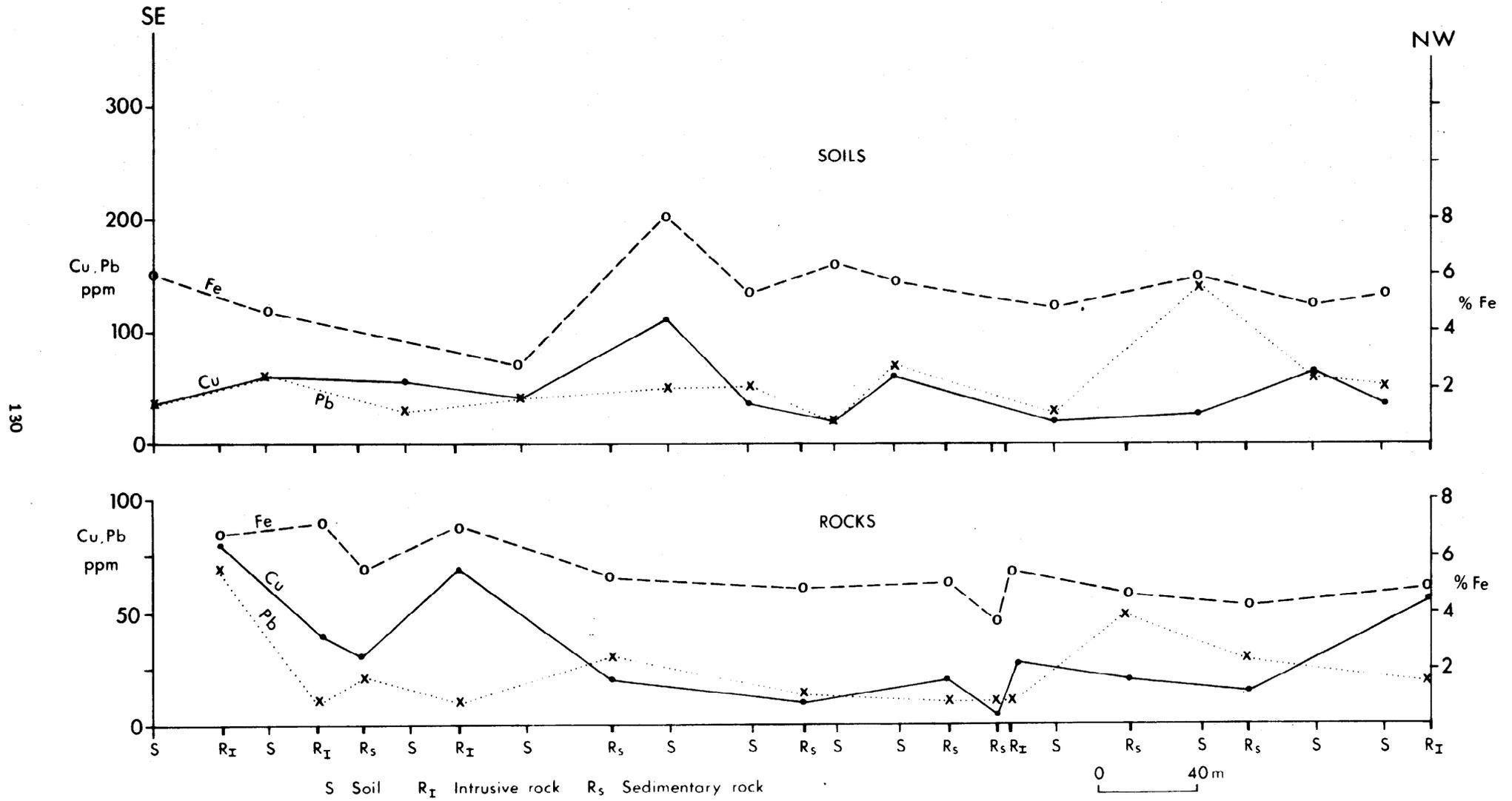
Fig 81A   Mynydd Foel Uchaf ; copper, lead and iron in soil and
rock chip samples collected along the traverse shown in Fig 77
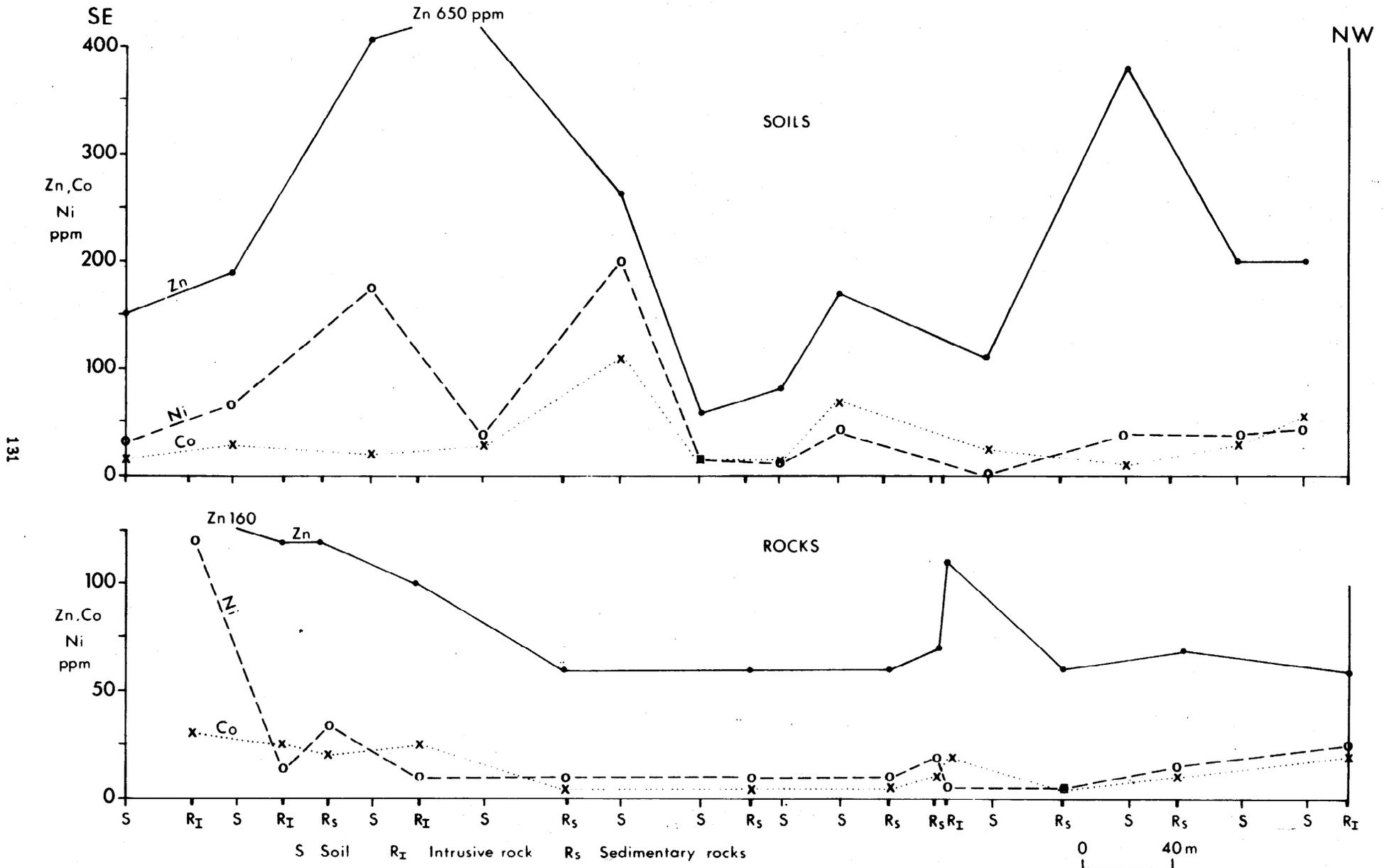
Fig 81B Mynydd Foel Uchaf ; zinc, cobalt and nickel in soil and
rock chip samples collected along the traverse shown in Fig 77

Table 19. Summary of analytical results in ppm for soil and rock samples from
Mynydd Foel Uchaf

		Median	Mean	Std. dev.	Maximum	Minimum	n
SOIL	Cu	40	47.1	25.3	110	20	12
	Pb	50	53.3	30.8	140	20	12
	Zn	195	238	177	650	60	12
	Co	22.5	32.9	30.8	110	10	12
	Ni	40	57.5	63.4	200	<3	12
	Fe%	5.44	5.49	1.26	8.06	2.87	11
ROCK	Cu	25	33.3	24.3	80	5	12
	Pb	20	24.2	18.8	70	10	12
	Zn	70	87.5	33.6	160	60	12
	Co	15	15.4	10.1	35	5	12
	Ni	12.5	23.3	31.6	120	5	12
	Fe%	5.05	5.37	1.08	7.1	3.8	12

weathering zone and superficial cover.

Lead values are consistently higher in soils than rocks and this may be related to the fixation of lead on organic matter, though the highest lead value, which was accompanied by a high zinc value, was not from an organic-rich sample. It probably reflects a secondary concentration and/or a small vein structure.

Iron levels were generally similar in rocks and soils. This was surprising in view of the patchy secondary concentrations of iron usually found in these soils. The lack of high values might be related to incomplete solution of hydrous oxides using the nitric acid sample attack, whilst other elements usually associated with iron in these phases such as cobalt and zinc were released.

Zinc, copper, cobalt and nickel levels in soils are much higher than in rocks in some samples whilst they are similar in others. The high values, particularly zinc, can usually be correlated with topographic depressions or streams and are probably caused in the first instance by precipitation, scavenging and absorption effects brought about by changes in physical conditions within the weathering zone. The highest levels of copper, nickel, cobalt and iron recorded in the area are in a soil sample from low ground and probably represent a transported basinal concentration. The lack of such strong enrichments in other similar depressions suggests an anomalous source in the vicinity.

Conclusions

The complex EM and magnetic anomalies recorded by the airborne survey were confirmed on the ground. The EM anomalies are probably attributable to carbon-bearing mudstone in the Maentwrog Formation, but the magnetic anomalies are linked to the presence of pyrrhotite which occurs both as lenses within the sedimentary rocks and in joints and fractures in all the rocks in the area.

The geochemical work gave indications of weak sulphide mineralisation in the area, but the general lack of high lead and copper values in rocks and soils which show local weak enrichment in zinc, cobalt and nickel indicates that it is only of the pyrite-pyrrhotite type recorded at surface.

A comparison between the geochemical and geophysical profiles shows no obvious relationship between EM and geochemical anomalies. However, magnetic anomalies caused by epigenetic pyrrhotite coincide in two places with high values for Co, Ni and Cu in soils. Thus, though the metal enrichments tend to occur in soils from small inter-outcrop depressions and near streams, suggesting that they may be transported secondary enrichments, the distance of movement may not have been great.

MYNYDD PENRHOS
Centre point: SH 734 233
6-inch sheet SH 72 SW

Geology

Mynydd Penrhos is a steep-sided afforested mountain. There are thick scree deposits on the west and south-east. On the north-east is the edge of a long strip of boulder clay which extends over the top of the ridge north of the mountain.

The lower part of the Maentwrog Formation (Fig. 82) is mostly concealed by scree. The upper part, however, consisting of dark grey mudstone is well exposed on the top of the mountain. The Ffestiniog Flags Formation consists of thinly interbedded, fine-grained sandstone and light grey siltstone and silty mudstone. Numerous thin sills of altered intermediate rocks and basic rocks are present in both formations. In addition there are two large intrusions, one of quartz diorite, the other microtonalite, which are part of a complex that extends northwards to Hafod Ffraith and includes both the porphyry copper deposit at Capel Hermon and the Bryn Coch prospect.

Intruding the microtonalite at SH 7375 2365 is an intrusion-breccia. Exposure in the area is poor but the pipe is known to measure at least 150 m in one direction. The rock consists of

DRIFT

G   *Scree and Head*

⬦   *Boulder Clay*

SOLID

Ff   *Interbedded siltstone and fine-grained sandstone*   *Ffestiniog Flags Formation*

Mw   *Sedimentary rocks, undivided*   *Mawddach Group*

MwS   *Interbedded silty mudstone and sandstone*   *Maentwrog Formation*

INTRUSIVE IGNEOUS

P   *Intermediate and basic undivided*

pMt   *Microtonalite*

qH   *Quartz diorite*

V   *Tuffisite*

SYMBOLS

Geological boundary, Solid

Geological boundary, Drift

Fault, crossmark on downthrow side

Inclined strata, dip in degrees

⬦   *Adit, abandoned*

SCALE
0   100   200m

Fig 82 Geological map of Mynydd Penrhos.

Contours of E.M. airborne in-phase component in ppm

Contours of aeromagnetic total field strength in nT referred to standard datum

Ground traverses showing area of in phase <100%

SCALE
0   100   200m
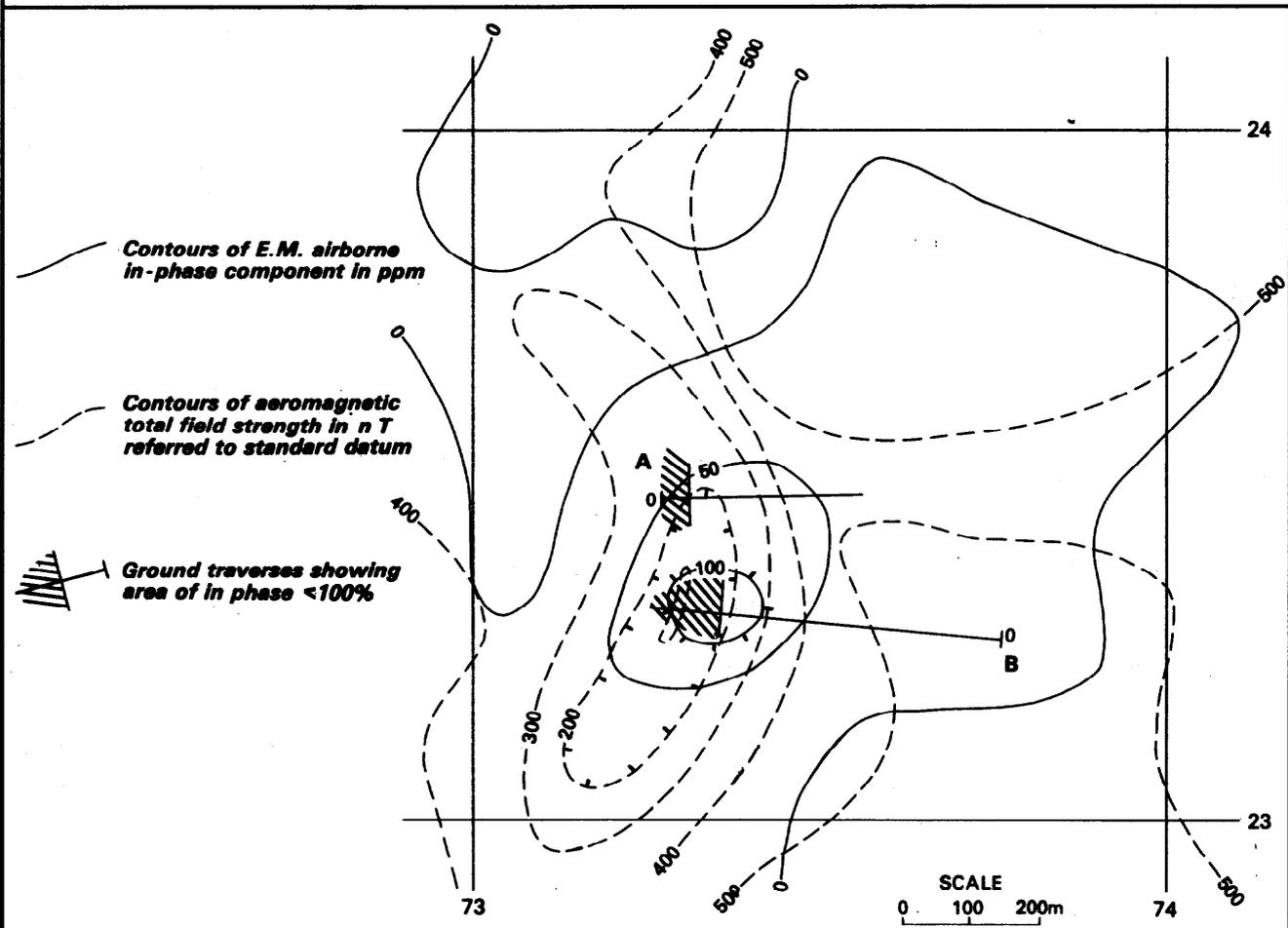
Fig 83 Geophysical data for Mynydd Penrhos.

133
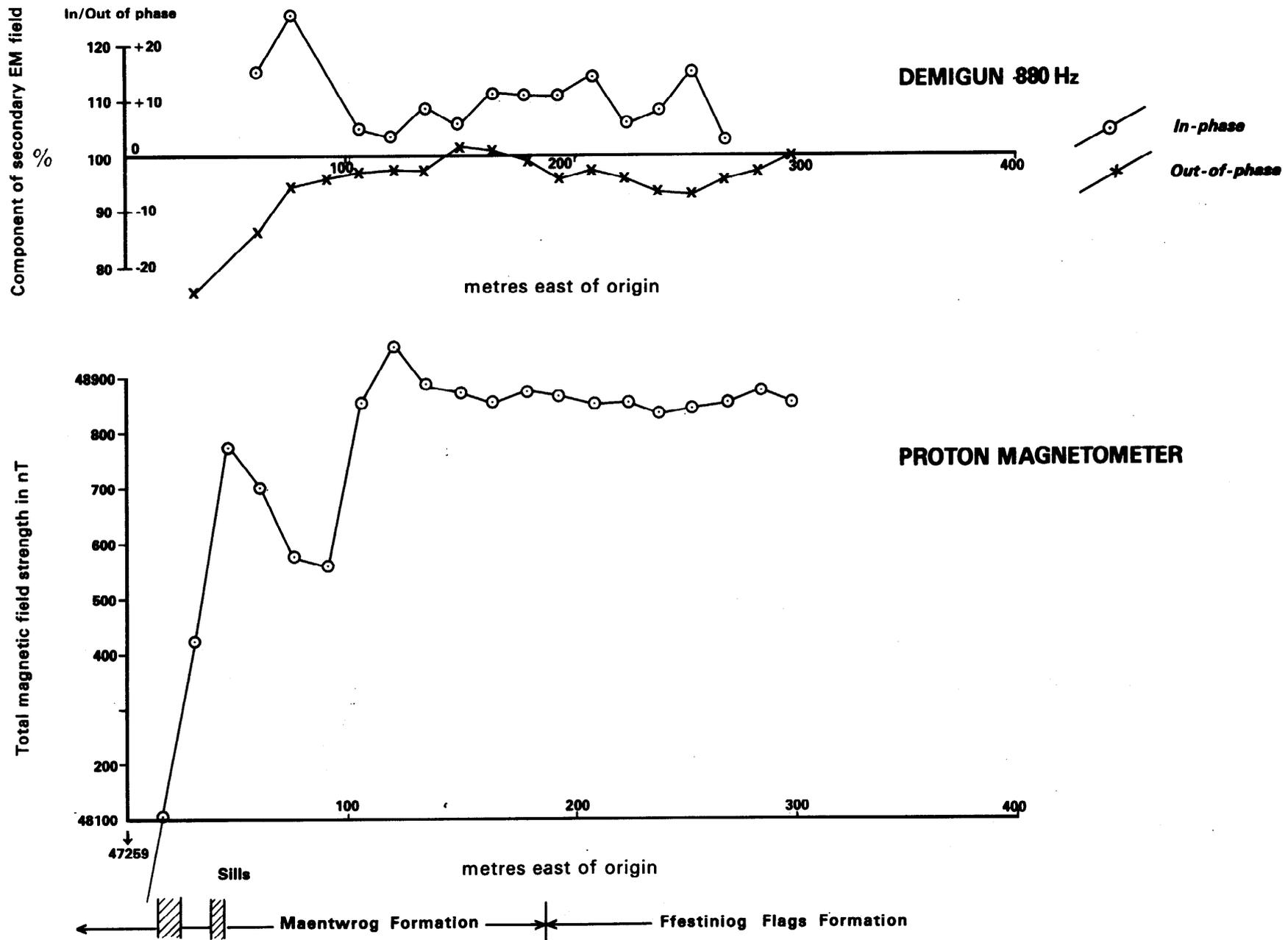
Fig 84 EM and magnetic information along traverse A, Mynydd Penrhos.
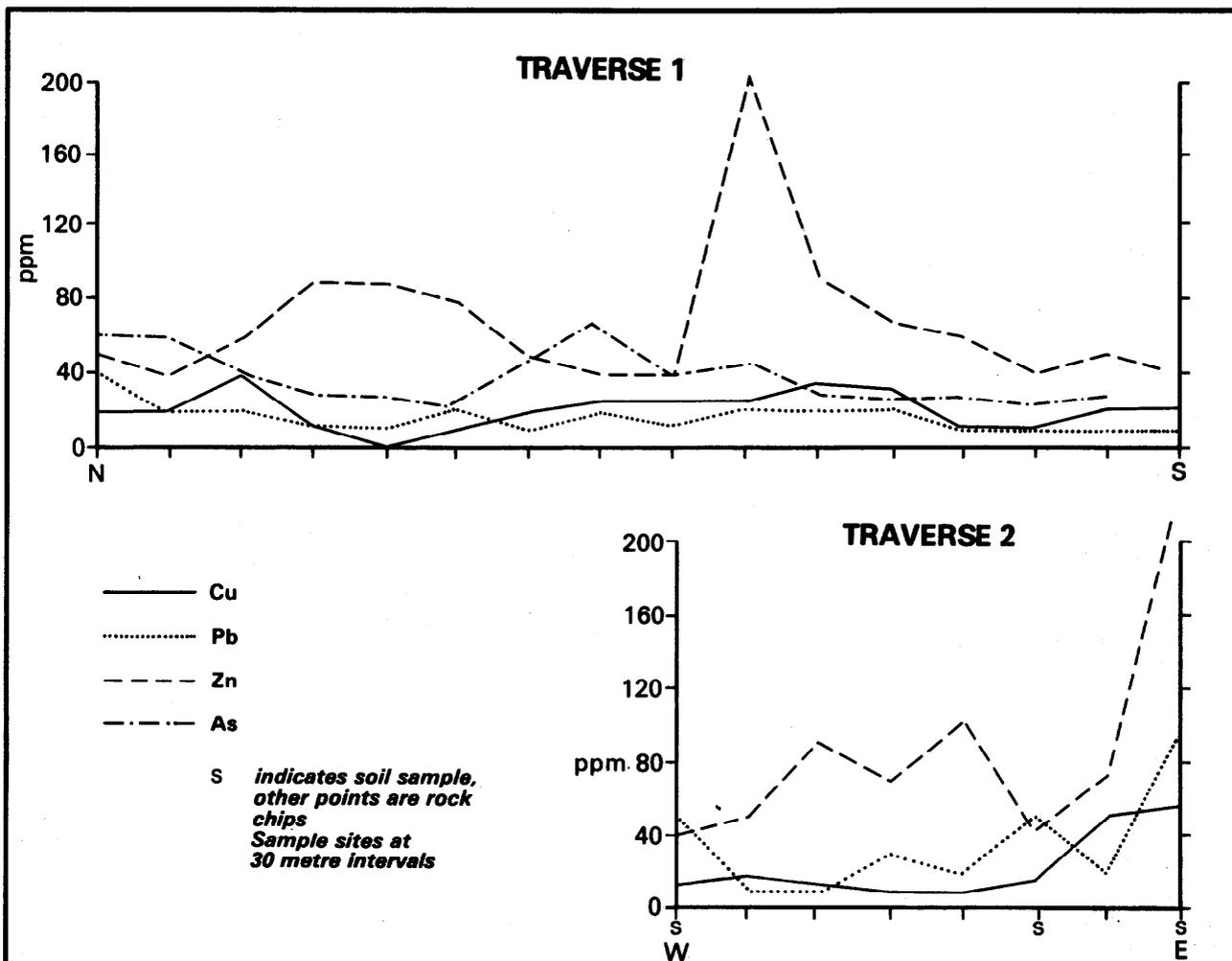
Fig 86 Cu, Pb, Zn and As values in rock chip and soil sample sites, Mynydd Penrhos.

