Base-metal and gold mineralisation in north-west Anglesey, North Wales

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Mineral Reconnaissance Programme Report 99

BRITISH GEOLOGICAL SURVEY

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DATA PACKAGE

This report provides an outline of mineral exploration surveys and subsequent drilling carried out by BGS in north-west Anglesey as part of the Mineral Reconnaissance Programme sponsored by the DTI. A comprehensive data package containing the results of this work is available at a current 1989 cost of £1000 sterling plus VAT. It includes:

A   Consultation with available BGS staff who carried out the investigations.

B   The opportunity to examine drill-cores, thin sections and microflora samples obtained during the investigation.

C   A data package containing the items listed below.

1   Lithological logs of boreholes.

2   Graphic borehole logs, summarising lithology, mineralisation, geophysical logs and chemical analyses of drill core and drill sludge.

3   Mineralogical and palaeontological reports on samples taken from the borehole cores.

4   Mn, Fe, Co, Ni, Cu, Zn, As, Mo, Ba and Pb analyses for 276 borehole core samples.

5   Au analyses for 129 borehole core samples.

6   Cu, Zn and Pb analyses for 2028 soil samples.

7   Fe, Cu, Zn and Pb analyses for 99 rock chip samples.

8   Geophysical (IP) survey data-sheets.

9   Maps showing the location of anomalies arising from the reconnaissance soil sampling survey.

10   1:10 000 scale maps showing the location of soil anomalies in the Carmel Head area, the contoured results of gradient-array IP and VLF(EM) geophysical surveys, rock sample sites and the location of boreholes.

11   1:2000 scale maps showing the Cu, Zn and Pb analyses for detailed soil surveys carried out across four geophysical anomalies.

12   Notes on the principal geophysical (IP) and geochemical (soil) anomalies.

Enquiries regarding the data package should be made to Dr D J Fettes, British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, or Mr J H Bateson, British Geological Survey, Keyworth, Nottingham NG12 5GG.

SUMMARY

A programme of mineral exploration has been carried out in north-west Anglesey. The objective was to assess the mineral potential of the area with special reference to sulphide deposits of similar type to those exploited at Parys Mountain. The results of the investigation indicate the presence of hitherto unknown base-metal mineralisation, accompanied locally by gold.

The area was selected for investigation following a geological appraisal of the Parys Mountain deposit and the principal controls on mineralisation. Fifteen widely spaced reconnaissance traverses were sited in the area on the basis of the known geology and controls on mineralisation, and soil samples collected along the lines at 20 m intervals.

Airborne electro-magnetic and magnetic geophysical data for the area were assessed with the assistance of ground measurements from the sites of prominent anomalies. Ground orientation surveys across known mineralisation were also carried out using a range of techniques. It was found that the airborne electro-magnetic (EM) data were confused by transmitter interference and that the magnetic data was of very limited use in detecting mineralisation. In contrast, very low frequency electro-magnetic (VLF-EM) ground survey data contained strong features related to mapped faultlines and steeply dipping geological boundaries, and induced potential (IP) techniques were sensitive to known mineralisation. Consequently, IP measurements were taken along 12 reconnaissance traverses, coincident or close to the soil sampling lines.

Both the IP and soil survey data indicated the presence of anomalies related to mineralisation and, as a result, more detailed IP and soil sampling surveys were carried out in the area between Carmel Head and Llanfairynghornwy. VLF-EM measurements were also taken across the principal IP anomalies in this area.

The sources of seven of the geophysical (IP) anomalies were investigated by a total of fifteen boreholes ranging in depth between 32 m and 122 m. These boreholes showed conclusively that the anomalies were related to buried base-metal sulphide (Cu, Zn, Pb) mineralisation, locally accompanied by gold. The mineralisation is polyphase: syngenetic/diagenetic pyrite and disseminated pyritisation (possibly associated with sericite alteration) events are followed by hydrothermal mineralisation characterised by quartz ± carbonate ± chalcopyrite ± sphalerite ± galena ± pyrite veins and impregnations. This mineralisation occurs in at least five separate structures whose style and location confirm the validity of the geological model. Geochemical and geophysical anomalies not investigated by drilling suggest the presence of further mineralised structures and extensions to those intersected by drill-holes.

INTRODUCTION

Anglesey, an island of about 750 km², forms the north-west corner of Wales and is separated from the mainland by the Menai Strait (Figure 1). The island is characterised by the gentle rolling topography of a peneplain with a few isolated hills (monadnocks) rising to between 150 and 180 m and the highest, Holyhead Mountain, reaching 220 m. The island has a temperate climate and almost all the land is farmed, much of it is under grass, but a few areas of high ground and/or poor soil are covered with heather. The population is distributed widely amongst scattered farms, hamlets, villages and a few small towns. Good rail and road communications exist with the rest of the United Kingdom. Other facilites include a deep water harbour at Holyhead, and an airfield. The few major industrial developments include an aluminium smelter and a nuclear power station.