Fig 85 Location of geochemical sample traverses and drainage sites on Mynydd Penrhos.
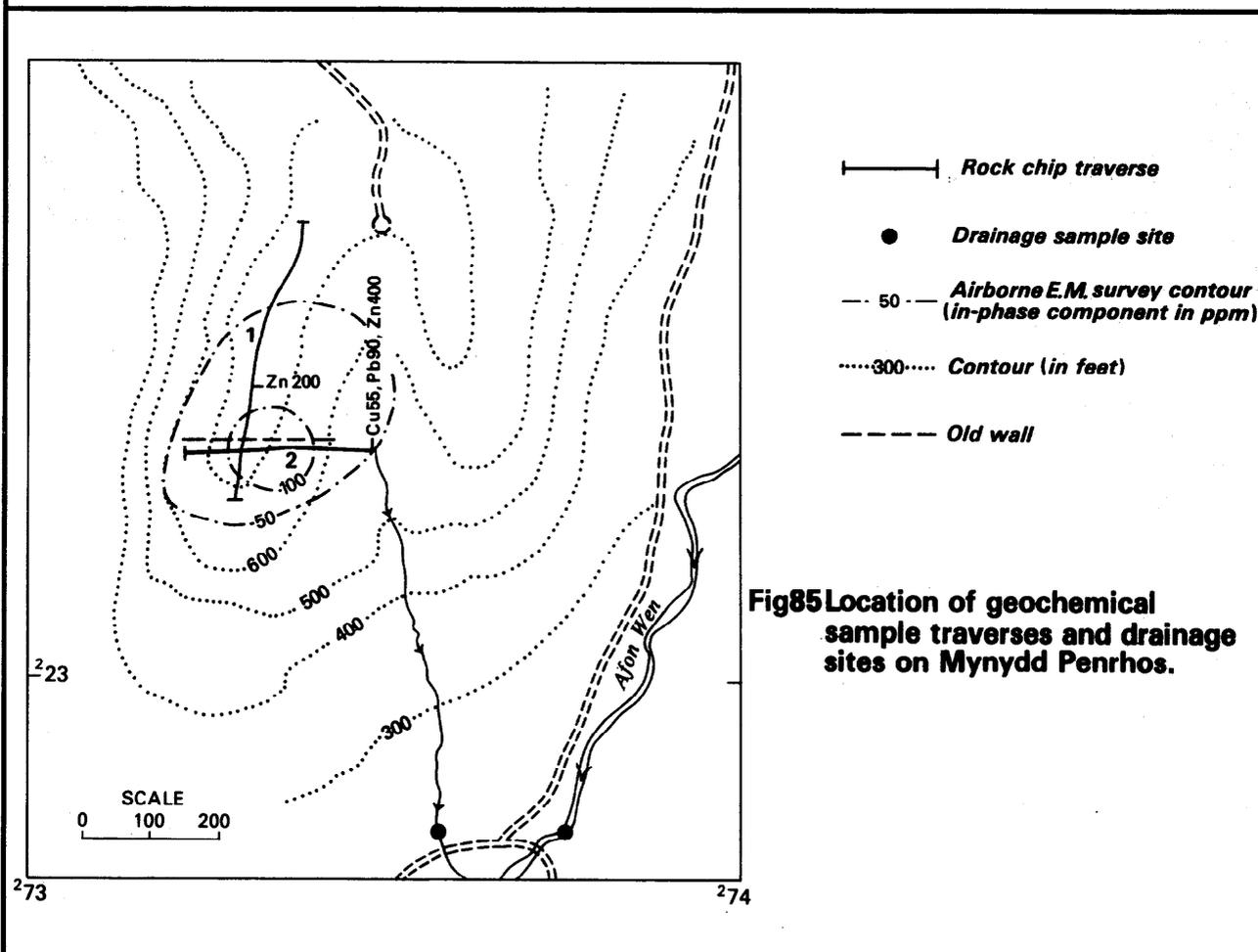
Table 20. Summary of analytical results in ppm of 21 rock samples from Mynydd Penrhos

	Arithmetic mean		Standard deviation		Maximum		Minimum	
	Sedimentary Rocks	Intrusives	Sedimentary Rocks	Intrusives	Sedimentary Rocks	Intrusives	Sedimentary Rocks	Intrusives
Cu	22	18	10.5	13.1	50	40	10	10
Pb	15	18	9.3	6.3	40	30	10	10
Zn	48	94	9.8	39	70	200	40	60
As	42	33	15.4	18.9	68	46	24	5

rounded to subangular fragments up to several centimetres long of silty mudstone, non-porphyritic microtonalite, quartz-feldspar-porphyry and coarse-grained sandstone in a poorly sorted clastic matrix of fragments of feldspar and quartz crystals with chlorite, sericite and epidote. Pyrite, which is locally abundant, is confined to the matrix.

The structure in the area is simple: the sedimentary rocks dip eastwards at up to 40° and in places minor north-east faults disrupt the strata. The Maentwrog mudstone always shows a cleavage.

Mineralisation

There are a number of thin quartz veins in the quartz-diorite intrusion, and one has been tried at SH 7385 2302. Nearby (SH 7389 2305) the adjacent microtonalite intrusion is rich in xenoliths of sedimentary rocks from the Ffestiniog Flags Formation and contains abundant pyrite and minor chalcopyrite with secondary malachite staining in the joints. The intrusion-breccia contains only pyrite.

Geophysics

Two east-west ground traverses using slingram and proton precession magnetometer were measured across part of the area of an airborne EM anomaly of 100 ppm coincident with a negative magnetic anomaly of 400 nT (Fig. 83). The traverses were incomplete because of the difficult terrain, but the work clearly shows that there is a close correlation between the airborne and ground data.

The EM anomalies (Fig. 84) can be related to the Maentwrog Formation, while the magnetic anomalies are related either to the basic and intermediate sills which form the crest of the ridge or to mudstone. Detailed comparisons between the two types of anomaly show that the ground anomalies are more restricted than is suggested by the airborne survey.

Geochemistry

A reconnaissance drainage survey site at SH 7359 2278 in the small stream draining the south-eastern side of Mynydd Penrhos (Fig. 85) shows anomalous amounts of Cu in both stream sediment (550 ppm) and panned concentrate

(107 ppm) samples, together with anomalous amounts of As (266 ppm) and Mo (9 ppm) in the sediment. Therefore, it was decided to take a small number of samples to look for evidence of copper mineralisation associated with the EM anomaly. The topography placed severe restraints on the sampling options in this area. A series of sixteen rock chip samples were taken at approximately 30 m intervals along the ridge and five rock chip and three soil samples were collected at the same interval along an east-west line whose position coincided with a firebreak. Soil samples were only collected where there was no available exposure. Of the rock samples ten are grey, cleaved, siltstone or mudstone and eleven are altered intermediate and basic intrusive rocks. The results of the rock determinations are summarised in Table 20.

Zinc and arsenic levels show some differences between the two rock groups, but statistical tests indicated that there is only a significant difference between the two populations in the case of zinc. Only one rock sample, a pyritic microdiorite from the ridge with 200 ppm Zn, shows element levels substantially above background (Fig. 86). This can be accounted for in terms of its high pyrite content. Elevated base metal values (55 ppm Cu, 90 ppm Pb and 400 ppm Zn) were also recorded in a dark brown gritty clay with a substantial organic content, which was collected in low ground near a small stream at the end of traverse 2. It is probable that in the first instance this is a secondary concentration related to waterlogged ground. Arsenic levels are all high compared with world averages, but high arsenic backgrounds appear to be a feature of this area and no sample is considered outstandingly anomalous.

Two samples of the intrusion breccia were also analysed to check for mineralisation not evident on the macroscopic scale, but both samples showed insignificant levels of Cu (10, 15 ppm), Pb (10, 20 ppm), Zn (30, 30 ppm), As (9, 3 ppm) and Mo (2, 4 ppm).

Conclusions

Both geophysical anomalies appear to be caused by rock types which do not appear to be associated with any mineralisation. This leaves the source of the anomalous drainage sample and the metal-enriched soil near the head of the stream unidentified. Whereas the latter is likely to be the result of a secondary concentration in a water-logged

DRIFT

Quaternary

~	**Peat**
u	**River terrace deposits, undivided**
ᴠ	**Boulder clay**

SOLID

Cambrian

Rhobell Volcanic Group

Rll	**Basalt of Rhobell Ganol Formation**
Byg	**Basalt of Blaen-y-glyn Formation**
Bᴮʳ	**Flow autobreccia in Rhobell Volcanic Group**

Mawddach Group

Dlu	**Black mudstone of Dolgellau Member**	} Cwmhesgen Fm.
Ff	**Interbedded siltstone and fine sandstone**	} Ffestiniog Flags Fm.

D **Dolerite**

SYMBOLS

⌐ ⌐	**Geological boundary, Solid**
⌐····	**Geological boundary, Drift**
⊥⌐	**Fault, crossmark indicates downthrow side, where known**
25⌐	**Inclined strata, dip in degrees**
60⌐	**Inclined cleavage, dip in degrees, where known**
✗	**Minor fold, axis horizontal**
⌐	**Inclination of igneous contact**
•	**Sediment and water sampling site**
✳	**Sediment, water and panned concentrate sampling site**
Znp	**Anomalous drainage results, in ppm s = sediment p = panned concentrate w = water**
ᴅ²	**Rock sampling site**
⊢—3—⊣	**Rock sampling traverse**

Fig 87 **Geological map of Nannau area showing the location of geochemical samples and anomalous results.**

depression the anomalies in the sediment and panned concentrate sample could indicate mineralisation in the catchment of this small stream, or result from contamination by drift derived from the known porphyry-style mineral occurrences to the north. The combination of anomalous elements in the stream sediment (Cu-Mo-As) supports the latter explanation.

NANNAU
Centre point: SH 775 271
6-inch sheet SH 72 NE

Geology

This is a rugged area of rough grazing on the western flanks of Rhobell Fawr. There is plenty of outcrop, except in the north where there is juvenile forest and boulder clay on slightly lower ground. Drainage is locally poor and many of the hollows on the mountain contain peat.

Volcanic rocks of the Rhobell Volcanic Group unconformably overlie black and dark grey silty mudstone of the Dolgellau Member of the Cwmhesgen Formation in the northern part of the area. The volcanic rocks comprise two formations (Kokelaar, 1977). The lower, the Blaen-y-glyn Formation, consists of basaltic lavas and tuffs. A characteristic of the basalt is the common presence of large amphibole phenocrysts. The tuffs are not common and include banded crystal tuff and lapilli tuff. These rocks are overlain by the Rhobell Ganol Formation which also consists essentially of porphyritic basalt with amphibole phenocrysts, but in many places it is intensely autobrecciated. In both formations the basalts are locally veined and impregnated by epidote which in places is associated with hematite. Pyrite and calcite occur in vesicles and pyrite forms numerous thin veins in basalt around SH 7716 2775 (Fig. 87).

Thin basaltic dykes intrude the lavas and in the northern outcrop there are some intrusions of altered ? microdiorite. There are many intrusions of dolerite in the Dolgellau Member presumably comagmatic with the extrusive rocks. The intrusions are irregularly shaped, sometimes stock-like and in places vein the adjacent country rock. Most consist of euhedral phenocrysts of plagioclase in a groundmass of plagioclase and chlorite, but alteration is locally intense. In some intrusions the feldspar is sericitised and in others the whole rock is intensely altered to carbonate. Leucoxenised opaque minerals are abundant, and there is usually a little pyrite. The large intrusions tend to consist of non-porphyritic, medium-grained feldspar-phyric dolerite.

The volcanic succession dips eastwards, though the locally variable dips within each formation may reflect minor folding. The Dolgellau Member, on the other hand, is locally intensely contorted, possibly because of deformation during the Rhobell Volcanic episode. The mudstone is usually cleaved.

Mineralisation

As mentioned above, pyrite veins and amygdales occur in the basalt. Pyrite is also present in veins and fractures adjacent to contacts between dolerite and mudstone of the Dolgellau Member, specifically at SH 7758 2771 and SH 7729 2800. At the latter locality there is also quartz veining along the contact. Other signs of mineralisation are limited to spots of secondary malachite observed in basalt at SH 7721 2701 and at other localities in the volcanic succession outside this area.

Geophysics

A series of disconnected airborne EM features appear to be the southern extension of the prominent north-south anomaly of up to 400 ppm associated with the Dolgellau Member of the Cwmhesgen Formation. 13 ground traverses were measured in the area (Fig. 88) to investigate these features.

In the north of the area the clear relationship between the Dolgellau Member and the EM anomaly was confirmed. However the anomalies appear to continue over the outcrop of the Rhobell Volcanic Group which suggests that the conductive horizon continues southwards beneath the volcanic rocks at a shallow (<60 m) depth to at least traverse G. This is supported by the evidence of the small inlier of Dolgellau Member at SH 7719 2761.

To the south of traverse G there is no significant EM anomaly until traverses C and B. In this area the airborne anomalies show negative out-of-phase components suggestive of artificial interference. A similar effect was noted on the ground, with an oscillating EM signal which also suggests some external influence. No source of interference, such as power lines or a radio transmitter, was noted and, therefore, these apparently artificial anomalies remain unexplained. They do not indicate a hidden continuation of the Dolgellau Member as in the north.

Geochemistry

Samples were collected over the southern EM anomaly and the southern part of the northern EM anomaly. Because of the very patchy soil and drift cover a combination of drainage and rock chip sampling was used.

a. Drainage sampling. Seventeen sites in the small streams crossing the southern anomaly were sampled. At four of them there was insufficient sediment to make a panned concentrate. The results are summarised in Table 21. Element distributions could not be determined satisfactorily because of the small sample population, so the results were compared with threshold levels determined for the reconnaissance drainage survey of the Harlech Dome. Results considered anomalous on this basis are plotted on Fig. 87.

Strongly anomalous values for copper (0.09 ppm) and zinc (0.32 ppm) in water were recorded from the area around SH 774 269. These results may reflect mineralisation in the area, but are

Contours of airborne EM in-phase component in ppm

Ground traverses showing areas of <100% in-phase component
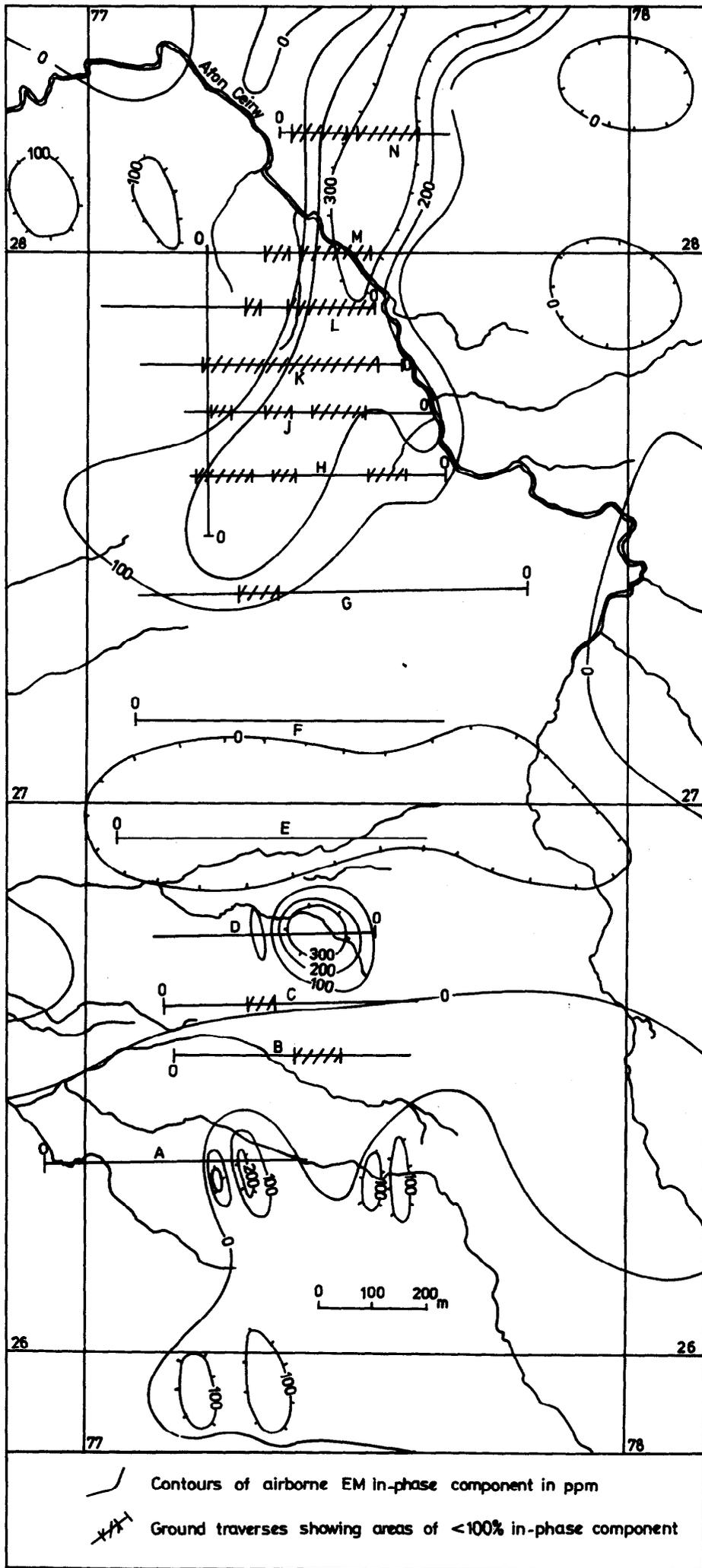
FIG. 88. GEOPHYSICAL DATA FOR NANNAU AREA

Table 21. Summary of analytical results in ppm for drainage samples from Nannau

	Median	Mean	Std. dev.	Maximum	Minimum
Stream sediments (n = 17)					
Cu	50	69.4	80.7	375	15
Pb	50	59.4	40.7	210	40
Zn	300	398	219	900	170
As	25	26.2	12.2	55	3
Ba	620	665	190.6	1038	386
Fe	51714	53342	5724	67082	46149
Mn	4617	5684	3845	16508	1756
Co	48	47.5	13.4	77	25
Ni	43	43.5	11.7	67	21
Mo	<1	-	-	2	< 1
Stream water (n = 17)					
Cu	<0.01	-	-	0.09	<0.01
Zn	0.03	0.051	0.073	0.32	0.01
Panned concentrates (n = 13)					
Cu	51	53.6	23.6	95	25
Pb	34	36.2	13.9	74	18
Zn	224	226	67.1	326	142
Ba	535	555	144	984	404
Fe	79140	82247	10626	99680	66660
Mn	1500	1465	301	1930	1080
Ni	30	30.7	4.83	38	23
Ti	6170	6167	716	7520	5050
Ce	420	570	407	1655	162
Sn	<9	-	-	13	<9

Table 22. Summary of analytical results in ppm for 51 rock chip samples from Nannau

	Median	Arithmetic mean	Standard deviation	Maximum	Minimum
Cu	80	86	40	190	< 3
Pb	20	21	13.4	100	10
Zn	80	82	31	250	30

probably enhanced by the greater solubility of these metals in acid conditions, for both results come from near the top of first order streams in a peaty environment. The only other strong anomalies come from the site sampled at SH 7640 2680 which is in a catchment reaching to the southern end of the northern EM anomaly. However, inspection of the stream indicated that the anomalies are at least enhanced by mineralised hardcore in the forest road which crosses the stream a little above the sample site.

A comparison of iron, manganese and nickel results in sediments and panned concentrates together with an examination of cobalt/nickel ratios suggests that, except for a few, relatively weak, zinc anomalies in sediment, secondary precipitates are not an important factor in this area. Copper in sediment and zinc and iron in panned concentrate show median levels similar to or higher than the threshold levels determined for the Harlech Dome. However, very few anomalous values of these or other elements determined were recorded, and, with the exception of iron, elements sought in both sediment and panned concentrate samples show little or no upgrading in the panned concentrate. This pattern strongly suggests that elements such as copper, lead, zinc and nickel are not present in the rocks as discrete sulphide phases but are scattered through silicate and oxide phases, and that most high values are attributable to the basaltic background.

b. Rock chip sampling. Thirty six samples were collected at approximately 20 m intervals

TRAVERSE 1

TRAVERSE 2

TRAVERSE 3

NORTHERN AREA

No.	COPPER	LEAD	ZINC
1	65	20	70
2	160	20	50
3	90	20	80
4	190	20	70
5	180	20	70
6	150	10	80
7	70	40	130
8	140	30	70
9	125	30	70
10	70	30	80
11	80	30	70
12	125	100	250
13	85	30	110
14	50	30	100
15	100	20	120

—— Cu   Pb ---- Zn

⌐__⌐ Sample points, 20m interval

Fig.89 Nannau; copper, lead and zinc in rock chip samples collected along the traverse lines shown in Fig. 87

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along three short traverses in the vicinity of the southern EM anomaly, and another fifteen samples from available exposures in the vicinity of the northern EM anomaly (Fig. 87). All samples are basaltic tuffs and lavas. The samples were analysed for copper, lead and zinc, and the data are summarised in Table 22.

The results for all three elements showed near normal distribution. No distinct breaks in element distributions were evident except for isolated relatively high values of 250 ppm zinc and 100 ppm lead. Threshold levels were therefore aribitrarily set at mean + two standard deviations which isolated as anomalous both these two values and two values of copper greater than 166 ppm from the northern EM anomaly. The traverse diagrams (Fig. 89) show the considerable variation in detail of copper and zinc results whilst lead results are uniform. The apparent lack of variation in lead values is thought to be largely the result of poor analytical precision at the low levels found in these rocks. No overall trends are discernible along the traverses, but all the anomalous results occur in the northern part of the area. Even the most anomalous results are unexceptional when compared with averages and ranges quoted for basaltic rocks (Prinz, 1968; Carmichael, Turner and Verhoogan, 1974). Therefore it is concluded that, in agreement with the drainage results, the bulk of the copper, lead and zinc are present in silicates and oxides rather than sulphides and any metal enrichment is weak and taking place in the north of the area.

Conclusions

In the north of the area the EM anomaly is probably caused by Dolgellau Member concealed at no great depth beneath the volcanic rocks. The southern EM anomalies, though possibly artificial, have not been adequately explained.

The drainage survey indicates high background levels of copper, zinc and iron compared with the Harlech Dome as a whole, but neither these levels nor the base metal content of the rock chips are exceptional for basaltic terrains.

The theory that the Rhobell Volcanic Group is mainly sub-aerial in origin (Kokelaar, 1977) does not enhance the prospect of finding syngenetic mineralisation in any but the basal rocks which might have been erupted in shallowing marine conditions. However, the intermediate intrusions and the eruptive rocks in this area are probably co-magmatic with the mineralised intrusions at Coed-y-Brenin (Allen and others, 1976) and genetically related to the copper mineralisation itself. For these reasons the drainage anomaly and the high metal values in rock chips from the northern area, which is peripheral to the main volcanic mass, are worthy of limited further investigation.

PONT Y SEL
Centre point: SH 795 205
6-inch sheet SH 72 SE

Geology

This is an area of relatively low-lying pasture land, in which, because of the extensive and thick cover of boulder clay, solid exposure is uncommon away from streams (Fig. 90). The succession consists of upper Cambrian and lower Ordovician rocks striking roughly north-east and either vertical or dipping steeply to the south-east. The Bala Fault trending roughly north-east passes near the south-eastern corner of the area and all the many faults hereabouts are parallel to it.

At the bottom of the succession the dark grey silty shales of the Dol-cyn-afon Member are tightly folded. In places the upper part of this formation and much of the black and white banded siltstone and sandstone in the lower part of the Allt Lwyd Formation is removed by faulting. The volcanic sandstones of this formation pass upwards into black mudstone containing a 70 m-thick band of acid tuff. Above the mudstone are the tuff and interbedded basic lavas of the Benglog Volcanic Formation.

Geophysics

The geophysical target is a complex area of airborne EM anomalies, some of which, with negative in-phase components, are probably of artificial origin. The accompanying aero-magnetic survey shows a north-east-trending anomaly with peak values of 200 nT (Fig. 91).

Three north-west traverses were measured across the EM and magnetic features. These ground results confirm that the EM anomaly is probably caused by a large power line running NE, smaller lines beside the road and a water pipe. The ground magnetic survey was also much affected by the power lines and water pipe but traverse C confirms the airborne survey and shows a small anomaly at depth, with a similar trend and form to the large anomaly to the north-west, which was not investigated on the ground, and which is caused by a dolerite intrusion. It is tentatively suggested that the investigation indicates the presence of a small dolerite intrusion at depth.

Conclusions

The airborne EM and magnetic anomalies are satisfactorily explained and give no indication of mineralisation.

RHYDAU
Centre point: SH 7970 3980
6-inch sheets SH 73 NE, 74 SE

Geology

This is an area of peat bog through which craggy outcrops rise. The stratigraphic succession (Fig. 92) consists of volcanic and

DRIFT

Quaternary

| ~ | Alluvium, undivided |
| ⩊ | Boulder Clay |

S

Ordovician

Z	Acid tuff	
ZB	Tuff and lava, undivided	Benglog Volcanic Formation
B	Basalt	
AVG	Sedimentary rocks, undivided	Aran Volcanic Group
Z^R	Acid tuff	
S^V	Volcanic sandstone	Allt Lwyd Formation
All	Siltstone, sandstone	

Cambrian

| Dyn | Grey mudstone of Dol-cyn-afon Member | Mawddach Group |

INTRUSIVE IGNEOUS

| D | Dolerite |

SYMBOLS

⸗	Geological boundary, Solid
⸗	Geological boundary, Drift
⊢	Fault, crossmark indicates downthrow side
$\swarrow_{50}$	Inclined strata, dip in degrees
✗	Vertical strata
✴	Vertical cleavage

Fig 90 Geological map of Pont-y-sel area.

— — Airborne E.M. in-phase component in ppm

—— Airborne magnetic field strength in nT referred to standard datum

—⅃ E.M. and Magnetic traverse lines; bar 0 indicates the beginning
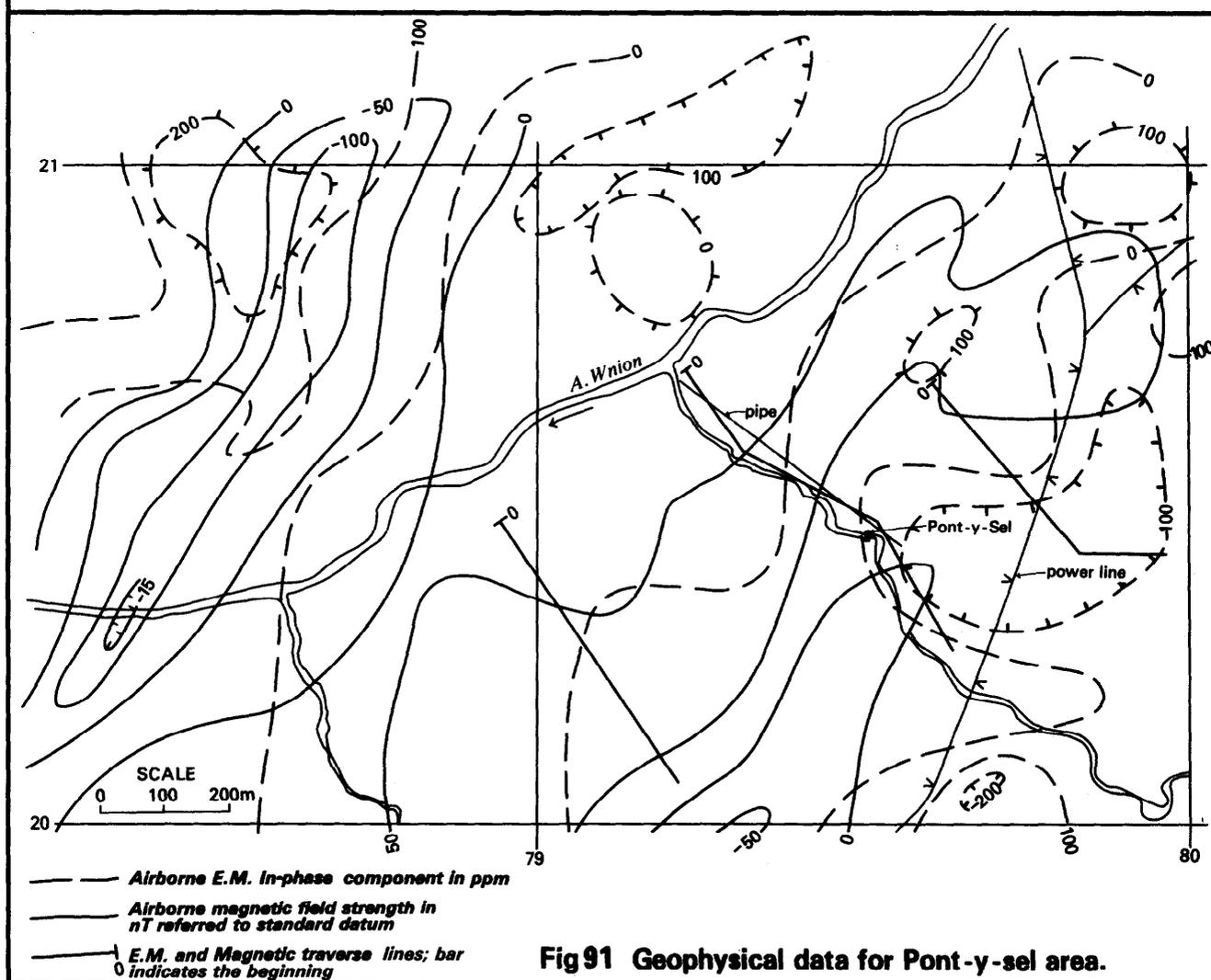
Fig 91 Geophysical data for Pont-y-sel area.

143
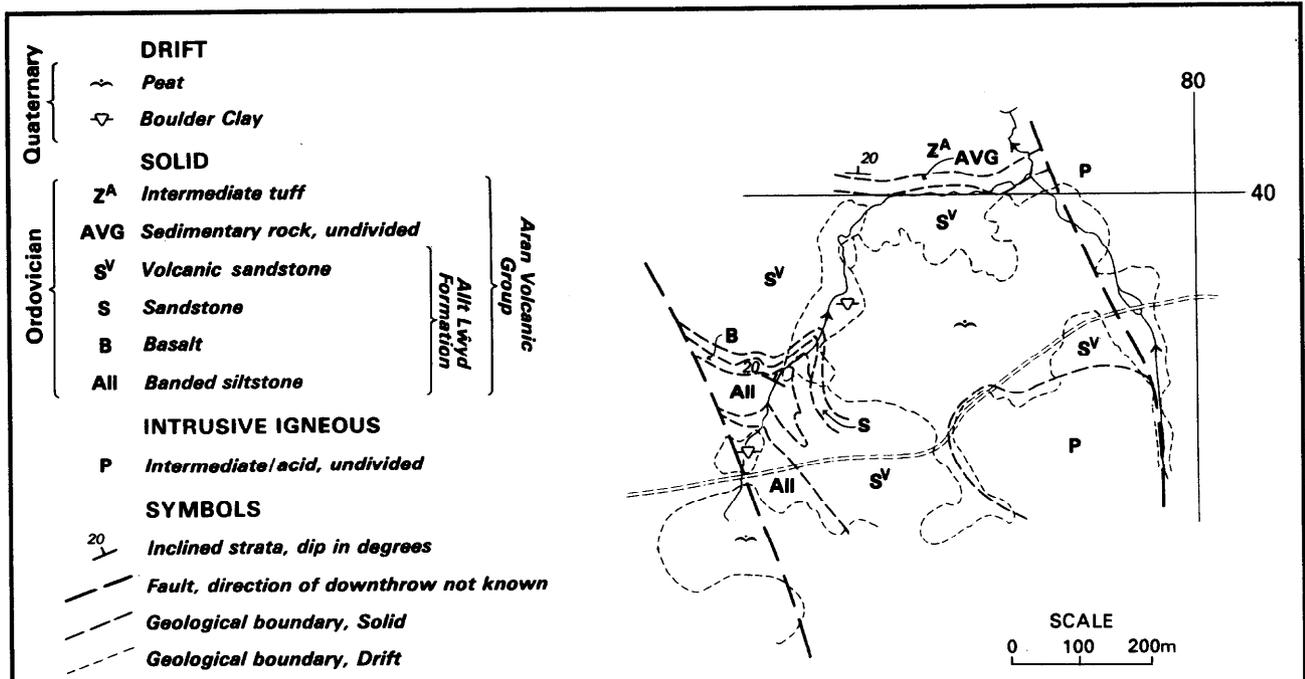
Fig 92 Geological data for Rhydau area.

DRIFT

Quaternary

~ Peat

▽ Boulder Clay

SOLID

Ordovician

Z^A Intermediate tuff

AVG Sedimentary rock, undivided

S^V Volcanic sandstone

S Sandstone

B Basalt

All Banded siltstone

Aran Volcanic Group

Allt Lwyd Formation

INTRUSIVE IGNEOUS

P Intermediate/acid, undivided

SYMBOLS

20 Inclined strata, dip in degrees

Fault, direction of downthrow not known

Geological boundary, Solid

Geological boundary, Drift

SCALE
0   100   200m

Fig 93 Geophysical data for Rhydau area.

Contours of in phase component of airborne E.M. in ppm

Ground E.M. traverse line, bar indicates the beginning

Proposed conductor

LIMIT OF AIRBORNE SURVEY

SCALE
0   100   200m

Fig 95 Geochemical data for the Rhydau area.

● Drainage sample site

Cu 160 Soil traverse, showing highest results in ppm

Zn90

Cu40 Pb80

Cu160

Cu160 Zn80

Pb100

Nant Rhydau-gloewon

Afon Taihirion

B4391

SCALE
0   100   200m

144

In-phase % Out-of-phase

line of Traverse D

1760 Hz

TRAVERSE B

in-phase

out-of-phase

200mN

0mN

SLINGRAM (1600 Hz)

Components of secondary EM field

ppm

0mN 20mW of Traverse B

ppm

300mS
20m E of Traverse B
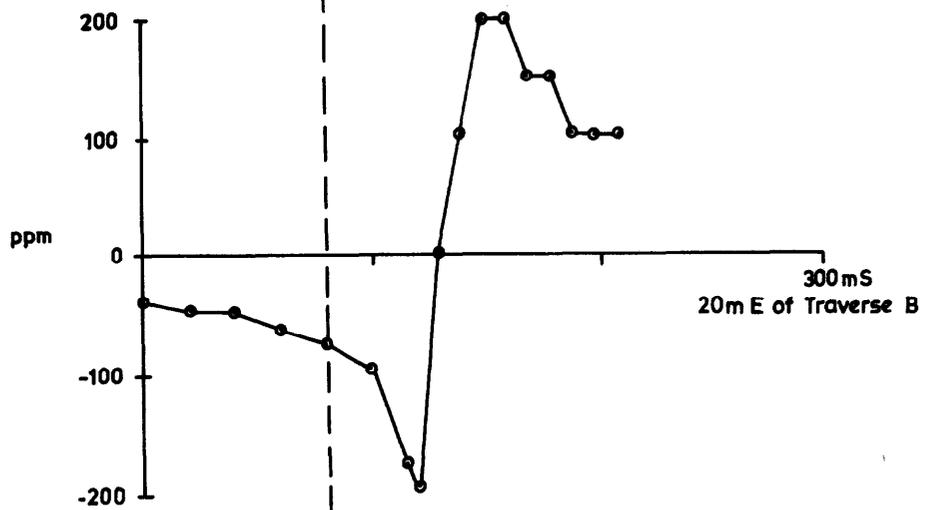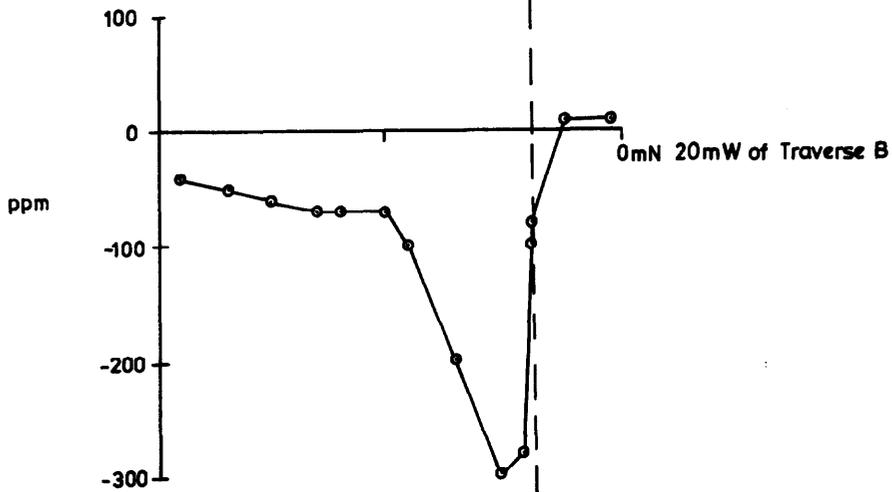
FIG.94.   EM TRAVERSES AT RHYDAU; TRAVERSE B USING SLINGRAM, THE LOWER TWO
USING A 'METAL DETECTOR'

TRAVERSE 1

TRAVERSE 2

TRAVERSE 3

Copper
Lead
Zinc
Sample points
R   Rock chip sample
P   Peat sample
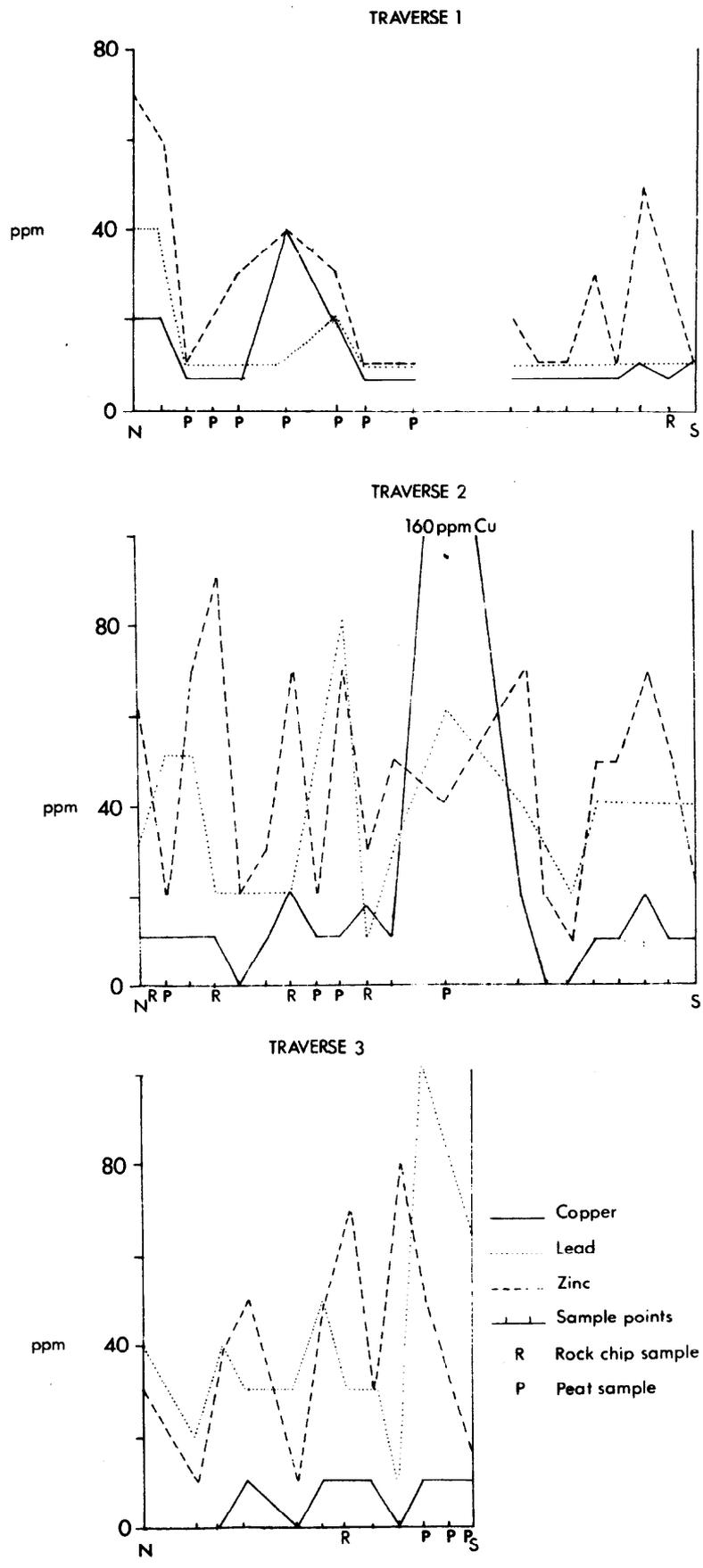
Fig.96 Rhydau; copper, lead and zinc in samples collected along the traverse lines shown in Fig.95

volcaniclastic rocks of early Ordovician age dipping at low angles to the north-north-east and confined between two strong north-north-west faults. The Allt Lwyd Formation consists of a lower division of black siltstone with laminae, beds and thick units of volcanic sandstone, overlain by a succession dominantly composed of volcanic sandstone. These are commonly bioturbated; they are interbedded with rare quartzose sandstone and more abundant black silty mudstone horizons and they contain one thin flow of amygdaloidal basalt. The Allt Lwyd Formation is overlain by a thin unit of black graptolitic mudstones which underlie crystal tuff.

A complex of porphyritic andesitic rocks in the south-east of the area is presumed to be an intrusion similar to the quartz-latite porphyries found elsewhere in this district. Similar rocks and dacites occur on the east of the main eastern fault.

Geophysics

Geonics EM17 slingram equipment was used to investigate a semicircular area of airborne EM anomaly with a peak value of over 300 ppm. Since the anomaly is on the edge of the area surveyed, its trend and shape is not evident from the airborne data (Fig. 93).

The results from the ground work are not conclusive. There are anomalies of uncertain interrelationships on three traverses. A strong anomaly on traverse B, incompletely defined to the south (Fig. 94) was confirmed by two short traverses 20 m away using the EM15 'metal detector', both of which demonstrated a thin, strong conductor dipping shallowly to the south. An anomaly on traverse D, which crosses the conductor along its strike for about 200 m, has the same origin. The conductive body is concealed by peat which overlies volcanic sandstone of the Allt Lwyd Formation. The airborne anomaly is possibly proved on the north end of traverse A where there is a strong but incomplete ground anomaly. No conclusions can be drawn as to its trend, shape or, because of poor exposure, its cause.

Geochemistry

The sediment sample collected above the road at SH 8039 3980 (Fig. 95) shows a relatively high lead content (150 ppm) compared with other samples taken in the general area, but the lack of any lead enrichment in the panned concentrate taken at the same site suggests that it is present in a light phase such as a secondary precipitate, organic matter, or feldspar, rather than a heavy lead mineral phase such as galena. All other metal values determined in the samples taken here and at the site upstream (SH 7982 4024) were well within the background levels determined for the Harlech Dome.

Because of the patchy soil, peat and boulder clay development in the area it was necessary to collect a variety of samples, consisting of rock chips, boulder clay beneath thin peat and peat where it was thicker than 120 cm, on three

traverses at 20 m intervals to look for any general indications of metal enrichment. The results for copper, lead and zinc on these samples are shown in Fig. 96; the two highest values recorded for each element (top 4% of the results) are also plotted on Fig. 95. A rigorous interpretation of the results was not possible because of the small number of samples and variety of sample types collected. The highest lead and copper results occur in peat samples, in concentrations which are not unusual in this environment (values of copper, lead and zinc greater than 1000 ppm are recorded in peat over mineralised seepages in North Wales). Lead and copper values in the rocks and boulder clay are generally low, with the most likely cause of the higher values being patchy enrichment in the secondary environment unrelated to any significant mineralisation. The two highest zinc values, in a volcanic rock and boulder clay samples are not dissimilar to the average zinc content of many common igneous rocks and slates (Turekian and Wedepohl, 1961; Vinogradov, 1962).