Mining and mineral exploration in Anglesey

During the late 18th and early 19th centuries Anglesey contained the richest copper mines in Europe at Parys Mountain, north-east Anglesey. These mines, which for two decades controlled the world price of copper, lasted for over 130 years, but have been abandoned for about 80 years. It has been estimated (Manning, 1959) that they produced at least 130 000 tons of copper metal, together with lead and zinc. Since 1961 Parys Mountain has been prospected extensively by inclined diamond drilling and there are now (1988) plans in hand to re-start mining for copper, lead, zinc, silver and gold. Present mining reserves are put at 5.3 million tonnes averaging 1.49% copper, 3.03% lead, 6.04% zinc, 2.02 troy ounces/tonne silver and 0.013 ounces/tonne gold (Gooding, 1988). Previously, Thomas (1972) had indicated some 30 million tons of ore, averaging 0.76% copper, between 250 and 650 m below the surface.

The Parys Mountain deposits have prompted mineral exploration elsewhere on Anglesey, but the only data published are those collected for the Mineral Reconnaissance Programme (MRP) funded by the Department of Trade and Industry (DTI). As part of this programme regional-scale geophysical and geochemical surveys were carried out to provide base-line mineral exploration data for Anglesey. An airborne geophysical survey across the northern part of the island was described by Smith (1979) and the results of a stream sediment geochemical survey, together with a reconnaissance field study of known mineralisation, were reported by Cooper, Nutt and Morgan (1982).

Selection of the survey area

Many of the borehole cores, records and assaying data produced during the prospecting activities at Parys Mountain during the last two decades were made available to the British Geological Survey (BGS). This data-base provided a valuable source of information and useful starting point when the MRP was extended to investigate the metalliferous mineral potential of Anglesey. Assessment of the geology and known mineralisation, together with the results of the reconnaissance stream sediment survey, indicated a number of areas, particularly in northern Anglesey, where the potential existed for base-metal mineralisation controlled by factors similar to those occurring at Parys Mountain. It was, therefore, decided to follow this line of investigation by carrying out
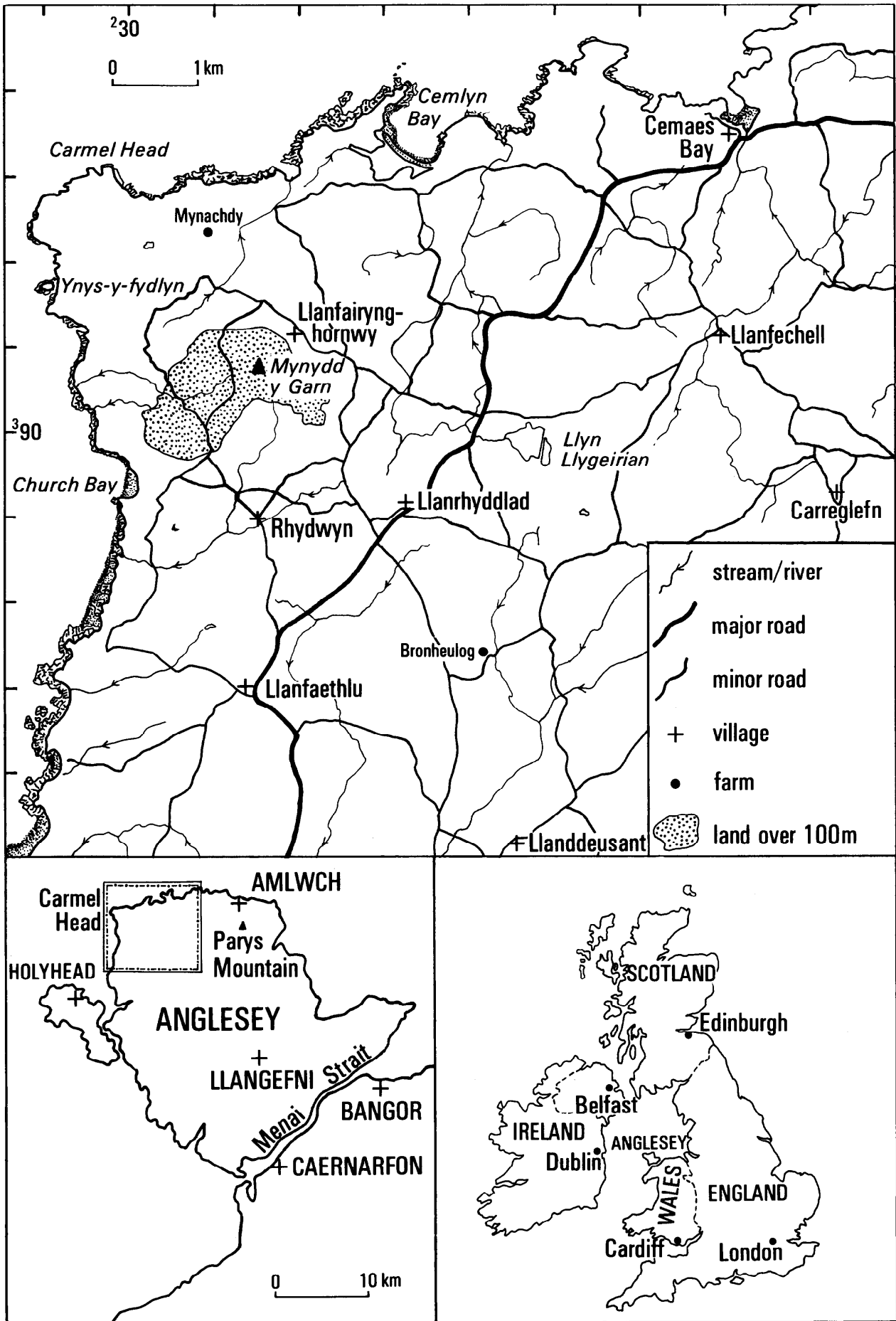
Figure 1 Location of the survey area

ground geophysical and geochemical surveys across north-west Anglesey. The aim was to identify any anomalies which might be related to mineralisation and to drill these so as to test the mineralisation model.