Conclusions

The EM anomalies proved on the ground have not been adequately explained. Geochemical investigations over the southern of the two anomalies give no indication of any significant mineralisation and it is considered that the expense of carrying out any further investigations in the area is not justifiable.

SARN HELEN
Centre point: SH 725 300
6-inch sheets SH 73 SW

Geology

This is a craggy area to the north of Craig-y-Penmaen. Drift is limited to small areas of peat or boulder clay in depressions between outcrops of the Rhinog, Hafotty, Barmouth and Gamlan formations. The Rhinog and Barmouth formations consist of coarse-grained turbiditic sandstone, in places pebbly, with thin intercalations of mudstone and siltstone. Between these formations, the Hafotty Formation consists of mudstone with horizons greenish siltstone and greywacke. In the siltstone there are 1-2 cm thick bands of pyrite and possibly pyrrhotite and in places lenses of pyrite about 1 cm long. The thin Manganese Ore Bed is present in the lower parts of this formation on the western side of the Harlech Dome, but has not been identified in this area. A few thin sills of feldspar-porphyry and other intermediate rocks intrude the sedimentary rocks (Fig. 97).

The bedding dips eastwards at low to moderate angles and the mudstone horizons show a steeply eastward-dipping cleavage. The main faults, including the Trawsfynydd Fault on the east of the area, trend north-north-west with subsidiary faults trending north-east.

DRIFT

Quaternary
~~ **Peat**

▽ **Boulder clay**

SOLID

Cambrian

Gn **Grey and purplish siltstone** } *Gamlan Formation*

BaG **Coarse-grained sandstone** } *Barmouth Formation*

Hf **Mudstone and sandstone, undivided** } *Hafotty Formation*

RhG **Coarse-grained sandstone** } *Rhinog Formation*

Harlech Grits Group

INTRUSIVE IGNEOUS

P **Intermediate and basic, undivided**

SYMBOLS

---- **Geological boundary, Solid**

------ **Geological boundary, Drift**

⊥— **Fault, crossmark indicates downthrow side**

↘14 **Inclined strata, dip in degrees where known**

:::::: **Track**
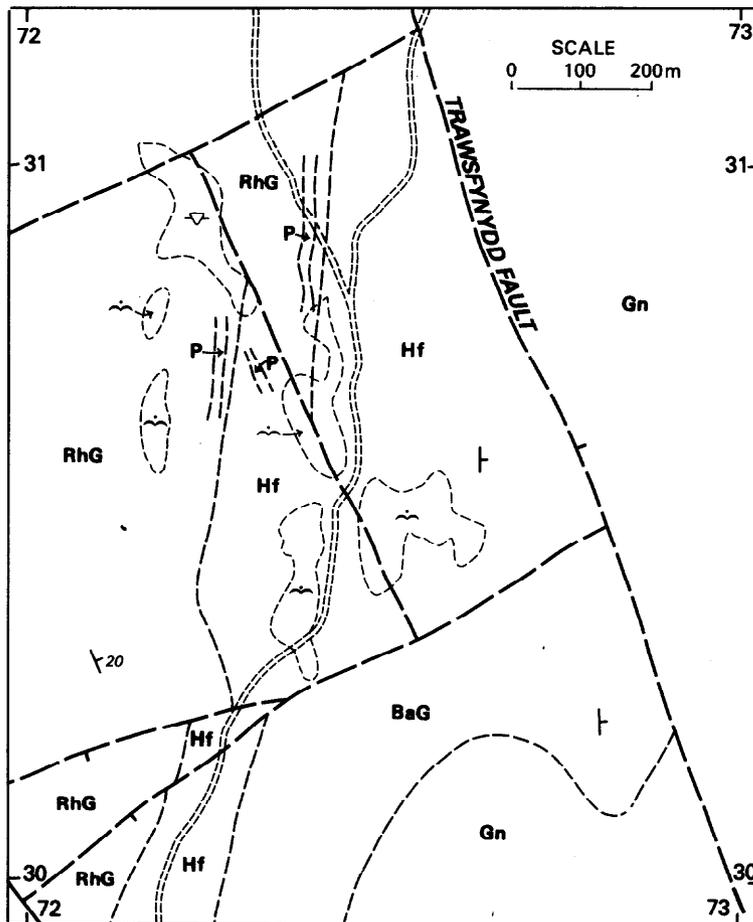
Fig97 Geological map of the Sarn Helen area.

FIG.98 GEOPHYSICAL DATA FOR SARN HELEN AREA

Contours of airborne EM
in ppm in-phase

Traverses of EM showing areas
of <100% in-phase

Track

FIG.99 GEOCHEMICAL TRAVERSE LINES IN SARN HELEN AREA

Track
Rock Sample
Soil Traverse

Table 23. Summary of rock chip and soil results from Sarn Helen. All except Fe are in ppm

	Median	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Rock chips (12)								
Cu	12.5	18.3	18.2	12.8	30.3	71	70	5
Pb	10	12.9	6.2	12.0	17.2	24.8	30	10
Zn	60	57.5	22.5	52.9	82.4	128	90	25
Fe%	4.34	3.96	1.77	3.51	6.05	10.41	6.02	1.40
Soils (27)								
Cu	20	25	10.2	23	37	60	45	5
Pb	30	30	7.6	29	38	49	50	20
Zn	60	64	20.4	61	88	127	100	20

Mineralisation

Barren quartz veins, no more than a few centimetres thick and many trending east-west, are common in the sandstones. One vein to the south of this area, at SH 7221 2976, lies along a north-west fault and contains abundant pyrite with some chalcopyrite. In addition to quartz the main gangue minerals are calcite and chlorite.

Geophysics

A north-south zone of small airborne EM anomalies was checked on the ground by 10 short slingram traverses. Anomalies were found on all except one, thus confirming the airborne survey. The anomaly pattern was not simple and was only strong in the northern part of the area (Fig. 98).

The northern anomaly lies over the Hafotty Formation. It is parallel to the geological strike, though it is not possible to estimate the dip from the data. The southern anomaly overlaps the Rhinog and Hafotty formations. There is no obvious origin for either of these conductors. Because the area is part of an artillery range, the ground was checked for pipes and cables using a metal detector, without finding any conductors.

Although there is no significant aeromagnetic anomaly peak in this area, a magnetometer was also used on the traverses and an inconsistent anomaly of up to 100 nT was found with the same trend as the EM anomaly.

Geochemistry

No reconnaissance drainage survey sites are located close to the anomaly, but the southern part of the area is drained by a stream which was sampled at SH 7148 2975. It shows a weak copper anomaly in sediment (85 ppm) which might be related to the copper vein mineralisation recorded in the upper part of the catchment. At a second site (SH 7132 3118) a sample from a stream which rises in the north-west of the area shows anomalous amounts of tin in the panned concentrate which is probably caused by contamination.

Twenty seven soil samples were collected at 20 m intervals on two short traverses across the EM anomaly. Samples consist largely of boulder clay beneath peat, some are of head and one of peat. Twelve rock chip samples (11 sedimentary rocks and one intrusive) were taken from available exposures subparallel and close to traverse 2 (Fig. 99). Several of the samples contain minor pyrite or pyrrhotite and one, a siltstone from SH 7245 3086, contains appreciable pyrite as fine grains and large cubes scattered along the bedding. All samples were analysed for copper, lead and zinc and, in addition, iron was determined on rock chips; the results are summarised in Table 23.

Copper and lead distributions in soil are near lognormal, while zinc tends towards normal. There are no inflexion points or distinct groups of high values discernible in the distributions. Traverse plots showed no distinct peaks. All the soil results appear to belong to the background population and no values which might be related to mineralisation were considered to be present. Distributions in rocks could not be ascertained because of the small number of samples and variable lithologies involved. The highest copper and iron contents occur in the sample of intermediate intrusive rock, but are not exceptional compared with values for this lithology found elsewhere in the Harlech Dome. Other copper values (< 25 ppm) and all zinc are within the background ranges for the rocks concerned. The pyritiferous sample contains no higher iron (4.7%) than other samples of similar type. high lead maximum can be attributed to the limitations in analytical precision at the levels found.

Conclusions

The airborne EM anomaly was confirmed on the ground and found to be associated with a weak magnetic anomaly. If the two have a common cause they might be attributable to pyrite and pyrrhotite in the siltstones. Soil and rock chip sampling over the anomalies gave no indication of metal enrichment in the area.
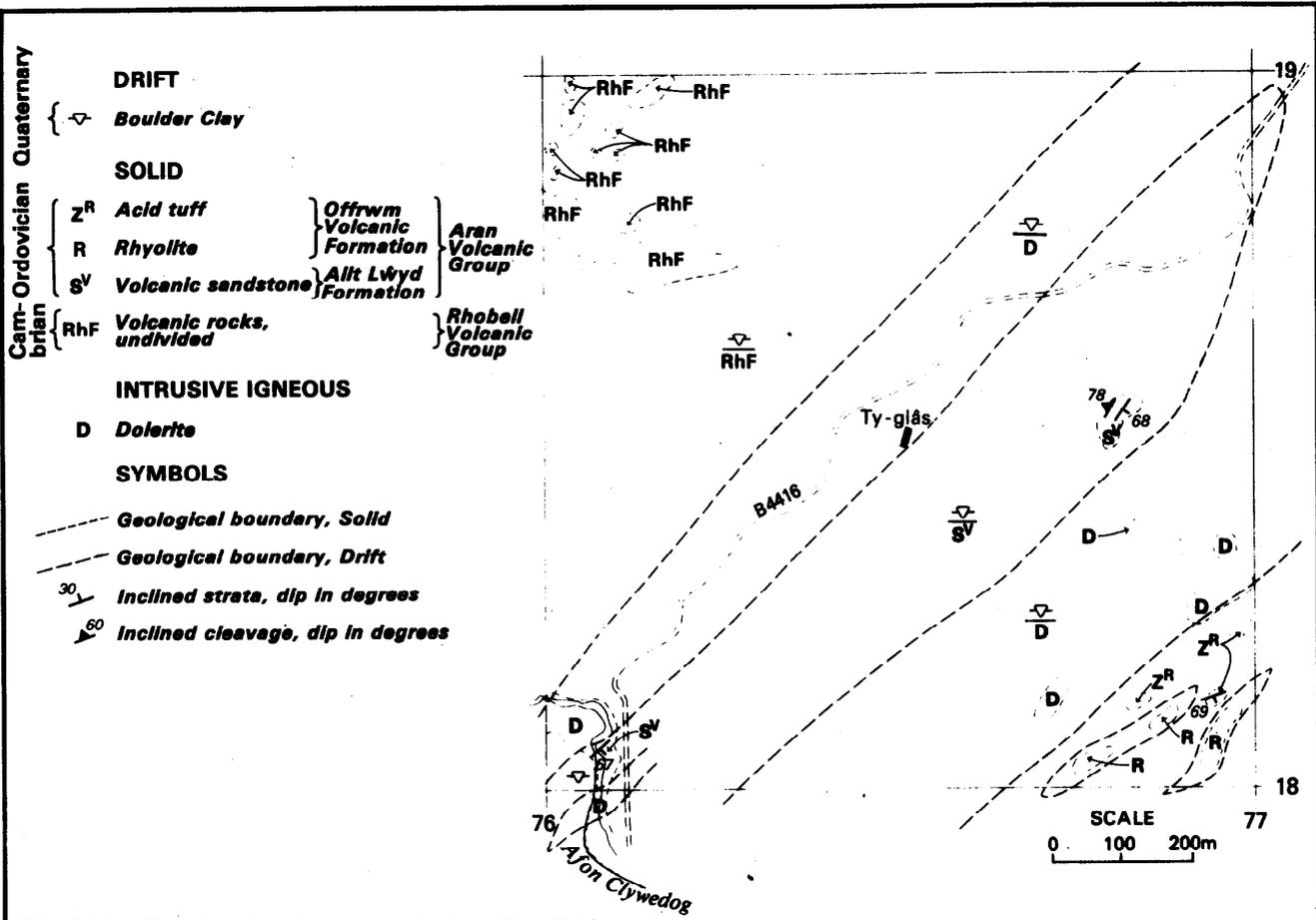
Fig 100 Geological map of the Ty Glâs area.

DRIFT
- ▽ Boulder Clay

SOLID

Z^R Acid tuff   } Offrwm
R Rhyolite   } Volcanic   } Aran
                        Formation   } Volcanic
S^V Volcanic sandstone } Allt Lwyd } Group
                        } Formation

RhF Volcanic rocks,   } Rhobell
      undivided   } Volcanic
                        } Group

INTRUSIVE IGNEOUS

D Dolerite

SYMBOLS

- - - - Geological boundary, Solid

- - - Geological boundary, Drift

30 Inclined strata, dip in degrees

60 Inclined cleavage, dip in degrees

Contours of aeromagnetic survey, contour intervals in nT above standard datum

Ground magnetometer traverse lines; bar indicates the beginning

Fig 101 Geophysical data for Ty Glâs area.

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TY GLAS
Centre point: SH 765 185
6-inch sheet SH 71 NE

Geology

Most of this area is covered by boulder clay and supports pastureland and woods. The stratigraphy, constructed from a few, isolated outcrops, consists of Rhobell Volcanic and Aran Volcanic groups in a relatively steeply, south-eastward dipping succession. The Rhobell Volcanic Group in this area consists of porphyritic basalt with some lithic tuff bands. The section through the Allt Lwyd Formation exposed in the Afon Clywedog consists of interbedded tuff and coarse, lithic sandstone near the top of the formation with the main part of the succession consisting of coarse-grained, sometimes pebbly volcanic sandstone and, near the base, interbedded grey siltstone. The Offrwm Volcanic Formation consists of rhyolite and acid ash-flow tuff (Fig. 100).

Two large dolerite sills merge into one large intrusion towards the north-east. The rock is relatively fresh, medium-grained and in places titaniferous.

Geophysics

Five east-west proton magnetometer traverses were measured across anomalies of 100 nT on the airborne magnetic map (Fig. 101).

The results confirm, in amplitude and rough position, the airborne anomaly. A field susceptibility meter was used to identify the magnetic rocks in the area and proved a maximum value of 25.5×10^{-3} SI units on a dolerite sill dipping to the south-east at SH 7598 1819. At SH 7609 1880 a ? tuff of the Rhobell Volcanic Group gave a value of 0.2×10^{-3} SI units.

Conclusions

Both the dolerite and the ? tuff of the Rhobell Volcanic Group are judged to be likely sources for the magnetic anomaly. Neither appear to be associated with any mineralisation.

TYDDYN GWLADYS
Centre point: SH 736 265
6-inch sheet SH 72 NW

Introduction

This area, which straddles the steep-sided Mawddach Valley, is entirely within pine forest. Because of its close proximity to the Coed-y-Brenin porphyry copper deposit the initial investigation of airborne EM anomalies here was expanded into a geochemical and geological examination of a larger area.

Geology

Head, scree and in places boulder clay conceal the solid geology of much of this area. Head, in particular, is widespread on the eastern valley side and is present as thin, unmappable smears over some areas which were for the most part mapped as solid.

The Gamlan, Clogau and Maentwrog formations are all represented. The Gamlan Formation is well exposed in the bed of the Mawddach where it consists of grey and greenish siltstone and mudstone, usually banded and containing thin beds and laminae of coarse-grained sandstone many of which are rich in sulphide minerals. The overlying Clogau Formation consists of hard, black mudstone and silty mudstone with some laminae of fine-grained sandstone. This formation is overlain by the Maentwrog Formation which contains hard siliceous siltstone and thick beds of quartzose sandstone in the lower part. Upwards there is a gradual increase in the proportion of siltstone which, in turn, is replaced by mudstone (Fig. 102).

Dolerite sills, ranging from less than a few metres to over 50 metres thick, are present in all parts of the succession.

A large, faulted intrusion of microtonalite in the eastern side of the area is possibly continuous under drift with the mineralised Coed-y-Brenin complex. The rock is medium-grained and non-porphyritic consisting of sericitised plagioclase, abundant strained interstitial quartz and, locally, chlorite pseudomorphs after secondary biotite. The pseudomorphs occur in large platy clusters, stringers and isolated small crystals associated with calcite, a little sericite, sulphide minerals and in places very small, enclosed plagioclase crystals.

The Trawsfynydd Fault, trending north-north-west, passes through the north-eastern part of this area. The main faulting, however, is east-north-east with downthrows mainly to the south and is nearly normal to the principal fold direction. The folds (an anticline with an axis nearly along the river bed, and an adjacent syncline to the west) plunge gently to the south and cannot be traced far outside the area.

Mineralisation

Both vein and disseminated mineralisation is present in this area. Veins have been worked at Tyddyn Gwladys and Cwm Heisian Issa mines and there are several trial workings, some of which are shown on the map (Fig. 102). The veins trend a little north of west and at Tyddyn Gwladys are associated with a fault. Worked initially for argentiferous galena, and later for gold, they contain mainly pyrite, sphalerite, galena and chalcopyrite in quartz gangue.

The south-east of the area includes part of the north Dolfrwynog Sett, which is one of the three flanking the Coed-y-Brenin copper deposit. In these Setts chalcopyrite was won from a number of small lodes which may be associated with either the disseminated mineralisation or the later Gold-belt vein mineralisation.

DRIFT

Quaternary
~ Peat
~ Alluvium, undivided
℮ Scree and head
⌄ Boulder clay

SOLID

Cambrian
Mw   Grey silty mudstone
MwS Interbedded sandstone and grey mudstone } Maentwrog Formation } Mawddach Group
Clu Black silty mudstone with rare sandy laminae } Clogau Formation
Gn   Grey and green silty mudstone, siltstone banded and with thin coarse grained quartzose sandy beds and laminae } Gamlan Formation } Harlech Grits Group

INTRUSIVE IGNEOUS

pMt Microtonalite
D   Dolerite

SYMBOLS

— — — Geological boundary, Solid
- - - - Geological boundary, Drift
—⊥— Fault, crossmark indicates downthrow side
—◇— Axial-plane trace, anticline
—✕— Axial-plane trace, syncline
—·—·— Quartz vein
⤢17 Inclined strata, dip in degrees
♤ Adit, abandoned
⊕ Shaft, abandoned

Fig102 Geological map of Tyddyn Gwladys area.
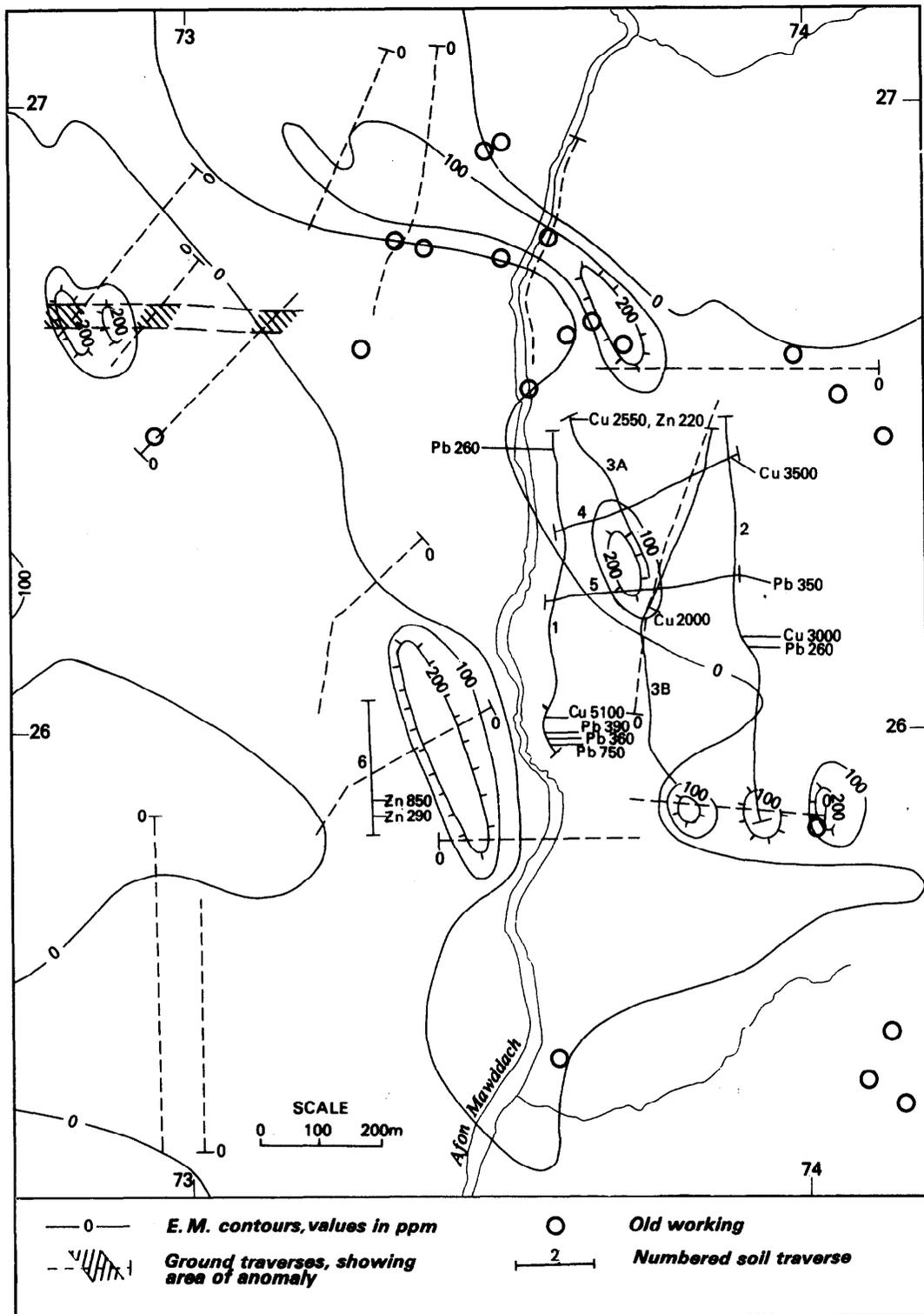
Fig 103 Airborne geophysical data, geophysical and geochemical
traverse lines and selected analytical values for Tyddyn
Gwladys area.

Table 24. Summary of analytical results in ppm for 147 soil samples from Tyddyn Gwladys

	Median	Arithmetic mean	Standard deviation	Geometric mean	Geometric mean+ geo. dev.	Geometric mean+ 2 x geo. dev.	Max.	Min.
Cu	440	658	635	463	1000	2230	5100	60
Pb	60	82	63	68	111	180	750	20
Zn	100	100	39	89	149	250	850	10

Signs of disseminated mineralisation in the microtonalite are common. Among them are veinlets and disseminated sulphides, chiefly pyrite and chalcopyrite. Malachite staining in joints is visible in outcrop, and thrift (Armeria maritima), a known copper indicator in this area (Rice and Sharp, 1976) has been observed growing on head overlying microtonalite.