In assessing the chances of finding economic mineralisation in the north-west corner of Anglesey similar to that at Parys Mountain it has to be borne in mind that, after many centuries of looking, the successful discovery of workable mineral deposits at Parys Mountain took eight years of intensive shaft sinking and related exploration. Following this discovery over a hundred years of mining and exploration took place before the last ore body to be mined was discovered. Similarly, in the modern era, continuous intensive exploration and drilling at Parys Mountain, over the last two decades, has resulted in the location of a number of major new ore bodies whose assessed tonnage is greater than the total output of the former Parys Mountain mines. Nevertheless over 75% of the exploration boreholes drilled failed to find economic mineralisation, even though the geological criteria for mineralisation were present. All this work took place in an intensively mineralised area less than one third the size of the studied area.

Location and physical features of the survey area

The area lies within Ordnance Survey 1:50 000 Sheet 114 (Anglesey). It occurs some 11 km north-east of Holyhead and 14 km west of Amlwch and Parys Mountain (Figure 1). The ground is covered by the BGS 1:50 000 Anglesey Special Sheet (Solid and Drift Editions).

Topographically, the land rises to 170 m to form the rounded hill of Mynydd y Garn, but much of the ground lies between 30–75 m, except to the north-east where it falls off to between 10–25 m. To the north and to the west the district is bounded by steep to vertical sea cliffs.

The ground consists mainly of rocky ridges, aligned generally east-west, with a thin cover of soil. Between the ridges there are thin infillings of boulder clay. This glacial deposit forms a more extensive tract in the north-east and south of the area. A number of small streams cross the region, often flowing through small hollows containing alluvium, before falling to the sea through steep gorges. Vegetation, other than grass, is sparse but an enclosure of thick forest runs east-west across the ground inland from Ynys-y-fydlyn. The area is traversed by narrow winding roads and populated by isolated farms, with the small village of Llanfairynghornwy lying at the foot of Mynydd y Garn (Figure 1).

Previous research

Early research into the geology of Anglesey culminated with the publication of the Geological Survey memoir (two volumes) and maps (Solid and Drift) covering Anglesey (Greenly,1919; 1920). A later paper by Greenly (1923) modified some of his earlier views and mapping in the north-west of Anglesey. The memoir includes a comprehensive account and bibliography of previous research, while an outline of later research was given by Cooper, Nutt and Morgan (1982). This was followed by Gibbons (1983), with a review paper on the Mona Complex of Anglesey. Within the area of north-west Anglesey the only other work of local value is that of Barber and Max (1979) and Bates (1972; 1974).

Research into the non-ferrous mineralisation of Anglesey has concentrated almost entirely on the area of Parys Mountain and very little has been published on the mineralisation occurring throughout the rest of the island. Cooper, Nutt and Morgan (1982) gave a brief summary of this work when describing the results of their own reconnaissance studies

GEOLOGY

The geology of Anglesey ranges from the complex to the simple and is amongst the most diverse in the whole of the United Kingdom, relative to the size of the island. Ranging in age from the Precambrian, through much of the Palaeozoic, there is a great variety of rock types and geological structures, together with a strong development of igneous rocks in all but the Upper Palaeozoic strata. Much of the island is covered by superficial deposits, especially those of glacial origin, boulder clay with sands and gravels. Alluvium, both marine and non-marine, is significant, while blown sand is a major deposit along the coast, especially in the west and south-west.

The BGS 1:50 000 geological map of Anglesey by Greenly (1920, reprinted in 1972 and simplified in Figure 2), proved to be adequate for the investigations undertaken in north-west Anglesey. No attempt was made to remap the ground systematically, although a field examination of the rocks resulted in interpretations differing from those of Greenly (1919). This was most evident when dealing with the stratigraphy, correlation, and structure of the rocks in the investigated area.

For descriptive purposes in this short account, the rocks of north-west Anglesey may be divided into three major divisions, the Mona Complex, Ordovician strata and igneous intrusions

Mona Complex

The Mona Complex, ranging in age from Precambrian to Cambrian and probably into the Ordovician, is part of the largest tract of exposed medium to high grade metamorphic rocks in the United Kingdom south of the Scottish Highlands. Greenly (1919) and later Shackleton (1975) divided the Mona Complex into a Bedded Succession (the Monian Supergroup) and the Gneisses or Gneissic Group. The gneisses were subdivided by Greenly (1919) into granitic, hornblende and biotite gneiss. Within the survey area the Bedded Succession consists mainly of sedimentary melanges (olistostromes) within Greenly's Gwna Group and volcanic deposits within his Church Bay Tuffs. Other deposits within the survey area include turbidites in Greenly's New Harbour and South Stack groups, and tuffaceous sandstones in the Skerries Grits. The rocks of the Bedded Succession have suffered low grade metamorphism being in the main metapelites and meta-psammites, slates or phyllites. The metamorphic grade of the Bedded Succession ranges up to the lower greenschist facies.

Throughout Anglesey Greenly (1919) and, later, Barber and Max (1979) regarded the gneisses as metamorphosed basement on which the sedimentary rocks of the Bedded Succession were deposited. However, Shackleton (1969; 1975), and, in part, Beckinsale and Thorpe (1979, p.438) interpreted the gneisses as being the highly metamorphosed parts of the Bedded Succession. The origin of the gneisses within the studied area is uncertain, for they are in either tectonic or unconformable contact with the Ordovician and tectonic contact with the Bedded Succession. Field evidence obtained during the investigations reported here suggests that they have arrived in their pre-
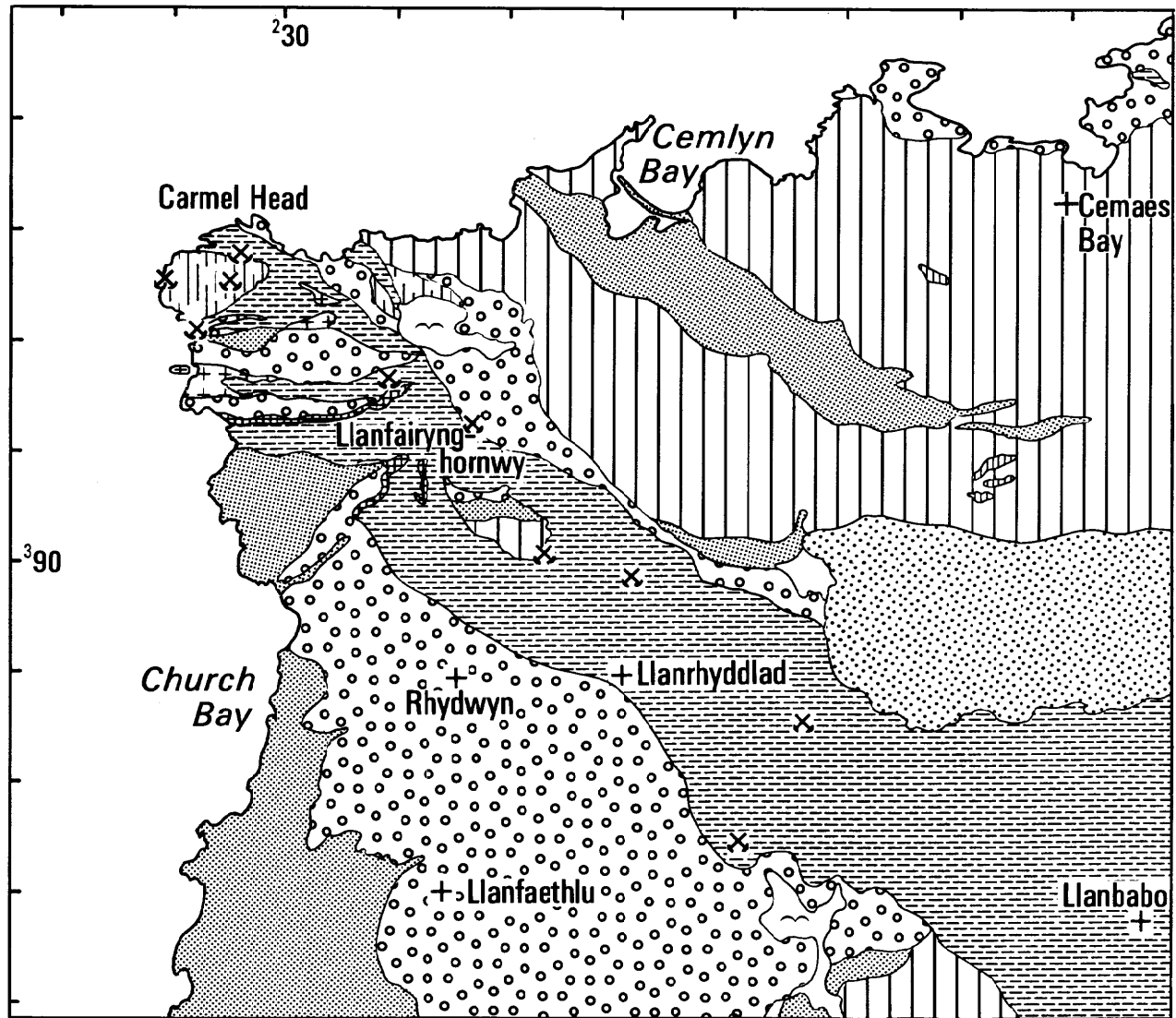
RECENT

	Alluvium
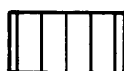
ORDOVICIAN

	Siltstones and mudstones with sandstones and conglomerates locally.

PRECAMBRIAN - ?ORDOVICIAN

	Gwna Group

	Fydlin Group

	Skerries Group (Church Bay Tuffs and Skerries Grits)

	New Harbour Group

	South Stack Group

	Gneiss (undivided)

INTRUSIONS

	Dolerite

	Ultrabasic rocks

✗	Mines and trials for base metals

Figure 2 Simplified geological map of north west Anglesey

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Table 1 Stratigraphic sequence in Anglesey (after Barber and Max, 1979)

Age	Structural discontinuity	Lithostratigraphic division		
	Orogeny			
Silurian (Llandovery)		Shales with thin tuff bands		
Ordovician (Arenig–?Caradoc)		Shales/mudstones with conglomerates, sandstones, oolitic ironstones, breccia beds and acid tuffs (includes Fydlyn Group)		
	Unconformity			
?Cambrian		Gwna Mélange — 2 Skerries Grits and Shales Gwna Mélange — 1 Church Bay Tuffs		
	Thrust or Unconformity		Bedded Succession	
Uncertain		New Harbour Group		
	Thrust			
Uncertain		Rhoscolyn Formation Holyhead Quartzite Fm. South Stack Formation	Holy Island Group	
	Orogeny			
Uncertain (Precambrian?)		Gneisses		

sent position as tectonic slices.