Sulphide minerals are ubiquitous in the sedimentary rocks in this area. Lenses and disseminations of pyrite and pyrrhotite are present parallel to the bedding in the Gamlan and Clogau formations and are presumed to be syngenetic in origin. Much of the sulphide in this area, however, is apparently associated with the pyrite halo around the disseminated copper deposit at Coed-y-Brenin (Rice and Sharp, 1976). For example, in a number of places pyrite and, less commonly, chalcopyrite are present as disseminations and veinlets with quartz and chlorite in siltstone of the Gamlan Formation. In the road-cutting at SH 7371 2709 pyrite and chalcopyrite are plentiful adjacent to a set of steeply westward dipping fault planes containing black, manganese hydrous oxides. Abundant, disseminated pyrite is found in the lower part of the Maentwrog Formation adjacent to the microtonalite intrusion in the area around SH 7375 2606 and less abundantly elsewhere. In the area east of the Trawsfynydd Fault both veinlets and disseminations of pyrite and chalcopyrite are common in mudstone.

Geophysics

Several strong, localised airborne EM anomalies with negative out-of-phase components were investigated on the ground using slingram equipment. Fourteen traverses, the positions of some of which were controlled by difficult terrain conditions, totalling 5.5 km were measured over the various anomalies (Fig. 103).

Only in the area around SH 730 266 was an airborne anomaly confirmed. It appears typical of a narrow, near-surface conductor such as a pipe and being coincident with a road it is reasonable to assume that this feature is of man-made origin. Elsewhere the results are sensibly uniform and the airborne anomalies are considered to be due to non-geological effects, such as EM noise or flexing of the EM "bird" over this area of steep terrain.

Geochemistry

Samples collected in the Afon Mawddach during the reconnaissance drainage survey gave anomalous results for a wide range of elements, but the presence of several old mines in the catchment effectively mask any other source of metal enrichment.

Soil samples were collected from head deposits along five traverses at 20 m intervals on the eastern side of the Mawddach (Fig. 103). A sixth traverse was sampled at the same interval on the western side of the river so that metal values on either side of the valley could be compared. A summary of the results for copper, lead and zinc is given in Table 24.

All three element distributions are approximately lognormal in form but complex in detail. Copper shows a lack of values around 600 ppm and an excess around 800 ppm compared with a perfect distribution. 93% of the samples contain greater than 100 ppm copper and this value was arbitrarily chosen as a nominal threshold level from experience in other geologically similar areas showing less widespread indications of mineralisation. Zinc has an excess of values below 50 ppm compared with a lognormal distribution; the 97.5% level (theoretically, the geometric mean + 2 geometric deviations) was arbitrarily chosen as the threshold. Lead shows a lognormal 'background' population with an inflexion point on the cumulative plot at 100 ppm indicating an excess of values above that level. The threshold level was therefore taken at the inflexion point (91% level). The top $2\frac{1}{2}$% of the results, equal to Cu > 2000 ppm, Pb > 180 ppm and Zn > 200 ppm are plotted on Fig. 103.

The area east of the Mawddach shows exceptional copper enrichment, which was also demonstrated by Rice and Sharp (1976) whose soil sampling grid for the Coed-y-Brenin disseminated copper deposit partly covered this area. The copper values in this work, however, appear to be higher than those obtained by Rice and Sharp, probably explicable by our sampling at greater depths coupled with some seasonal and analytical variation. Rice and Sharp (op. cit.) showed that copper is highly mobile in the groundwater of this area and that as a result large anomalies do not necessarily reflect underlying mineralisation. It is probably significant that on traverses 4 and 5, despite considerable detailed variation (Fig. 104) an overall trend of increasing copper content in head is discernible uphill, towards the east and the known disseminated mineralisation. The low

Fig.104A, Tyddyn Gwladys; copper, lead and zinc in soil samples collected along traverse lines 1 and 2 shown in Fig.103

TRAVERSE 3A

TRAVERSE 3B

—— Cu ⋯⋯ Pb — — —Zn
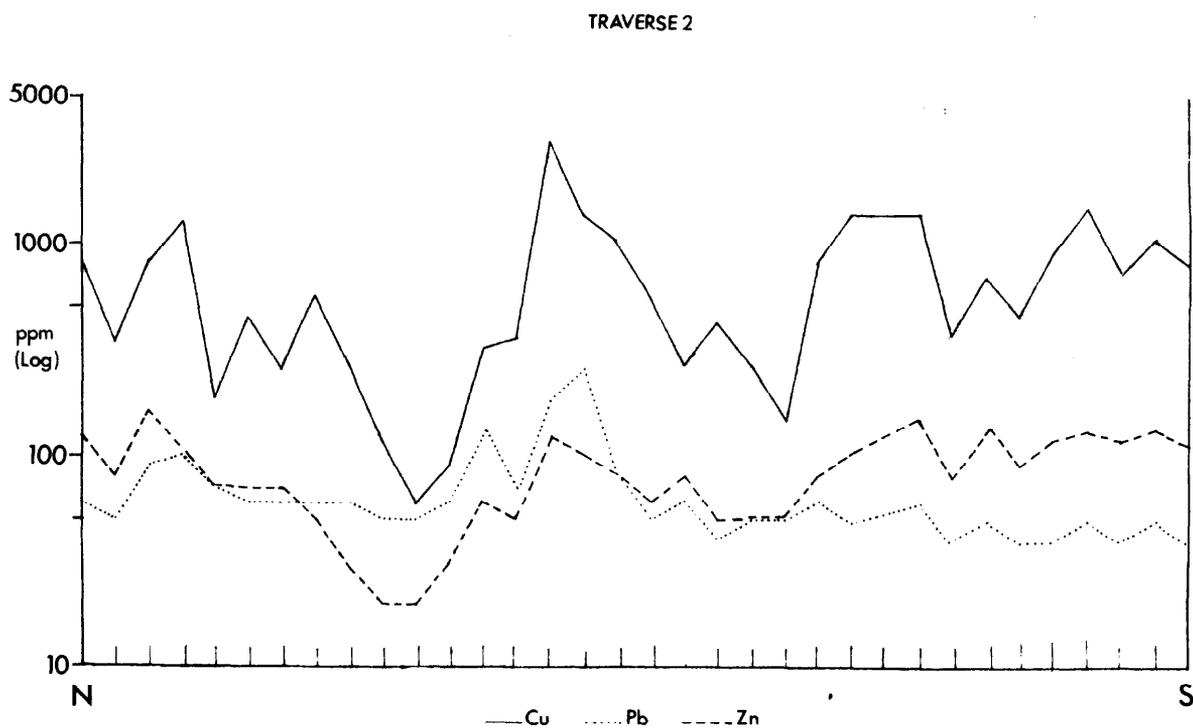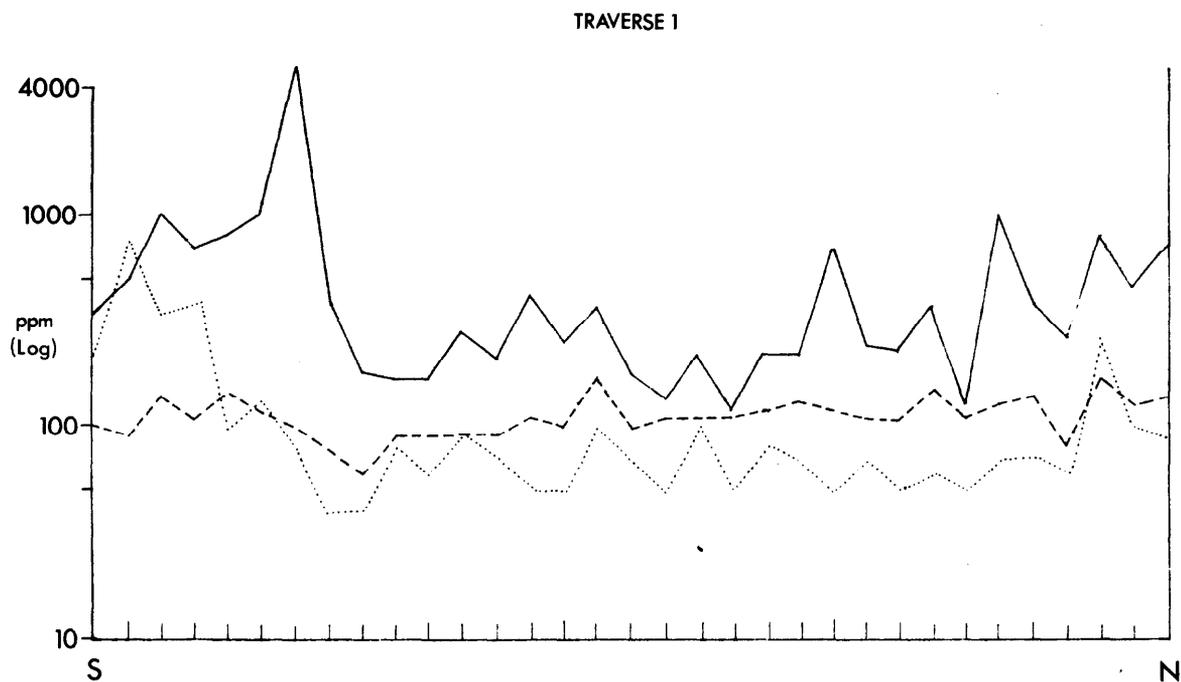
Sample points, 20m intervals
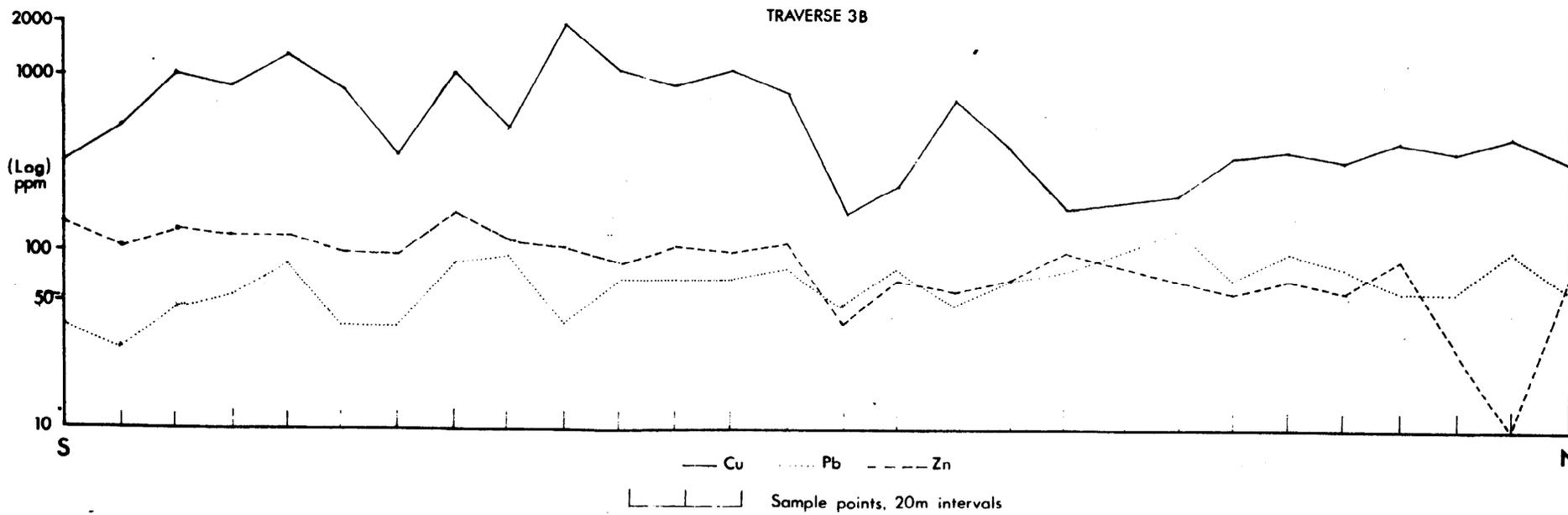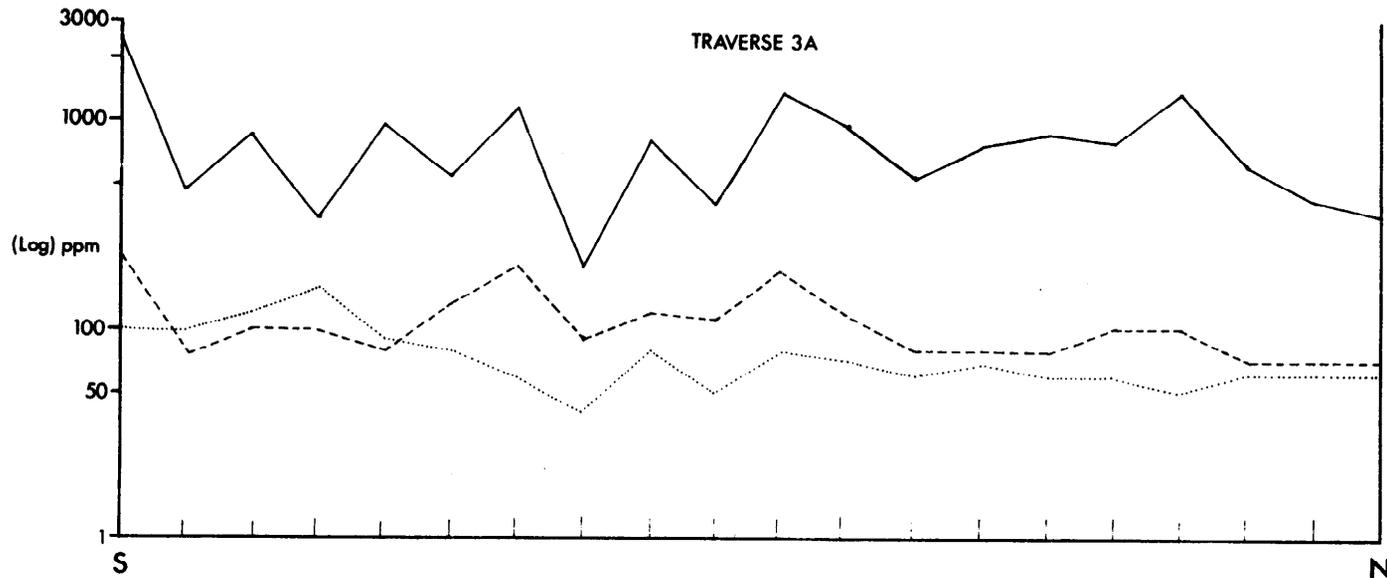
Fig.104B. Tyddyn Gwladys; copper, lead and zinc in soil samples collected along traverse line 3 shown in Fig.103
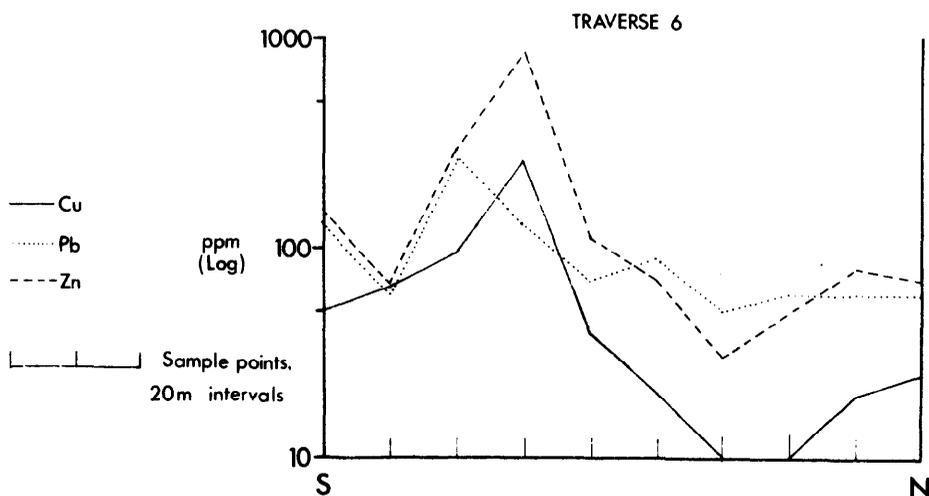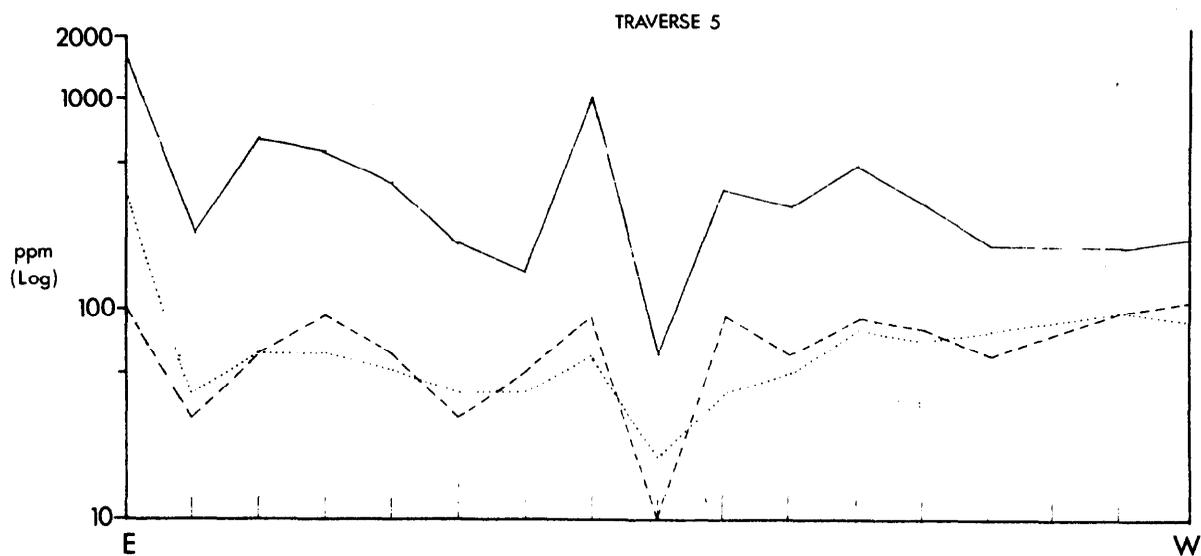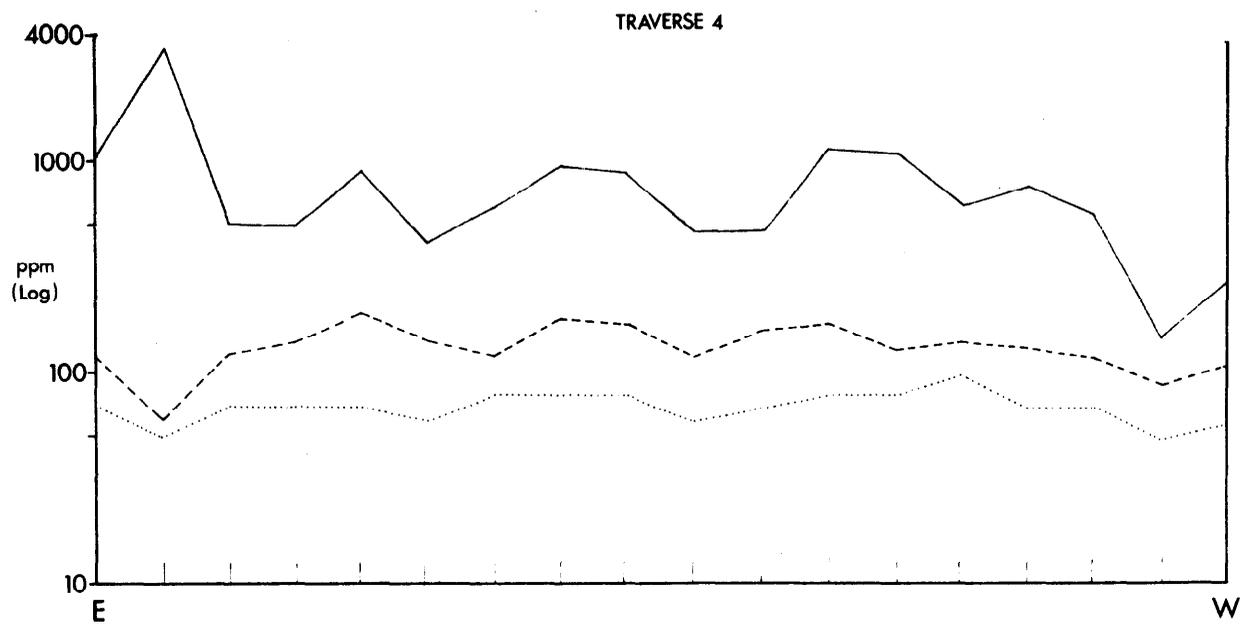
Fig.104C, Tyddyn Gwladys; copper, lead and zinc in soil samples collected along traverse lines 4 – 6 shown in Fig.103

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values of copper on traverse 6 confirm a source on the eastern side of the Afon Mawddach. The lack of lead and zinc anomalies together with the large area containing high copper values indicates that a disseminated body is the most likely source for the copper anomalies. This source may either be the known zone of cupriferous rocks delineated by Rice and Sharp (op. cit.) about half a kilometre to the east, or an extension of that mineralisation closer to these soil anomalies.

Though very high copper values may result from sampling a copper 'pan' which is intermittently developed in the drift in this area, the highest copper result is near lead anomalies adjacent to a trial working in a vein at the south end of traverse 1 and it is suspected that this copper value is high because of a combination of a high background derived from disseminated mineralisation (?transported anomaly) and additional copper from vein mineralisation. Rice and Sharp (op. cit.) showed that high lead and zinc values are not associated with the disseminated mineralisation in this area. This also suggests that the lead anomalies on traverses 2 and 5, which are associated with copper peaks, may also indicate vein mineralisation. The copper-lead-zinc anomaly on traverse 6 occurs over the margin of a dolerite intrusion and may be related to either vein mineralisation or metal rich seepages along the margin of the intrusion.

Conclusions

All the airborne EM anomalies seem to be the result of non-geological causes and are not related to mineralisation.

Geochemical soil sampling indicates the presence of copper-lead-zinc vein mineralisation in this area and extensive copper enrichment in the soils of the type usually indicative of disseminated copper mineralisation. It is not clear, however, whether the copper enrichment is a transported anomaly from the mineralisation at Coed-y-Brenin or indicates a separate but possibly related area of disseminated copper mineralisation. Further work, in the form of bedrock and soil sampling both here and northwards to Hafod Fraith, would be needed to clarify these points.

WAUN HIR
Centre point: SH 758 312
6-inch sheet SH 73 SE

Geology

This large area, used as an artillery range for many years, rises gently eastwards, and is extensively covered with thick boulder clay with patches of thick peat.

About half the area (Fig. 105) is underlain by Maentwrog Formation, which consists of dark grey laminated mudstone and silty mudstone, in places pyritic, and with rarely developed laminae and thin beds of fine-grained sandstone. Overlying it is the Ffestiniog Flags Formation, which comprises light grey siltstone interbedded with thinly bedded fine-grained sandstone; the latter

is usually laminated or cross-bedded.