Although Barber and Max (1979) erected a stratigraphic sequence for Anglesey (Table 1), it has not been possible to erect a simple succession for the rocks within the Bedded Succession of the district, because nowhere is there a continuous sequence. This difficulty is further complicated by the fact that there are a number of mélange horizons. The mélanges are interbedded with non-mélange deposits, mainly tuffs and turbidites, some of which pass laterally into mélange. Although Greenly (1919, pp.551–552), described some Ordovician mélanges he believed that most of them were Precambrian in age and included them in his Gwna Group. Barber and Max (1979, fig. 2) proposed two major horizons of Gwna mélange (Table 1), while Wood (1979) indicated that there were several mélange horizons. A further complication is that during this survey a late Cambrian to early Ordovician microflora was obtained from borehole samples of a mélange mapped as Gwna mélange by Greenly (Nutt and Smith, 1981b). Elsewhere on Anglesey Lower Cambrian microfossils have been obtained from the Gwna mélange (Muir and others, 1979). Lithologically some of the Ordovician mélanges in the studied area are identical with some of the Gwna mélanges, as was noted by Bates and Davies (1981, p.14). Thus Greenly's Gwna Group has apparently little stratigraphical significance, including as it does an extensive range of lithologies of widely differing age. Likewise the passage of so-called Gwna mélange into the non-mélange deposits of the Church Bay Tuffs and Skerries Grits as well as the Ordovician sediments casts doubts on all the former proposals for the stratigraphy of the Bedded Succession in north-west Anglesey, including that shown in Table 1. Further detailed work is required to resolve these problems.

Ordovician

The Ordovician rocks of north-west Anglesey are mainly

sedimentary with at least one and possibly two horizons of volcanic tuff (see below). The principal rock-types include sandstones and conglomerates, mudstones, siltstones and slates, breccia beds and mélanges, oolitic ironstones and acid vitric tuffs. They are Llanvirn or Caradoc in age. Except for the volcanic deposits, a modern account of the Ordovician sedimentary rocks in the north-west of Anglesey has been given by Bates (1972). New evidence for the age of some of these rocks was obtained from boreholes during this survey: samples of the Porth-y-Nant Shales of Bates (1972, fig.6) from near to the type locality, which Bates (1972, p.54) indicated were probably Caradoc in age, yielded a Llanvirn microflora.

Felsitic tuffs of the Fydlyn Group (Greenly, 1919), occur above and below so-called Gwna mélange and are interbedded with mélange deposits, including sandstones and pelites, at the type locality of Ynys-y-fydlyn [SH 291 917]. To the east the tuffs are associated with Ordovician sedimentary rocks. Barber and Max (1979) suggested that the acid tuffs of the Fydlyn Group were Llanvirn/Caradoc in age, equivalent to the volcanic rocks of Parys Mountain. Bates (1979) agreed that this suggestion could be true, but indicated that the tuffs could equally well belong to the Arvonian. A small number of chemical analyses by BGS on Fydlyn and Arvonian acid tuffs do not support the latter point of view. Comparisons of the Fydlyn data with that from Parys Mountain (Thanasuthipitak, 1974) are inconclusive, partly because there is a shortage of 'immobile' trace element analyses for the Parys Mountain rocks.

The field evidence, in the type area, on the relationships of the Fydlyn tuffs to the Ordovician sedimentary rocks is difficult to interpret unequivocally (see also Greenly, 1919, p.464), although the tuffs appear to pass up conformably into the Ordovician sediments. However, to the west-south-west of Mynachdy Farm, exposures [SH 304 922] of undisturbed, but cleaved, acid vitric tuffs occur interbedded with Ordovician mudstones. These exposures were interpreted by Greenly (1919, p.534) as the

outcrop of an acid sill. This relationship of undisturbed (i.e. non-slumped) tuffs in close proximity to disturbed (i.e. slumped) tuffs is a feature of the volcanic deposits of Parys Mountain (Nutt, Ineson and Mitchell, 1979).

Structure

Structurally the area is dominated by east-west striking folds, faults and thrusts. The folds are generally asymmetrical with axial planes dipping northwards. Likewise, east-west striking slaty cleavage usually dips northwards, as do the thrust planes. The east-west folds and faults are cut off by later north-westerly trending faults, some of which exhibit strike slip movement. A recent detailed account of the structures in the Lower Palaeozoic rocks has been given by Bates (1974). He also described the structural evolution of the area during the end-Silurian and later regional deformational events.

It is not proposed to discuss in detail the position of Anglesey within plate tectonic models (see Gibbons, 1983). Suffice to say that the pre-Ordovician setting of Anglesey appears to have been within a fore-arc environment subjected to collage tectonics, but from the Ordovician onwards, during the Lower Palaeozoic, Anglesey was part of the Welsh Marginal Basin in a back-arc setting (Kokelaar and others, 1984).