An intrusion of microtonalite, showing in different places both concordant and slightly discordant contacts, is exposed beneath extensive drift cover only in the lowest parts of Nant Hir and the tributaries that flow into it from the south. No mineralisation is known in the area.

Geophysics

In this area are many isolated small, airborne EM anomalies, which do not in general appear on adjacent flight lines. However a tentative continuity can be traced between some of them.

The area of interest was covered by 11 ground slingram traverses. Several anomalies were found, confirming some of the airborne indications (Fig. 106). There is no correlation between the anomalies and the observed geology. However, the area was used as an artillery range, and many buried metallic objects remain, including cables and pipes. These probably explain most, if not all, of the geophysical features.

Geochemistry

Highly anomalous results were obtained from sediment, panned concentrate and water samples collected during the reconnaissance drainage survey in the tributaries of the Nant Hir, and weaker anomalies in sediment were recorded in the main stream (Fig. 107). Although the anomalous sites are in the vicinity of a microtonalite intrusion the large size of some of the metal anomalies, the presence of a military firing range, large tin anomalies at some sites, and the derivation of virtually all sediment from the drift suggest that the anomalies are at least partly the product of contamination.

To gain additional information a number of extra water samples were collected and analysed for copper and zinc (Fig. 107); anomaly levels determined for the regional survey were applied to the results. The pattern of results suggests that the highly anomalous results (>0.05 ppm Cu, >0.10 ppm Zn) are related either to an area used for burning cordite or to a hilltop used for drying pig bristles (Fig. 107). Two of the streams carrying the highly anomalous waters also contain the sites of the large panned concentrate anomalies and it is concluded that these are also largely the product of contamination. However, more weakly anomalous water and sediment results from the Nant Hir, well removed from the highly contaminated area, suggests that there is some other source of metal enrichment in the general area.

Sediment values in the Nant Hir are at least enhanced by co-precipitation with iron and manganese hydrous oxides, as indicated by the presence of high metal values in sediments, but not in the corresponding concentrates. However the results still suggest an abundance of Cu, Pb, Zn and As in the area. Anomalous waters in apparently uncontaminated areas such as at SH 7534 3186 also suggest a metal-rich source in the area. Unfortunately without further data it is impossible to say whether this source is a particular lithology, mineralisation, or the scattered, rotting, military hardware buried in the drift.

Fig 105 Geological map of Waun Hîr area.

DRIFT

Quaternary

~ Peat

~ Alluvium, undivided

U River terrace deposits, undivided

▽ Boulder clay

SOLID

Cambrian

Ff Interbedded sandstone and siltstone } Ffestiniog Flags Formation

Mw Sedimentary rocks, undivided } Maentwrog Formation

Mawddach Group

INTRUSIVE IGNEOUS

pMt Microtonalite

SYMBOLS

— — Geological boundary, Solid

---- Geological boundary, Drift

┴ Fault, crossmark indicates downthrow side

14⟋ Inclined strata, dip in degrees

⬦ Axial-plane trace, anticline

✳ Axial-plane trace, syncline

SCALE
0   100   200m

Fig.106 Geophysical data for the Waun Hîr area.

The figure contains the following labels:

Legend:
- Contours of airborne EM in ppm
- Ground E. M. traverses with shaded areas of <100% in-phase.

Map labels:
- Nant Hîr
- WAUN HÎR
- Road

Contour values: 0, 25, 50, 75

Grid coordinates: 30, 31, 32 (vertical); 75, 76 (horizontal)

SCALE
0 100 200 m

Fig 107 Geochemical data for Waun Hĩr area.

DRIFT

Quaternary

~ **Peat**
~ **Alluvium, undivided**
⩔ **Boulder Clay**

SOLID

Cambrian

Mw **Sedimentary rocks, undivided** } **Maentwrog Formation**
MwS **Interbedded sandstone and siltstone**
Clu **Black mudstone** } **Clogau Formation**
Gn **Sedimentary rocks, undivided** } **Gamlan Formation**

Mawddach Group

Harlech Grits Group

INTRUSIVE IGNEOUS

P **Intermediate, undivided**
pMt **Microtonalite**

SYMBOLS

--- **Geological boundary, Solid**
--- **Geological boundary, Drift**
⊥— **Fault; crossmark indicates downthrow side. R indicates reversed fault**
-·- **Quartz vein**
40⟋ **Inclined strata, dip in degrees**
⤫ **Vertical strata**
↗70 **Inclined cleavage, dip in degrees**
⤫— **Axial plane trace, syncline**
⟡— **Axial plane trace, anticline**
↩ **Minor fold, direction of plunge shown, amount in degrees**

Fig 108 Geological map of Y-Gors area.

Ground survey contours of total magnetic field strength in nT.

Airborne survey contours of total magnetic field strength in nT
Both are referred to standard datum

Ground traverse line, bar indicates the beginning
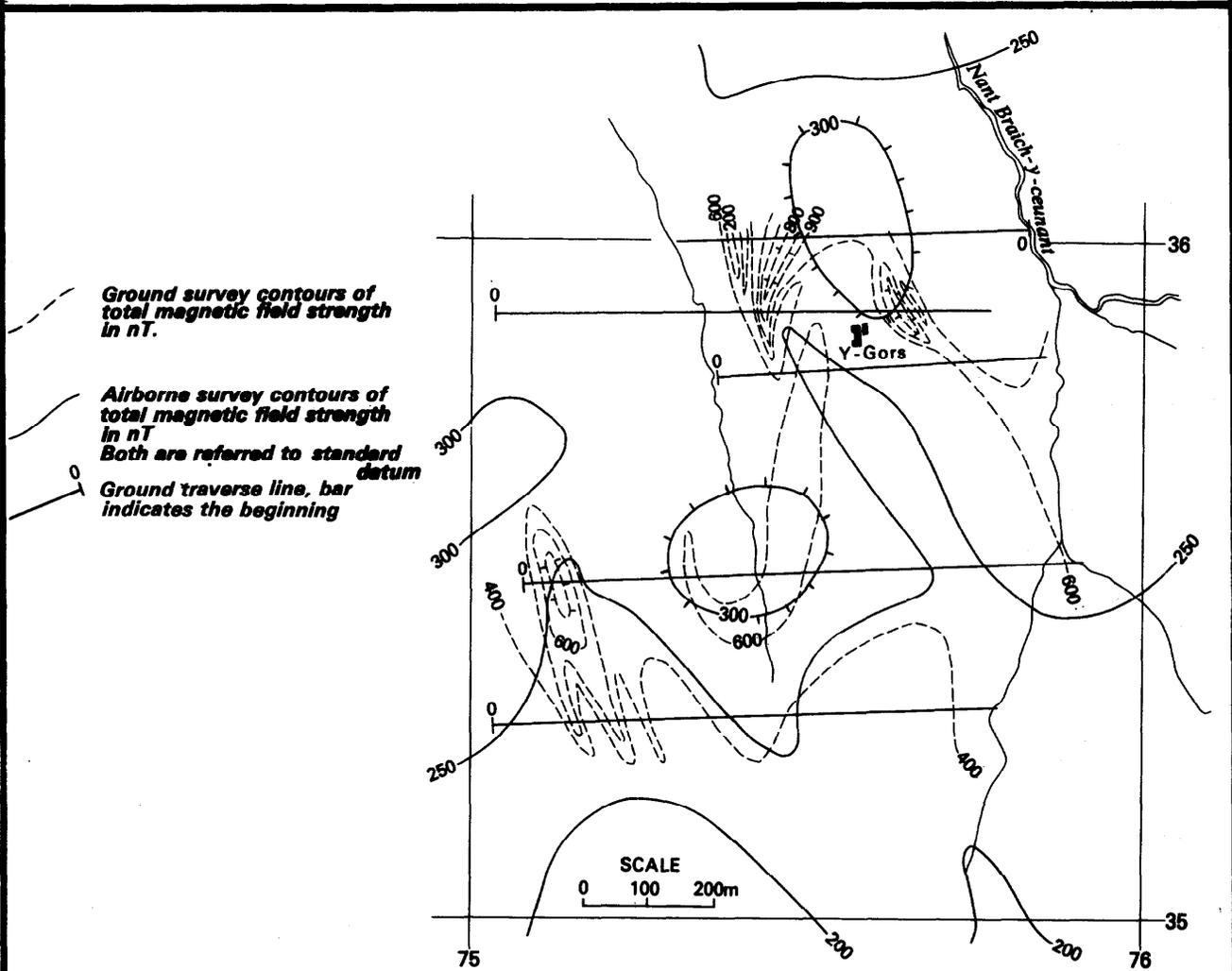
Fig.109 Geophysical data for Y-Gors area.

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Conclusions

The geophysical anomalies are most likely to be caused by buried metal relics of the old artillery range and it is concluded that contamination also explains the high magnitude geochemical anomalies in this area. However, the possibility cannot be ruled out that these effects could be screening weaker anomalies which may be directly or indirectly related to bedrock mineralisation but it is suggested that the thick drift and the hazards of prospecting on the artillery range are serious disadvantages to any further possible work.

Y GORS
Centre point: SH 755 355
6-inch sheet SH 73 NE

Geology

Most exposure is on the high ground in the south-western and eastern parts of the area. Elsewhere there is thick boulder clay, part of the extensive cover in the Prysor valley (Fig. 108).

The oldest stratigraphic units, the Gamlan and Clogau formations, are concealed by boulder clay in this area. The Maentwrog Formation consists of a lower unit of interbedded sandstone and siltstone and an upper part of dark grey, often pyritic, mudstone containing sandy laminae and rare beds, and light grey silty bands. In the lower unit, sandstone beds may be up to 1 metre thick, but mostly they are less than 10 cm thick.

There are parts of two large microtonalite intrusions in the area and some small sills of altered microdiorite.

Sedimentary rocks are tightly folded in places; the axial trend is consistently roughly north-south and is parallel to the direction of reversed faulting. There is a major normal fault with the same trend. North-east and east-north-east faults are younger than the reversed faults. The Maentwrog Formation is strongly cleaved.

Mineralisation

Quartz veins have been recorded in the east-north-east faults, but sulphide minerals have not been observed in them.

The stream Braich-y-ceunant crosses the Maentwrog Formation to the north of this area (SH 7598 3640) and in it beds of massive sandstone and interbedded siltstone are rich in disseminated pyrrhotite and minor chalcopyrite. The rocks also contain thin quartz veins. Pyrite, pyrrhotite and chalcopyrite occur in joints and along cleavage planes.

Geophysics

Airborne magnetic anomalies of about 150 nT were investigated with five east-west total magnetic field traverses, which run approximately normal to the geological strike. The airborne EM anomaly closely related to the outcrop of the Clogau Formation was not checked.

A contour map of the ground survey (Fig. 109)

confirms the position of the airborne anomalies but the detailed trends and amplitudes are different. The anomalies fall over the Clogau and the lower part of the Maentwrog formations.

Conclusions

Both the Clogau and Maentwrog formations contain pyrrhotite in sufficient quantity to cause the magnetic anomalies, which are, therefore, not considered of economic significance although they may be reflecting unexposed vein mineralisation in the area.

CONCLUSIONS

REGIONAL AND GENERAL INVESTIGATIONS

1. Investigations into the causes of EM anomalies, in conjunction with the ground follow-up of specific anomalies, revealed that both carbon and sulphide-bearing rocks produce anomalies. Relatively low concentrations of carbonaceous material, particularly in an amorphous form, cause anomalies over black mudstone in the Dolgellau Member. However, in the Clogau Formation low concentrations of sulphide minerals in lenses, disseminations and veinlets also create anomalies. In the mudstone formations with little carbonaceous material as little as 2-3% sulphide, suitably distributed, can be sufficient to cause EM anomalies.

2. The magnetic survey identified several areas of pyrrhotite enrichment in the country rock. Mineralogical investigations revealed that possibly syngenetic pyrrhotite was present in certain mudstone formations, but that the concentration was increased by the introduction of epigenetic pyrrhotite into the country rock during the vein mineralisation. The aeromagnetic survey data, therefore, might be used to identify areas of potential vein mineralisation where there is good geological control.

3. Coincident EM and magnetic anomalies indicated the presence of stratabound concentrations, mainly of pyrrhotite, but with sub-economic quantities of base metal sulphides in mudstone. Not all such anomalies were followed up; the completion of this work being dependent on the results of the geochemical drainage survey.

4. The aeroradiometric survey agrees with earlier ground survey work and indicates that only dark mudstone bands in the Dolgellau Member show any uranium enrichment. The radiometric readings on outcrop reach only about three times the level for mudstones and cannot be considered economically significant.

5. The reconnaissance fluid inclusion study indicates that the method has potential as an exploration tool. It was found that there are differences between the fluids in quartz veins that

are associated with the Coed-y-Brenin porphyry copper deposit and the quartz veins that have been mined in the Gold-belt. It is also possible to distinguish between quartz veins containing Pb/Zn sulphide assemblages that are likely to be auriferous and those that are not.

6. The rock geochemistry study showed that the porphyry copper mineralisation at Coed-y-Brenin was probably co-genetic with the end-Tremadoc magmatism that gave rise to both the volcanic pile at Rhobell Fawr and microdiorite and micro-tonalite intrusions in the Cambrian. This episode of mineralisation is, therefore, considerably earlier than the end-Silurian 'Gold-belt' minerali-sation.

7. The Glasdir copper deposit is reinterpreted as a mineralised intrusion-breccia pipe. This, and several other breccia pipes, dykes and sills are manifestations of the Rhobell Fawr volcanism. The copper mineralisation at Glasdir probably took place penecontemporaneously with the intrusion of the pipe, and therefore is genetically related to the porphyry copper mineralisation.

DETAILED INVESTIGATIONS BY AREA

8. Fourteen of the areas that were investigated yielded signs of mineralisation. These are:

a. Benglog and Hengwrt Uchaf, where there are signs of base metal mineralisation asso-ciated with Ordovician volcanic rocks. In both areas the EM anomalies probably relate to bands of mudstone within the volcanic succession. Geochemical indications, however, suggest that there may be associated mineralisation and at Benglog it may be of the stratabound volcanogenic type.
b. Bryn Coch, Tyddyn Gwladys and Hafod Fraith, where there are indications of dissemi-nated copper mineralisation. Hafod Fraith lies to the north, Tyddyn Gwladys to the west and Bryn Coch south of the proved porphyry copper deposit at Coed-y-Brenin. It is uncertain at present whether these three areas contain extensions of the known mineralisation or separate orebodies. In all three there are indications of vein mineralisation.
c. Dol Haidd, Mynydd Bach and Craiglaseithin, where possible base metal mineralisation in veins was located. At Craiglaseithin and Dol Haidd there are indications of weak, local, dispersed sulphide mineralisation. Findings suggest that in none of these areas is their sufficient justification for further work.
d. Mynydd Foel Uchaf, Hafod-y-fedw and Y Gors, where epigenetic pyrite-pyrrhotite mineralisation was identified in the Maentwrog Formation. This is not uncommon in the southern and eastern Harlech Dome and in places appears to be associated with the end-Silurian mineral veining.
e. Ffridd Dol-y-moch and Waun Hir, where geophysical and geochemical results suggest

that mineralisation may be concealed beneath thick, extensive drift in areas where results are influenced by contamination problems.
f. Nannau, where there is weak copper enrichment in volcanic rocks that are co-genetic with the Coed-y-Brenin porphyry copper mineralisation.

9. Pilot investigations carried out at Garth Gell demonstrated the association between epigenetic pyrrhotite in the country rock and mineralised quartz veins. At Glanllafar it was shown that the sulphide concentrations in the Clogau Formation are not likely to be rich in base metals.

10. EM anomalies investigated at Banciau'r Eisteddfod were attributable to conductive over-burden, at Mynydd Penrhos to a stratigraphic cause unrelated to mineralisation in the Maentwrog Formation and at Sarn Helen to stratiform pyrite and pyrrhotite in the Hafotty Formation. At Rhydau the cause of EM anomalies in Ordovician volcanic rocks was not identified, but geochemical indications suggest that they are unrelated to mineralisation. At Pont-y-sel EM and magnetic anomalies are artificial.

11. Magnetic anomalies were verified at Ffridd Bryn-coch, Foel Boeth, Gorwyr, Llanfachreth and Ty Glas. In all cases they have simple, but different, geological causes, unrelated to any mineralisation.

RECOMMENDATIONS

1. Of the fourteen areas in which signs of mineralisation were recognised it is felt justifiable to recommend further work only in seven of them. In the others the indications are either weak or suggestive of vein mineralisation of a type which would not be profitable to exploit under present economic circumstances. The seven areas are:

a. Benglog and Hengwrt Uchaf, where there is the possibility of massive stratabound sulphide deposits as well as vein mineralisation. Both areas warrant further geochemical and geophysical studies.
b. Hafod Fraith, Tyddyn Gwladys and Bryn Coch, which contain signs of disseminated copper mineralisation. In all three areas geochemical and geophysical studies in addition to drilling would be necessary first to establish the relationship between the geochemical anomalies and the known mineralisation at Coed-y-Brenin and then to demonstrate the presence of orebodies.
c. Ffridd Dol-y-moch where further work is necessary to verify whether or not there is any significant mineralisation beneath the drift.
d. Nannau, where the possibility of copper mineralisation in the volcanic rocks at the bottom of the Rhobell Fawr pile can be investi-gated initially with geochemical and geophysical methods.

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2. The Glasdir copper deposit is a mineralised pipe. Pipes in other parts of the world show a tendency to be mineralised intermittently along considerable lengths and there is a possibility of more mineralisation beyond the depths of working at Glasdir. Any further work there would involve drilling for these targets.

3. A north-north-east-trending zone extending from Foel Fawr to the Afon Mawddach contains the Glasdir and Coed-y-Brenin copper deposits, in addition to some of the prospects named above. This area as a whole should be subjected to detailed geochemical and geophysical studies.

4. The absence of economically useful strata-bound sulphide deposits in the Clogau Formation, though suspected, is not yet proved. Further work is recommended on this formation in the event of any geochemical anomalies coincident with geophysical anomalies in this formation becoming evident in the regional geochemical drainage survey.

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The bibliography and the geological map were compiled by R.J. Tappin.

REFERENCES AND BIBLIOGRAPHY

Included in this section is a comprehensive list of references which relate to the economic geology of the area.

ALLEN, P.M., COOPER, D.C., FUGE, R. and REA, J. 1976. Geochemistry and relationships to mineralisation of some igneous rocks from the Harlech Dome, Wales. Sect. B. Trans. Instn Min. Metall., 85, pp. 100–108.

ALLEN, P.M. and EASTERBROOK, G.D. 1978. A mineralised breccia pipe and other intrusion breccias in the Harlech Dome, North Wales. Sect. B. Trans. Instn Min. Metall., 87, B157–161.

ALLEN, P.M. and JACKSON, A.A. 1978. Bryn-teg borehole, North Wales. Bull. Geol. Surv. G.B. No. 61.

ANDREW, A.R. 1910. The geology of the Dolgelley Gold Belt, North Wales. Geol. Mag., 47 pp. 159–171, 201–211, 261–271.

ANON [J.R.G.], 1858. Gold in Wales. Geologist, 1, p. 159.

ANON, 1860. Welsh gold. Trans. Manchr geol. Min. Soc., 2, p. 36.

ANON, 1895. Gold in Wales. Pall Mall Gazette, 12 articles between June 27th and August 30th.

ANON, 1900. Gold mining in Wales. The Statist, August 25th, pp. 325–327.

ANON, 1960. Gold mining in Britain. Gemmologist, 29, 347, pp. 114–116.

ANSTED, D.T. 1858. Letter from Professor Ansted on gold in Wales. Geologist, 1, pp. 154–155.

ARCHER, A.A. 1959. The distribution of non-ferrous ore in the Lower Palaeozoic rocks of North Wales. In, The future of non-ferrous mining in Great Britain and Ireland. Instn Min. Metall. pp. 259–276.

BELLHOUSE, M.A. 1966. Welsh gold mines. Amat. Geolst, 1, 2, pp. 25–35.

BICK, D.E. 1978. The Old Metal Mines of Mid Wales, Part 5: Aberdovey, Dinas Mawddwy and Llangynog. Pound House, Newent, Glos.

BOOTH, W.H. 1903. Gold mining in Wales. Cassier's Mag. 23, 4, pp. 491–512.

BRITISH MUSEUM (NATURAL HISTORY), 1973. British and Irish gold. Mineralogy Leaflet No. 4, 8 pp.

BRUMBY, G.R. and SHEPHERD, T.J. 1978. Improved sample preparation for fluid inclusion studies. Min. Mag. 42, 297–298.

BURLEY, A.J., CORNWELL, J.D. and TOMBS, J.M.C. 1978. Geophysical field techniques for mineral exploration. I.G.S. DIMRP No. 20.

CALVERT, J. 1854. Gold rocks in Great Britain and Ireland .... with a treatise on the geology of gold. (London: Chapman and Hall) pp. 114–126.

CARMICHAEL, I.S.E., TURNER, F.J. and VERHOOGEN, J. 1974. Igneous Petrology. McGraw-Hill, New York.

CLEMENT, J.H. 1863. Description of specimens of gold and gold-ores exhibited by the Vigra and Clogau Company and by Mr. Readwin at the International Exhibition. Proc. Geol. Ass., 1 (1859–1865), pp. 279–282.

COLLINS, R.S. 1975. Gold. Mineral Resources Consultative Committee. Mineral Dossier No. 14 (London, H.M.S.O.).

COX, A.H. and WELLS, A.K. 1921. Lower Palaeozoic rocks of the Arthog-Dolgelley district (Merionethshire). Q. Jl. geol. Soc. Lond. 76, 254–324.

COX, A.H. and WELLS, A.K. 1927. The geology of the Dolgelly District, Merionethshire. Proc. Geol. Ass., 38, pp. 265–331.

CRIMES, T.P. 1970. A facies analysis of the Cambrian of Wales. Palaeogeog. Palaeoclim. 7, 113–170.

DAVIES, D.C. 1881. Metalliferous minerals and mining. 2nd edition (London: Crosby Lockwood) pp. 40–43, 144.

DAVIS, J.D. and GUILBERT, J.M. 1973. Distribution of the radioelements potassium, uranium and thorium in selected porphyry copper deposits. Econ. Geol. 68, 145–160.

DEAN, A. 1845. Notes respecting the discovery of gold ores in Merionethshire, North Wales. Rep. Br. Ass. Advmt Sci. [for 1844], p. 56.

DEANE, N. 1961. Gold in Wales. Gemmologist, 30, 360, pp. 121–122.

DEWEY, H. and EASTWOOD, T. 1925. Copper ores of the Midlands, Wales and the Isle of Man. Mem. geol. Surv. spec. Rep. Miner. Resour. Gt Br., 30, pp. 39–48.

DEWEY, H. and SMITH, B. 1922. Lead and zinc ores in the pre-Carboniferous rocks of West Shropshire and North Wales. Part II - North Wales. Mem. geol. Surv. spec. Rep. Miner. Resour. Gt Br., 23, p. 37, pp. 55–56.

DUNKLEY, P.N. 1978. The geology of the south-western part of the Aran Range, Merionethshire, with particular reference to igneous history. PhD thesis University of Wales, Aberystwyth.

EASTERBROOK, G.D. and BASHAM, I.R. Investigations into the causes of electromagnetic anomalies in Cambrian and Ordovician sediments of the Harlech Dome. Mineralogy Unit Report No. 210.

EASTERBROOK, G.D. Mineralogical examinations of miscellaneous specimens from the Harlech Dome. Mineralogy Unit Report No. 214.

EMMONS, W.H. 1937. Gold deposits of the world, with a section on prospecting. 1st edition (New York: McGraw-Hill) p. 308.

FEARNSIDES, W.G. 1905. On the geology of Arenig Fawr and Moel Llyfnant. Q. Jl. geol. Soc. Lond. 61, 608–640.

FLETT, J.S. 1930. Gold in Great Britain. C.R. XV International Geological Congress, Pretoria. The gold resources of the world. pp. 169–170.

FORBES, D. 1867. Researches in British mineralogy. Phil. Mag. Series IV, 34, pp. 329–354.

FORBES, D. 1868. Gold from the Clogau quartz lode No. 2, Geol. Mag., 5, p. 224.

FORBES, D. 1868. Stream gold from the River Mawddach, Geol. Mag., 5, p. 225.

FORSTER, A. Density, porosity, magnetic susceptibility, remnant magnetism, resistivity and formation factor determinations on nine samples from North Wales. Engineering Geology Unit Report No. 83.

FOSTER, H.D. 1968. The glaciation of the Harlech Dome. PhD thesis, Univ. London.

FOSTER-SMITH, J.R. 1977. The Mines of Merioneth. British Mining, No. 6, 41 pp.

GEOLOGICAL SURVEY OF GREAT BRITAIN, 1965. Aeromagnetic map of Great Britain, Sheet 2. First Edition (Chessington, Surrey: Ordnance Survey).

GILBEY, J.W.G. 1969. The mineralogy, paragenesis and structure of the ores of the Dolgellau Gold Belt, Merionethshire, and associated wall rock alteration. Ph.D. thesis. Univ. Lond.

HALL, G.W. 1956. An ancient gold and copper mine [Vigra]. Min. Mag., Lond., 95, pp. 277–279.

HALL, G.W. 1975. The gold mines of Merioneth. (Gloucester: Griffin Publications) 120 pp.

HARVEY, P.L. 1967. A Welsh Klondyke - the gold reef of Merioneth. Br. Caver., 46, pp. 48–57.

HELGESON, H.C. and GARRELS, R.M. 1968. Hydrothermal transport and deposition of gold. Econ. Geol. 63, 622–635.

HENWOOD, W.J. 1852. Notice of the Copper Turf of Merioneth. 38th Annual Report of the Royal Institute of Cornwall, pp. 41–43.

HENWOOD, W.J. 1857. Notice of the Copper Turf of Merioneth. Edinburgh New Philosophical Journal, Series 2, 5, pp. 61–63.

HENWOOD, W.J. 1871. Notice of the Clogau gold mine, in North Wales. Trans. R. geol. Soc. Corn., 8, 1, pp. 635–642.

HOFFMAN, S.J. 1977. Talus fine sampling as a regional geochemical exploration technique in mountainous regions. J. Geochem. Expl. 7, 349–360.

HUDDART, L.H.L. 1904. St. David's gold mine, North Wales. Trans. Instn Min. Metall., 14, pp. 199–219.

HUNT, R. 1855–1881. Mineral statistics of the United Kingdom of Great Britain and Ireland. Mem. geol. surv. G.B.

HUNT, R. 1865. British gold, with especial reference to the gold mines of Merionethshire. Quarterly Journal of Science, 2, pp. 635–643.

HUNT, R. 1875. The gold mines of North Wales. Dr. Ure's Dictionary of Arts, Manufactures and Mines. 7th edition, 2, pp. 609–698.

INESON, P.R. and MITCHELL, J.G. 1975. K-Ar isotopic age determinations from some Welsh mineral localities. Trans. Instn Min. Metall. Sect. B. 84, B7–16.

KINGSBURY, A.W.G. 1965. Tellurbismuth and meneghinite, two minerals new to Britain. Min. Mag. 35, 424–5.

KENNEDY, N.W. 1951. Gold in Britain. J. Gemm., 3, pp. 101–105.

KENNEDY, N.W. 1961. Gold in Wales. Gemmologist, 30, 358, pp. 87–89.

KOKELAAR, B.P. 1977. The igneous history of the Rhobell Fawr area, Merioneth, North Wales. Ph.D. thesis. Univ. College, Aberystwyth.

LEAKE, R.C. and SMITH, R.T. 1975. A comparison of stream sediment sampling methods in parts of Great Britain. In: Elliott, I.L. and Fletcher, W.K. (Eds.); Geochemical

Exploration 1974, 579–594. Elsevier, Amsterdam.

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

LOUIS, H. 1930. Report of Professor Henry Louis as to the possibilities of developing the production of gold and other minerals in Merionethshire. Mines Department (London: H.M.S.O.) 15 pp.

LYNAS, B.D.T. 1973. The Cambrian and Ordovician rocks of the Migneint area, North Wales. Jl. geol. Soc. Lond. 129, 481–503.

MACDONALD, W.F. 1935. Gold mining in Merionethshire: diamond drilling possibilities. Min. Wld Engng Rec., 129, p. 309.

MACLAREN, J.M. 1903. The occurrence of gold in Great Britain and Ireland. Trans. N. Engl. Inst. Min. mech. Engrs., 52, pp. 437–510.

MADOC-JONES, G.W. 1975. Vigra-Clogau-St. David's mine areas. British Mining, 1, pp. 63–68.

MADOC-JONES, G.W. 1976. Synopsis: Clogau St. David's gold mine, Bontddu, Merionethshire. British Mining, 3, pp. 12–16.

MATLEY, C.A. and WILSON, T.S. 1946. The Harlech Dome, north of the Barmouth Estuary. Q. Jl geol. Soc. Lond., 102, pp. 1–46.

MOHR, P.A. 1959. A geochemical study of the shales of the Lower Cambrian Manganese Shale Group of the Harlech Dome, North Wales. Geochim. Cosmochim. Acta 17, 186–200.

MOORBATH, S. 1962. Lead isotope abundance studies on mineral occurrences in the British Isles and their geological significance. Phil. Trans. R. Soc. 254A, 295–360.

MORGAN REES, D. 1969. Mines, mills and furnaces. National Museum of Wales (London: H.M.S.O.) pp. 2–15, 49–51.

MORRISON, T.A. 1975. Goldmining in Western Merioneth. Merioneth Historical and Record Society (Llandysul) 98 pp.

MURCHISON, R.I. 1867. Siluria (London: John Murray) p. 450.

NASH, J.T. 1976. Fluid-Inclusion petrology - data from porphyry copper deposits and applications to exploration. U.S. Geol. Surv. Prof. Paper 907D.

NORTH, F.J. 1962. Mining for metals in Wales (Cardiff - National Museum of Wales) pp. 58–60, 65–69.

OWEN, H.J. 1950. The treasures of the Mawddach (Bala) pp. 54–79.

PARRY, J. 1862. Aur Sir Feirionydd. The Gold of Merionethsire. Dolgellau (translated from Welsh by J. Rowlands 1931).

PARSLOW, G.R. 1974. Determination of background and threshold in exploration geochemistry. J. Geochem. Expl. 3, 319–336.

PHILLIPS, J.A. 1862. Gold mining and gold discoveries made since 1851. Journal of the Society of Arts, 10, pp. 419–429.

PHILLIPS, J.A. and LOUIS, H. 1896. A treatise on ore deposits (London: Macmillan) pp. 292–295.

PHILLIPS, L. 1918. Report of the Controller of the Department for the development of mineral resources in the United Kingdom. Ministry of Munitions of War (London: H.M.S.O.).

PLANT, J. 1865. On the discovery of Paradoxides davidis at Tyddyngwladis near Dolgelly, North Wales. Trans. Manchr geol. Min. Soc., 5, pp. 76–80.

PLANT, J. and WILLIAMSON, E. 1866. The geology and fossils of the Lingula Flags or Primordial Zone of the gold districts of North Wales. Trans. Manchr geol. Min. Soc., 5, pp. 220–231.

PLANT, J.A. 1971. Orientation studies on stream sediment sampling for a regional geochemical survey in northern Scotland. Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.) 80, B324–B345.

PONSFORD, D.R.A. 1955. Radioactivity studies of some British sedimentary rocks. Bull. Geol. Surv. G.B. No. 10, 22–44.

POWELL, D.W. 1955. Gravity and magnetic anomalies in North Wales. Q. Jl. geol. Soc. Lond. 111, 375–397.

PRINZ, M. 1968. Geochemistry of basalts; trace elements. In: Hess, H.H. and Poldervaart, A. (Eds.), Basalts (Vol. 1) 271–319. Interscience, New York.

RAMSAY, A.C. 1854. On the geology of the gold-bearing district of Merionethshire. Q. Jl geol. Soc. Lond., 10, pp. 242–247.

RAMSAY, A.C. 1858. The physical structure of Merionethshire and Caernarvonshire. Geologist, 1, pp. 169–174.

RAMSAY, A.C. 1881. The geology of North Wales. Mem. geol. Surv. Gt Br. 2nd edition. pp. 59–65.

REA, W.J. 1972. Igneous activity and metallogenesis in the Ordovician in North Wales: a review. In Mineral exploitation and economic geology (Aberystwyth: Univ. Wales) 45–9.

READWIN, T.A. 1858. [Letter on gold in the Dolgellau district]. Geologist, 1, p. 159.

READWIN, T.A. 1860. Of the gold discoveries in Merionethshire. Trans. Manchr geol. Min. Soc., 2, pp. 97–101.

READWIN, T.A. 1861. On the occurrence of gold in Wales. Chem. News, Lond., 4, pp. 272–274.

READWIN, T.A. 1861. On the occurrence of gold in Merionethshire. Geologist, 4, pp. 511–516.

READWIN, T.A. 1862. On the gold of North Wales. Rep. Br. Ass. Advmt. Sci. [for 1861], pp. 129–130.

READWIN, T.A. 1862. List of gold ores from Merionethshire, North Wales [exhibited at the International Exhibition, 1862]. (Manchester; "Examiner" Office).

READWIN, T.A. 1863. On the gold-bearing strata of Merionethshire. Rep. Br. Ass. Advmt Sci. [for 1862], pp. 87–91.

READWIN, T.A. 1864. On the recent discovery of gold near Bala Lake, Merionethshire. Rep. Br. Ass. Advmt Sci. [for 1863], pp. 86–87.

READWIN, T.A. 1871. Notes on a Merionethshire gold quartz crystal, and some stream gold recently found in the River Mawddach. Rep. Br. Ass. Advmt Sci. [for 1870], pp. 84–85.

READWIN, T.A. 1879. Notes on some minerals of the Mawddach Valley. Mineralog. Mag., 3, pp. 122–127.

READWIN, T.A. 1884. Note on Welsh gold. Mineralog. Mag., 6, p. 108.

READWIN, T.A. 1887. Gold in Wales. Industrial Review, 27–34, p. 515.

READWIN, T.A. 1888. On the occurrence of gold in Wales. Proc. Geol. Ass., 10, pp. 339–344.

RICE, R. and SHARP, G. 1976. Copper mineralisation in the forest of Coed-y-Brenin, Wales. Sect. B. Trans. Instn Min. Metall., 85, pp. 1–13.

RIDGWAY, J. 1975. The stratigraphy and Ordovician volcanic rocks on the southern and eastern flanks of the Harlech Dome in Merionethshire. Geol. Jl. 10, 87–106.

RUDLER, F.W. 1905. A handbook to a collection of the minerals of the British Islands. (London: H.M.S.O.), p. 127, pp. 129–130.

SALTER, J.W. 1865. Notes explanatory of a map of the faults of the Dolgelly gold district, undertaken for Mr T.A. Readwin. Geol. Mag., 2, pp. 558–561.

SALTER, J.W. 1866. Explanation of a map of the faults in the gold district of Dolgelly. Rep. Br. Ass. Advmt Sci. [for 1865], pp. 73–74.

SEWARD, T.M. 1973. The complexes of gold and the transport of gold in hydrothermal ore solutions. Geochim. Cosmochim Acta 37, 379–399.

SHIIKAWA, M., WAKASA, K. and TONO, N. 1974. Geochemical exploration for kuroko deposits in north-east Honshu, Japan. In: Elliott, I.L. and Fletcher, W.K. (Eds.); Geochemical Exploration, 65–76. Elsevier, Amsterdam.

SINCLAIR, A.J. 1974. Selection of threshold values in geochemical data using probability graphs. J. Geochem. Expl. 3, 129–149.

SMITH, E.A. 1895. Gold in the British Isles. Knowledge, 18, pp. 33–34.

SMYTH, W.W. 1862. Gold mining at Clogau, North Wales. Mining and Smelting Magazine, 1, pp. 359–366.

SMYTH, W.W. 1870. Occurrence of gold in North Wales. Trans. R. geol. Soc. Corn.

TAYLOR, S.R. 1964. Abundance of chemical elements in the continental crust: a new table. Geochim. Cosmochim. Acta. 28, 1273–1284.

THOMAS, H.H. 1913. [Brief account of Prince Edward mine]. Summ. Progr. geol. Surv. 1912, p. 65.

THOMAS, T.M. 1961. The mineral wealth of Wales and its exploitation. (London: Oliver and Boyd), pp. 209–212, 218–219.

TUREKIAN, K.K. and WEDEPOHL, K.H. 1961. Distribution of the elements in some units of the earth's crust. Geol. Soc. Amer. Bull. 72, 175–192.

URQUIDI-BARRAU, F. 1973. Regional geo-chemical variations related to base metal mineralisation in Wales. Ph.D thesis, Univ. London.

VANDERBILT, A.T. 1888. Gold not only in Wales, but also in Great Britain and Ireland (London), pp. 51–72.

VINOGRADOV, A.P. 1962. The average content of chemical elements in the main types of igneous rocks of the earth. Geochemistry, 7, 641–664.

WELLS, A.K. 1925. The geology of the Rhobell Fawr District, (Merioneth) Q. Jl. geol. Soc. Lond. 81, 463–538.

WOODLAND, A.W. 1939. The petrography and petrology of the Lower Cambrian manganese ore of West Merioneth. Q. Jl. geol. Soc. Lond. 95, 1–35.

Mineral Statistics are contained in the following:

Mining Records. Mineral statistics of the United Kingdom of Great Britain and Ireland. R. Hunt. Mems. geol. Surv. Gt Br., 1855–1881.

Mineral Statistics (London: Home Office, annually 1882–1896).

Mines and Quarries: General Report with Statistics (London: Home Office annually 1897 to 1919).

Mines and Quarries: General Report with Statistics (London: Mines Department, Board of Trade, 1920).

Annual Report of the Secretary of Mines (London: Mines Department, Board of Trade, annually 1921–1938).

APPENDIX I

GEOCHEMICAL SAMPLING, ANALYTICAL AND DATA PROCESSING TECHNIQUES

SAMPLING TECHNIQUES

(i) Soils. Soil sampling was the standard method used to investigate anomalies; other materials were only sampled for special reasons, for example when there was poor soil development. Soil samples were taken at intervals along traverse lines, set up in directions to cut known geological structures and the geophysical anomalies, with additional traverses at right angles when the orientation and style of mineralisation were uncertain. Traverses were normally sampled at 20 m intervals. This close spacing was necessary to detect vein type structures in an area where pilot studies had shown that dispersion could be very limited because of poor soil development and impermeable drift cover. Samples were collected with a hand auger from as deep as possible up to a maximum of 1.20 m. Whenever possible, samples were collected from below the organic rich topsoil or peat cover and therefore, in this area, consisted of boulder clay, head, or fluvio-glacial deposits overlying bedrock. Small amounts of organic matter inevitably found their way into samples

from the overlying organic layer, particularly when this consisted of deep peat. Organic-rich material was only collected when peat cover exceeded 1.2 m, or peat rested directly on bedrock. At each sampling site material was collected from at least three auger holes made within a small area (5 m radius) around the sampling point. Occasionally sites were displaced by unfavourable ground at the sampling point. The weight of sample varied considerably, but was usually within the range 100-200 g. Traverse lines were laid out with compass and tape in the more remote upland areas where there were few fixed points. In lowland areas, where numerous fixed points in the form of field boundaries were available, sites were paced out between closely spaced fixed points using a 1:10,000 scale map.

(ii) Rocks. Rock chip samples were collected where there was either no drift cover or it was very patchy and peat covered. Samples were, with one exception, collected on rough traverse lines at 20 m intervals with the traverse orientation, position and sampling points determined in the same way as for soil sampling. Samples consisted of numerous small chips of fresh rock weighing in total 1-2 kg, depending on the grain size of the rock, collected by breaking up large blocks of rock from three or more points on an exposure within about 4 m of the sampling point. Several sampling points were displaced from the exact point on the traverse line by exposure availability.

(iii) Drainage samples. In two areas where soil development was poor, drainage samples as well as rock chips were taken. In addition the whole Harlech Dome has been covered by a reconnaissance scale (1 sample site/1.5 sq km) drainage survey. The results of this survey will be presented in a separate report, but available results for samples derived from the areas of the geophysical anomalies investigated are described in the relevant section.

At each drainage site up to three different samples were collected:

a) Water sample. A sample of the stream-water, avoiding suspended matter, was collected in a 30 ml polythene bottle and acidified with 0.3 ml perchloric acid in the field to prevent sorption of metals onto the walls of the container.

b) Sediment sample. Sites were chosen, where there was a choice, in midstream at likely sites of heavy mineral accumulation, such as below large boulders, rapids and waterfalls. Sediment was wet sieved at site to pass 100 mesh (0.15 mm), using as little water as possible in order to retain much of the clay and silt fraction. The -100 mesh fraction was allowed to settle for a few minutes, excess water was decanted off and the wet sample was bagged and returned to the laboratory.

c) Panned concentrate. Sediment was wet sieved and the -8 mesh (2.0 mm) fraction collected in a pan. When about 5 kg of -8 mesh material had been collected it was panned down until about 30 g of concentrate remained, this was bagged and returned to the laboratory.

The sampling methods have been the subject of orientation studies to establish sampling errors and optimise methods. These are not detailed here, but similar work in other areas has been published (Plant, 1971; Leake and Smith, 1975).

SAMPLE PREPARATION AND ANALYSIS

(i) Soils. Samples were dried and sieved, and the -85 mesh (0.18 mm) fraction taken for analysis. Analysis for Cu, Pb, Zn and occasionally iron was carried out by Atomic Absorption Spectrophotometry (AAS) following digestion of the sample in boiling concentrated nitric acid for one hour. Complete sample dissolution is not achieved by this method and metals present in some oxide and silicate phases will not be detected. Arsenic was determined on a few samples using the silver diethyldithio-carbamate method. Detection limits were approximately Cu 3 ppm, Pb 5 ppm, Zn 5 ppm and As 2 ppm.

(ii) Rocks. Samples were passed through a jaw crusher, split, and a portion ground using a tema mill for 15 minutes prior to analysis for Cu, Pb, Zn and occasionally Fe and As using the methods described for soil samples.

(iii) Stream waters. These were analysed for Cu and Zn by AAS without further sample preparation. If high Cu or Zn was recorded Pb was also sought. Detection limits were approximately Cu 0.01 ppm, Zn 0.01 ppm, Pb 0.05 ppm.

(iv) Stream sediments. These were dried and then ground for 30 minutes, giving a grain size of approximately 300 mesh (0.05 mm). Samples were analysed for Cu, Pb and Zn using the method described for soils. Arsenic was determined by X-Ray Fluorescence Spectrometry after making a pellet by mixing 12 g of sample with 3 g of 'elvacite' and pressing in a die. Other elements (V, Cr, Mn, Fe, Co, Ni, Mo, Sn and Ba) were all determined by Optical Emission Spectrography. Detection limits were approximately Cu 3 ppm, Pb 5 ppm, Zn 5 ppm, As 2 ppm, Cr 10 ppm, V 10 ppm, Fe 0.5%, Mn 50 ppm, Co 10 ppm, Ni 10 ppm, Mo 1 ppm, Sn 5 ppm and Ba 100 ppm.

(v) Panned concentrates. Samples were dried, mixed and split. A 12 g subsample was taken and ground in a tema mill for 5 minutes with 3 g of 'elvacite' before pelletising and analysis by X-ray Fluorescence Spectrometry for the following elements, with detection limits in ppm, where known, given in brackets: Cu (6), Pb (13), Zn (3), Ba (27), Mn (6), Ni (5), Sn (9), Sb (11), Ce (21), Fe and Ti.

In all analytical work, precision and accuracy were monitored by replicate sampling, re-analysis of random samples, and the inclusion of standard in each group of samples.

DATA ANALYSIS

To save space raw data are not presented in this report and only a statistical summary of the results has been given for each area. The raw

data are held in the Keyworth Office of IGS and can be made available on request. As the majority·of element distributions tended to a lognormal form the geometric mean and geometric deviation (i.e. the antilog of the standard deviation of log transformed data) are quoted in the summary of results. The value of the geometric mean + two geometric deviations is also quoted as this has been used as the threshold level by some authors. Median values are also quoted, as this is considered the best estimate of the central tendency of the sample population when, as is often the case, it has an imperfectly defined form. The arithmetic mean and standard deviation are quoted as they are perhaps the best known and most commonly used sample population para- meters, although they are of little use here except for comparison with quoted means from other sources.

Only elementary statistical methods have been used and there has been little scope to study inter-element relationships in many areas because of

    (i)   the small number of samples in each group in many areas,

    (ii) the small number of variables determined in soils (which formed the bulk of the samples), and

    (iii) the complicated distributions shown by many variables.

Except when sample numbers were very small, histograms and cumulative frequency curves were plotted for each element in a group of data. Anomaly levels were set whenever possible from the evidence of the cumulative frequency plots using the methods described by Lepeltier (1969), Parslow (1974) and Sinclair (1974). If cumulative frequency curves did not clearly delineate anomalous sample populations, then histograms were used to look for discontinuities in the results at levels which might be significant in terms of mineralisation. Failing any evidence of breaks in the data, anomalies were more arbitrarily defined on percentile levels and mean plus standard deviation (or geometric mean + geometric deviation) levels, with regard to the general level of the results and levels defined as anomalous in other similar areas.

The majority of results are plotted graphically along traverse lines as this (a) allows instant visual recognition of high values, (b) gives an idea of inter-element relationships, (c) allows recognition of high values which might not be anomalous in terms of the whole area but may be of significance in terms of the immediate environ- ment, and (d) shows overall trends along traverses. It is intended that this empirical approach be used in conjunction with the numerical values defined statistically, the latter providing a level for comparison between areas and a rigorous method of defining significant anomalies.