Igneous intrusions

Intrusions within the studied area consist mainly of dolerite dykes, sills and irregularly shaped, boss-like bodies. Other, more basic, dykes of hornblende picrite occur in the north-east of the area.

Intrusive igneous activity took place during the end-Silurian tectonism. Field evidence indicates that some of the dolerite intrusions post-date the folding and cleavage development in the Ordovician sedimentary rocks, but pre-date the northerly dipping thrusts and north-westerly trending faults. The age of the hornblende picrites is uncertain, though Greenly (1919, p.515) indicated that they post-dated the dolerites and tectonic activity; Bates (1974) however described some picrite sills which probably pre-dated the folding.

Superficial deposits (drift)

The whole surface of Anglesey bears the mark of glacial activity. During the Pleistocene glaciation the island was completely over-ridden by ice, predominantly from the Irish Sea, moving generally south-westwards. Superficial deposits, chiefly boulder clay, were deposited from this ice.

A belt of ground virtually devoid of superficial deposits extends south-eastwards from Penbryn-yr-eglwys [SH 291 925] across the studied area. Within this belt thin patches of boulder clay may be found between rocky ridges and exposures. To the north-east and south-west of the belt, boulder clay cover is extensive with isolated drift-free areas.

The boulder clay consists mainly of grey clay, with pebbles and boulders, containing seams of gravel. It is generally thin (up to 10 m thick), except where it is infilling hollows or forming drumlins. In these circumstances thicknesses of up to 40 m + have been recorded.

Post-glacial deposits consist mainly of alluvium, both lacustrine and fluvial. The largest area of lacustrine alluvium occurs [SH 313 921] to the south-east of Mynachdy. Further tracts occur along the line of the stream flowing into Llyn y Fydlyn [SH 293 917], while other small deposits are to be found in the south of the area. Fluvial, with some lacustrine alluvium occurs in the south-east of the district, along the line of the un-named river [SH 348 864] flowing south westwards into the estuary of the Afon Alaw.
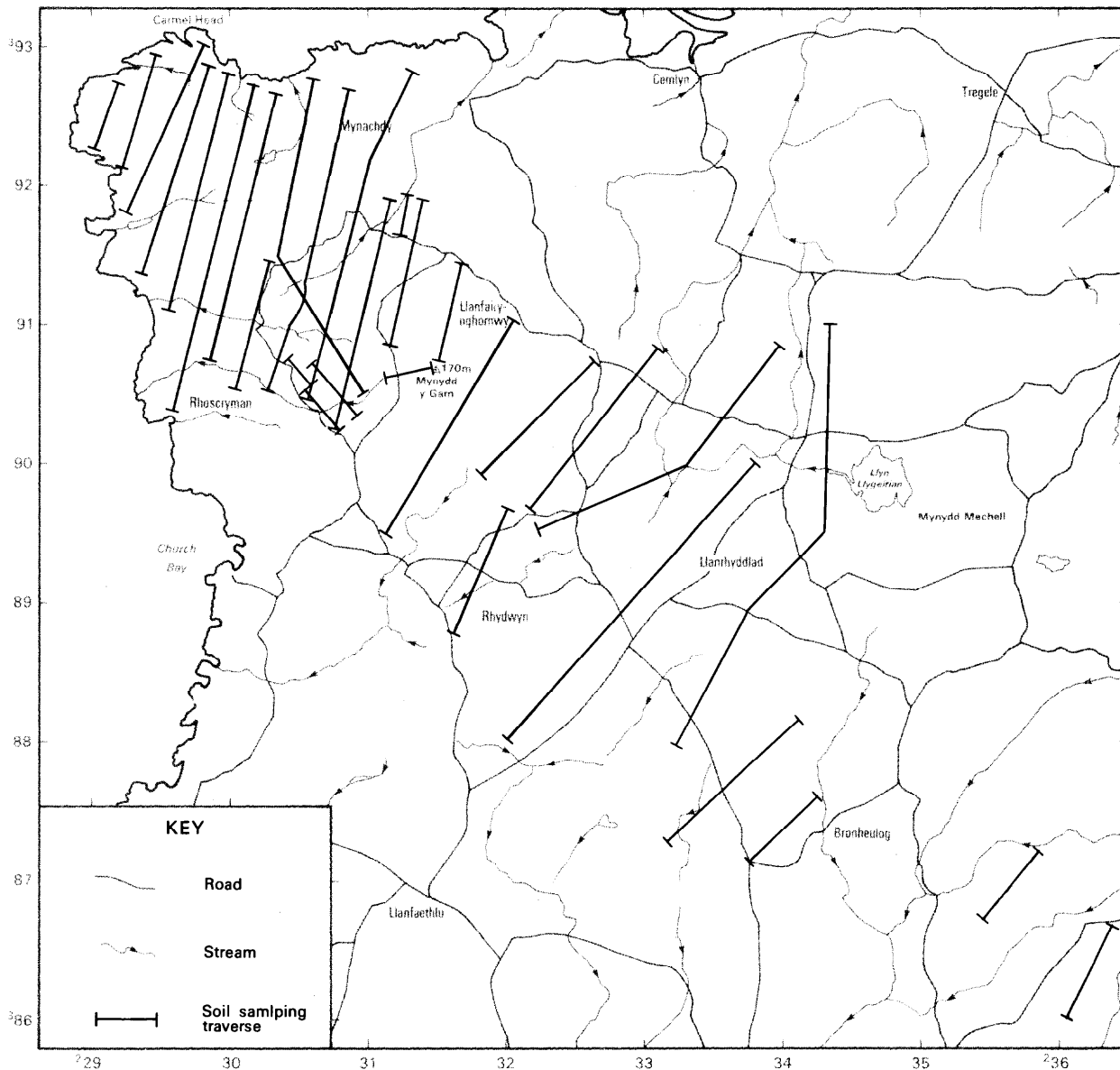
MINERALISATION