When sample numbers in a given area were very small, anomalies were determined by comparison with larger, similar sample popula- tions. Rock chip results were compared with the total sample of the rock-type collected from everywhere within the Harlech Dome and with averages quoted for various rock types in the literature (Turekian and Wedepohl, 1961; Vinogradov, 1962; Taylor, 1964; Carmichael, Turner and Verhoogen, 1974) to give a rough guide to element levels, but detailed comparisons were not possible because of the uncertain sample populations and the use of a single descriptor (the mean) for the reference population whose distribution was unlikely to be normal.

Drainage sample anomaly levels used are those determined for the reconnaissance drainage survey of the Harlech Dome. Threshold levels were determined from cumulative frequency plots of results from approximately 400 sample sites over the whole of the Harlech Dome, but are of a provisional nature because some of the results (about 10% for most elements in sediments and concentrates, but 50% in the case of arsenic in sediment) were not available when the calculations for this work were carried out.

Enclosure 1 Map showing location of areas covered by detailed investigations.

Scale approx. 1 : 50,000

The types of investigation carried out in each area are indicated as follows:-

G   Geochemical survey

GEOPHYSICAL SURVEYS:

EM   Electromagnetic induction

M   Magnetic

R   Resistivity

VLF   Very Low Frequency

IP   Induced Polarisation

Enclosure 2 Simplified solid geological map of the Harlech Dome and adjacent areas.
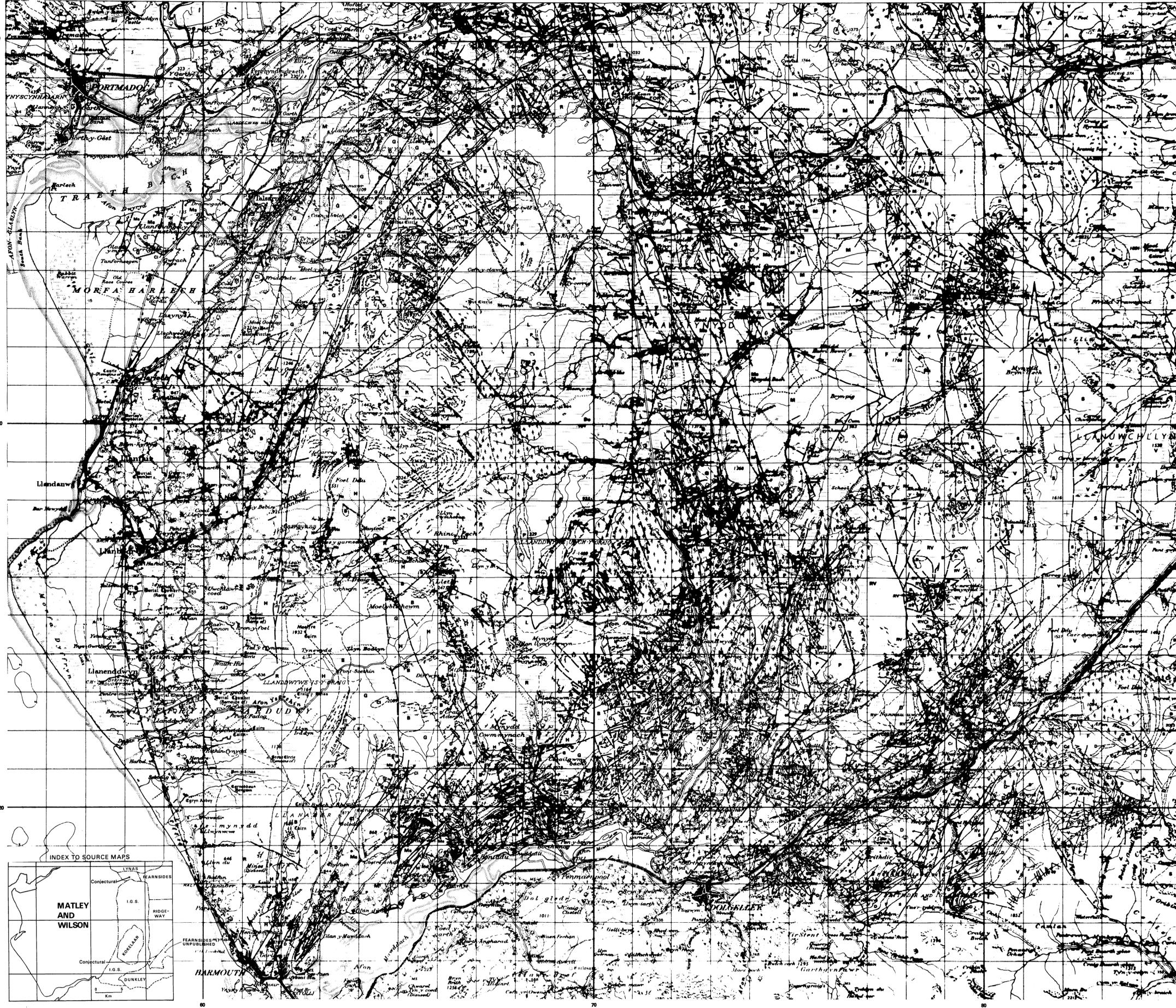
ENCLOSURE 2

SIMPLIFIED SOLID GEOLOGICAL MAP OF THE
HARLECH DOME AND ADJACENT AREAS

Scale approx 1 : 50,000

Consisting of the Harlech (135) 1 : 50,000 Sheet and parts of the
Barmouth (149), Bala (136), Snowdon (119), Corwen (120) sheets

Compiled by R.J.Follows from published and unpublished
maps of the Institute of Geological Sciences; and from the
maps of P.N.Dunkley, W.G.Fearnsides, B.P.Kokelaar,
B.D.T.Lynas, C.A.Matley and T.S.Wilson, and J.Ridgeway.
Harlech and Bala 1 : 50,000 Provisional sheets are in preparation
for publication by I.G.S.

Topographic base photographically produced from
O.S. 1 : 63,360 Sheet 116 (without contours) and is
therefore not true to scale.

SCALE

0 1 2 3 4 5 Kms
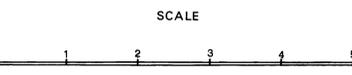
INDEX AND EXPLANATION

Symbols used are unique to this map.

SEDIMENTARY AND EXTRUSIVE ROCKS

Description	Symbol	Member	Formation	Group
Volcanic rocks, including acid to basic tuffs and lavas, tuffite and tuffaceous mudstone	V			Aran Volcanic Group (ORDOVICIAN)
Sedimentary rocks, including Allt Lwyd Formation (with Garth Grit at base), volcaniclastic sediments of the Offrwm, Benglog & Craig y Bwlch Volcanic formations; shale & siltstone of the Caneaid Iago Formation (including Henllan Ash Member), mudstone & siltstone of the Nant Hir Fm.	S			Aran Volcanic Group
Andesitic basalt & volcanic breccia with minor dacite, tuff & tuffaceous mudstone	RV			Rhobell Volcanic Group
Grey siltstone and mudstone.	Cr	Dol-cyn-afon Member	Cwmhesgen Formation	(CAMBRIAN)
Dark grey-black mudstone and siltstone.	Cd	Dolgellau Member	Cwmhesgen Formation	
Grey silty mudstone, thinly interbedded with sandstone, showing similar structures to Vigra Flags.	F		Ffestiniog Flags Formation	Mawddach Group
Dark grey mudstone.	M	Penrhos Shales	Maentwrog Formation	
Grey mudstone interbedded with sandstone up to 1m thick ("ringers" of Matley and Wilson), often showing slump-bedding, cross-bedding and ripple marks.	Ms	Vigra Flags	Maentwrog Formation	
Dark grey mudstone.	Cl		Clogau Formation	
Green, grey, purplish-grey mudstone with several thick units of coarse sandstone.	G		Gamlan Formation	
Grey, grey-green, thickly bedded coarse sandstone with sporadic mudstone bands and pebbly beds.	B		Barmouth Formation	
Bluish/greenish grey mudstone, often striped, with sporadic thin beds of sandstone. Ore Bed is near base. Manganese Sandstone (Hs) locally thick.	H, Hs		Hafotty Formation (Manganese Group of Matley & Wilson)	Harlech Grits Group
Grey, grey-green, thickly-bedded, medium-coarse-grained sandstone with mudstone bands and pebble beds.	R		Rhinog Formation	
Blue/purple-grey cleaved mudstone with some green bands. Sandstone bands are rare.	L		Llanbedr Formation	
Green-grey siltstone and fine-medium grained feldspathic sandstone, commonly finely laminated. Some coarse pebbly beds.	Do		Dolwen Formation	

INTRUSIVE ROCKS

Symbol	Description
D	Dolerite including quartz and hornblende-dolerite.
P	Intermediate intrusions, including microdiorite, quartz-diorite, quartz-microdiorite, microtonalite, intermediate basic intrusion complexes.
A	Acid intrusions; including quartz-latite, rhyolite

Geological boundary, Solid.

Fault, crossmark indicates downthrow side.

Linear feature, presumed to be fault (where no displacement is shown).

Lode.

INDEX TO SOURCE MAPS

MATLEY AND WILSON

LYNAS
FEARNSIDES
I.G.S.
RIDGEWAY
Conjectural
KOKELAAR
I.G.S.
Conjectural
FEARNSIDES UNPUBLISHED
DUNKLEY

0   5   Km
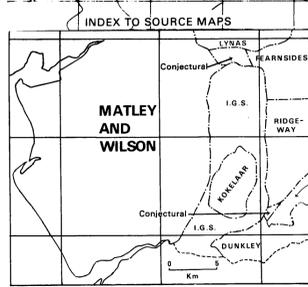
Enclosure 3   Map showing the location of
old workings, excluding those for Manganese,
in the Harlech Dome area.
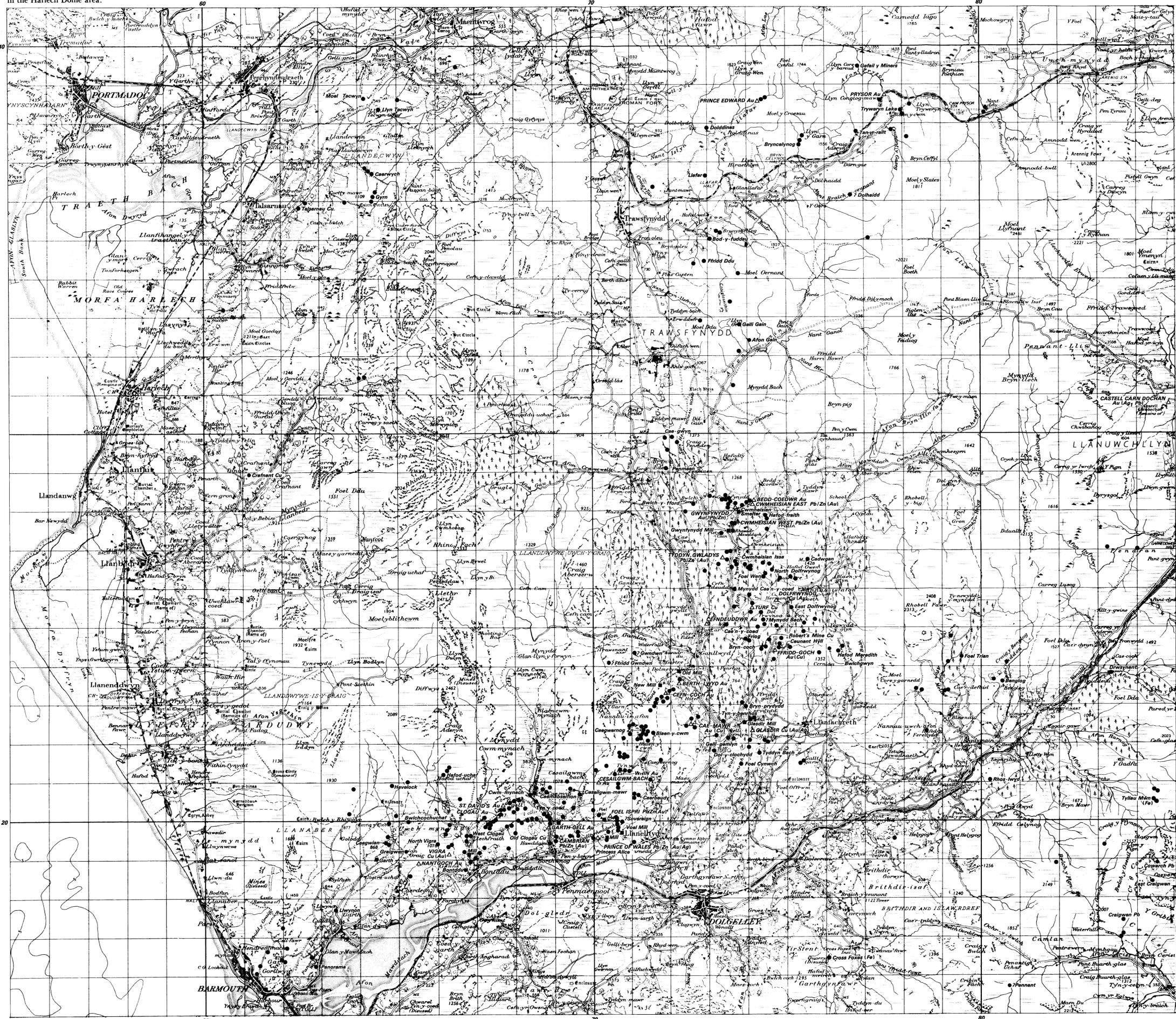
ENCLOSURE 3

MAP SHOWING LOCATION OF OLD WORKINGS, EXCLUDING THOSE FOR MANGANESE, IN THE HARLECH DOME AREA

Scale approx. 1 : 50,000

Topographic base photographically produced from OS: 1 : 63,360
Sheet 116 (without contours) and is therefore not true to scale.

Compiled by R.J.Follows.

SOURCES:

Ordnance Survey six-inch sheets "County Series" (Mer' nethshire. Revision of 1899 - 1900)

Morrison, T.A.	1975.	Goldmining in Western Merioneth Merioneth. Historical & Record Society.
Hall, G.W.	1975	The Gold Mines of Merioneth. Griffin Publications Gloucester
Foster-Smith, J.R.	1977.	The Mines of Merioneth British Mining No. 6
Readwin, T.A.	1862.	On the gold-bearing strata of Merionethshire. Brit. Ass. Adv. Sci.
Dewey, H. and Eastwood, T.	1925.	Copper ores of the Midlands, Wales, the Lake District and the Isle of Man. Spec. Rep. Min. Res. G.B. XXX.
Dewey, H. and Smith, B.	1922.	In. Lead and zinc ores in the Pre - Carboniferous rocks of West Shropshire & North Wales. Part II. North Wales. Spec. Rep. Min. Res. G.B. XXIII.

Bick, D.E. 1978. The old metal mines of Mid-Wales, Part 5; Aberdovey,
Dinas Mawddwy & Llangynog.
Pound House, Newent, Glos.

Field maps of P.M. Allen, R.J. Follows, A.A. Jackson, B.P. Kokelaar,
B.D.T. Lynas, P.N. Dunkley.

EXPLANATION:

CLOGAU
△   Main entrance to named mine which had some recorded
gold production or was a main producer of copper.

Hafod-uchaf
●   Surface expression of working (or group of workings)
including adits, shafts, trail pits, and surface excavations
(open stopes etc). Names given where known.

■   Mill site

Note: The name which is given beside a single locality, would
usually have referred to the sett and would have covered
all the workings in it.

Metals known to have been worked are given beside
mine names.

Au   Gold
Cu   Copper
Pb   Lead
Zn   Zinc
Ag   Silver
Fe   Iron

Alternative mine names:-

The names on the right are alternatives to those,
given on the left which are used on the map.

△	
Beddcoedwr	Marina
Cambrian	Maestryfer, Taincynhauaf
Caemabseifion	East Clogau
Cefn coch	New California
Cefndeuddwr	Eden
Cwmheisian East	Cwmheisian Ucha
Cwmheisian West	Cwmheisian Ganol
Gwynfynydd	Gwyn, Morgan, Mount Morgan, British Gold Fields
Foel Ispri	Imperial, Moel Ispri, Voel Ispri
Prince Edward	Bwlch y Llu, Moel Croesau
Prince of Wales	Hafod y Morfa
Prysor	Cwmprysor, Arenig
Turf	West Dolfrwynog
Wnin	Wnion, Union, Ty'n y Llwyn, Sovereign

Benglog	Drwys-y-nant
North Dolfrwynog	Moel Hafod Owen
Talsarnau	Talsarora
Galligain	Pen y stryd
Princess Alice	West Prince of Wales
West Clogau	Llechfraith
Drwsynant	Princess Alice
Cowarch	Penyrallt

ENCLOSURE 4

MAP SHOWING LOCATION OF LODES
IN THE HARLECH DOME AREA

Scale approx. 1 : 50,000

Topographical base photographically produced from OS: 1 : 63,360
Sheet 116 (without contours) and is therefore not true to scale.

Compiled by R.J.Follows.

SOURCES:

Andrew, A.R. 1910. The Geology of the Dolgelley Gold-belt,
North Wales, Geol. Mag., 7, pp. 159 - 71, 201 - 11, 261 - 71.

Gilbey, J.W.G. 1969. The mineralogy, paragenesis and structure of
the ores of the Dolgellau Gold Belt, Merionethshire, and
associated wall - rock alteration. Ph.D. Thesis. Univ. Lond.

Field maps of C.Matley and T.S.Wilson, P.M.Allen, R.J.Follows.

EXPLANATION:

⌒⌒⌒ Quartz vein at surface

◌ Outcrop of Clogau Formation

ENCLOSURE 5

HARLECH DOME AERORADIOMETRIC SURVEY

(TOTAL GAMMA COUNT)
UNCORRECTED DATA

Key

——	350 cps
——	550 cps
▨	>700 cps
H	High
L	Low

All values approximate.

Full scale deflection 6000 cps

SCALE   1:50,000

N

Enclosure 6 Simplified contour map of airbourne electromagnetic survey of Harlech Dome area.
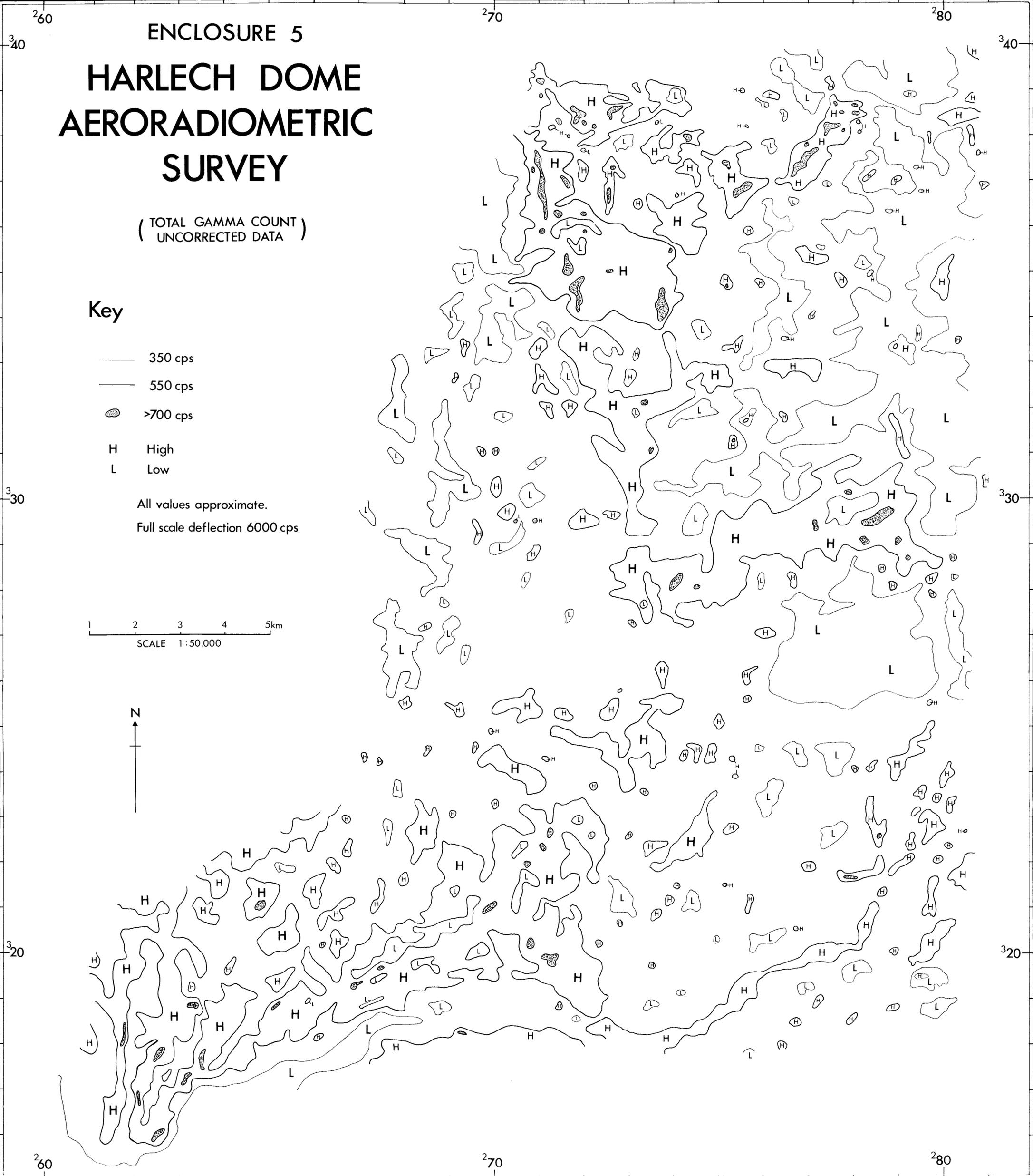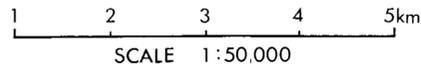
Enclosure 6
Simplified contour map of airborne electromagnetic
survey of Harlech Dome area

0 1 2 3 4 5
Kilometres

N

Contours of electromagnetic field strength
(In-phase component) at 50 p.p.m. intervals

Indicates low

Enclosure 7
Simplified contour map of aeromagnetic survey
of Harlech Dome area

0   1   2   3   4   5

Kilometres

N
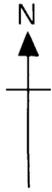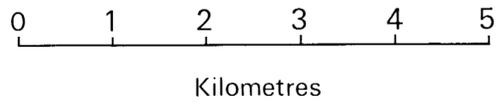
——50—— Contours of magnetic field strength at 50 nT intervals

Indicates magnetic low

Values are referred to a linear field for the British
Isles at epoch 1955·5 given for any point by the
equation :-

$$T = 2·1728\,Y - 0·259\,X + 47033\,nT$$

where Y, X are respectively the N.G. northing and
easting for that point.