Prior to the MRP activities, unpublished work by BGS at and around Parys Mountain had established that the most favourable site for copper, lead and zinc mineralisation was at, or adjacent to, the contacts of acid rocks (igneous or sedimentary) with dark grey to black mudstones or pelites. In addition if the mineralisation intersected basic igneous intrusions, mainly dolerites, there was a marked increase in copper values. It was also noted that the form of mineralisation was generally controlled by the pre-mineralisation cleavage of the host rock, usually the grey to black pelites.

A reconnaissance field survey of the non-ferrous mineralisation of Anglesey (Cooper, Nutt and Morgan, 1982) established that this mineralisation could be divided into three groups on the basis of a number of parameters which included: metals present, the orientation and apparent age of the mineralisation, and the age, lithological and structural control of the host rock. The three groups, identified by their principal ore-metal content, were: (a) copper, (b) copper, lead, zinc and (c) barium (baryte), lead. Only group (b) appeared to be of significant economic importance.

Group b (copper, lead and zinc), well illustrated by the deposits of Parys Mountain but also found elsewhere, is nearly always associated with Lower Palaeozoic rocks. These rocks are mainly sedimentary, but include extrusive acid volcanic rocks and intrusive basic rocks. They may form the hanging wall, the foot wall, or both walls, to the mineralisation. The mineralisation is preferentially developed within Ordovician or Silurian dark grey to black pyritic mudstones or pelites at, or adjacent to, the junction of these dark host rocks with a competent rock originally rich in silica. The competent rocks include lavas, ash-flow tuffs, granite gneisses, sandstones, conglomerates and mélanges rich in silica, particularly sandstone or acid tuff mélanges.

The mineralisation always consists of quartz, pyrite and chalcopyrite; galena and sphalerite are also usually present, either singly or together. While quartz is the ubiquitous gangue mineral, a carbonate (usually dolomite) may be present. This mineralisation generally occurs as lodes, or mineral impregnations forming lens-shaped bodies. The strike of these deposits is usually between east-north-east through east to east-south-east, although at Parys Mountain north striking lodes are also present. These orientations are controlled by Lower Palaeozoic tectonic structures. In many instances mineral deposition clearly post-dates the formation of faults and cleavage in the host rock, a view previously expressed by Bates (1974) although the mineralisation may be cut off by later faulting.

This 'group b' type of mineralisation occurs mainly in the northern half of Anglesey, where it forms belts of mineralisation and metasomatism which may be traced roughly east-west across the island. The mineralisation is considered to be epigenetic, although a volcanogenic (syngenetic) origin has been suggested to explain, at least in part, the Parys Mountain deposits (see review Cooper,

Figure 3 Location of soil survey traverse lines

Nutt and Morgan 1982). On Anglesey evidence of volcanism associated with mineralisation is known only at Parys Mountain and in the north-west corner of Anglesey, the area selected to seek further deposits of this type.

Prior to the detailed investigations reported here, the proven mineralisation (both worked and unworked) in north-west Anglesey was indicated by Cooper, Nutt and Morgan (1982). The locations of old mines and trials are shown in Figure 2. Although the workings were insignificant by Parys Mountain standards the following is a brief indication of their mineralisation.

At the Gadair Mine [SH 295 928] east-west striking copper, lead, zinc mineralisation occurs at the junction of grey to dark grey Ordovician mudstones and slates with granite gneisses. The nearby copper mineralisation of Penbrynyreglwys [SH 295 924 and SH 289 925] appears to have been entirely within the granite gneisses. Gilfach Mine [SH 308 914] worked east-west copper mineralisation where it cuts a dolerite intrusion within Ordovician sedimentary rocks. At the Cefn Du Bach Mine [SH 331 898] the workings for copper appear to have been entirely within Ordovician mudstones. Mynydd y Garn Mine adit [SH 318 913], blocked 105 m in, appears to have been

heading for copper workings occurring at a junction between dark grey Ordovician mudstones with sandstones or mélange. A nearby filled-in shaft, close to the junction, showed evidence of lead mineralisation. To the south-east further workings [SH 323 901] for copper took place in Ordovician mudstones containing fragments of green schist (Mona fragmentals). At the Porth yr Hwch Mine [SH 292 921] workings for copper were directed at a junction between felsitic ash-flow tuffs and Ordovician mudstones. The workings for copper at Bron-heulog [SH 342 874] (Greenly, 1919, p.846) could not be located, but nearby workings for copper, in Ordovician mudstones at Ynys-Gwyddel [SH 347 885], were located. Other mineral excavations in the area (Cooper, Nutt and Morgan, 1982, fig. 3) are small and unnamed.

GEOCHEMICAL SURVEYS

Soil sampling

Reconnaissance soil sampling was carried out at 20 m intervals along 15 north-east trending traverse lines between Carmel Head and Llanbabo. Following analysis, additional lines were sampled to reduce the distance

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between traverses in the areas of greatest interest. The location of all traverse lines is shown in Figure 3. A 0.5 g sub-sample of the minus 80 mesh (0.18 mm) fraction of each soil sample was analysed for Cu, Zn and Pb by atomic absorption spectrophotometry (AAS) following digestion in hot concentrated nitric acid for one hour. Detection limits were: Cu 2 ppm, Zn and Pb 5 ppm.

Table 2 Summary of soil sample analyses

Element	Median	Mean	Maximum	Minimum	Threshold
Cu	20	20.4	530	<2	51
Zn	60	68.5	720	10	101
Pb	30	44.4	1800	<5	71

All results in ppm. For calculating means results less than the detection limit were set at half the detection limit.

A summary of the analytical results for soil samples collected along traverses is given in Table 2. Cumulative frequency curve analysis was used to determine threshold levels and thereby define anomalous samples (Parslow, 1974; Sinclair, 1976). The curves for all three elements have a 'dog-leg' to sigmoidal form and indicate the presence of a lower (background) population and a group of samples belonging to a higher (anomalous) population whose parameters cannot be defined precisely. Threshold levels (Table 2) were set where the plots depart significantly from the straight lines defined by the background populations. On this basis 3% of Cu, 8% of Zn and 7.5% of Pb results were defined as anomalous.

Many of the anomalous results form continuous sequences along traverse lines, giving anomalies of 60–100 m in length. Correlation of anomalies between traverse lines is less good than was expected. This is partly because the distribution of anomalies is strongly influenced by the movement and concentration of metals in the weathering zone (the 'secondary environment'). This is evident from (a) the location of many anomalies over or marginal to boggy ground or seepages, and (b) the combination of anomalous metals: where the ground conditions suggest a secondary concentration commonly only Pb or Zn is anomalous, whereas anomalies over well-drained shallow soils are usually polymetallic and of a lower magnitude. Zn and Pb anomalies are the broadest and of the greatest magnitude, suggesting that they are more affected by secondary redistribution than Cu, as Cu, Zn and Pb enrichments in mineralised rocks were found to be of broadly similar magnitude. Pitting of some anomalies indicated that high Pb concentrations were often associated with organic rich soil and high Zn with grey boulder clay beneath bogs or the oxidised b-horizon. As expected, pitting also showed that anomalies formed or enhanced by secondary concentration phenomena displayed a variable, often reducing, metal content with depth. Profiles from well drained anomalies and others where there was evidence that they overlay mineralisation, generally showed an increase in metal content with depth.

The metal content of a soil anomaly in this area does not therefore necessarily reflect the metal content of the source and several anomalies are displaced from their sources.

Many soil anomalies are coincident with zones of

silicification, brecciation, shearing, quartz veining and lithological boundaries. There is also some correlation with geophysical anomalies. In four areas where correlation of soil anomalies between traverse lines was uncertain or their relationships to the geology or geophysical anomalies in doubt, more information was gained by collecting additional samples from a number of short, closely spaced traverses. Details of this work, together with the reconnaissance sampling results, are contained in the data package.

Rock sampling

Rock-chip sampling was carried out across quartz vein structures, in the vicinity of some soil anomalies, and at 30–40 m intervals along a coastal traverse from Porth Ogo'r-geifr [SH 2903 9277] to Porth yr Hwch-fach [SH 2911 9217]. Most of the 99 rocks collected were quartz veined or altered. Except for some pyritic rocks only minor amounts of sulphide minerals were seen in the samples. A few contained visible chalcopyrite, galena, sphalerite or green secondary copper minerals. Most quartz veins appeared barren except for minor pyrite. Some quartz veins contained aggregates of secondary iron minerals and/or a vuggy texture suggesting that sulphide minerals may have been oxidised and metals leached from the rock.

Table 3 Summary of rock-chip sample analyses

| Element	Median	Maximum	Minimum	Mean
Fe(%)	3	14	<1	3.1
Cu	35	8600	5	175
Zn	70	3660	<5	181
Pb	40	10000	<5	244

Except for Fe, all results are in ppm. Results less than the detection limit set at half the detection limit for statistical calculations.

Fe, Cu, Zn and Pb were determined by AAS on a solution obtained following digestion of a 0.5 g sub-sample of the powdered rock in hot concentrated nitric acid for one hour. A summary of the analytical data is given in Table 3. This acid attack did not completely dissolve the rocks and, therefore, the analytical results will only indicate the amount of the metals determined held in sulphides and loosely bound or adsorbed in other phases. The maximum Cu and Zn concentrations were recorded in samples from old mine tips, but several apparently barren or weakly mineralised rocks and quartz veins also contain appreciable concentrations of metals, particularly Pb. For example, no galena was noticed in the sample containing the maximum Pb concentration, and it is suspected that Pb may be contained in minerals such as cerussite or anglesite. Lower, but still high levels of Zn (1300 ppm) and Cu (570 ppm), were also recorded in rocks apparently devoid of Zn and Cu sulphides.

GEOPHYSICAL SURVEYS

Magnetic and EM surveys

Magnetic and electromagnetic (EM) ground surveys were carried out to investigate anomalies revealed by the airborne geophysical survey (Smith, 1979). Measurements
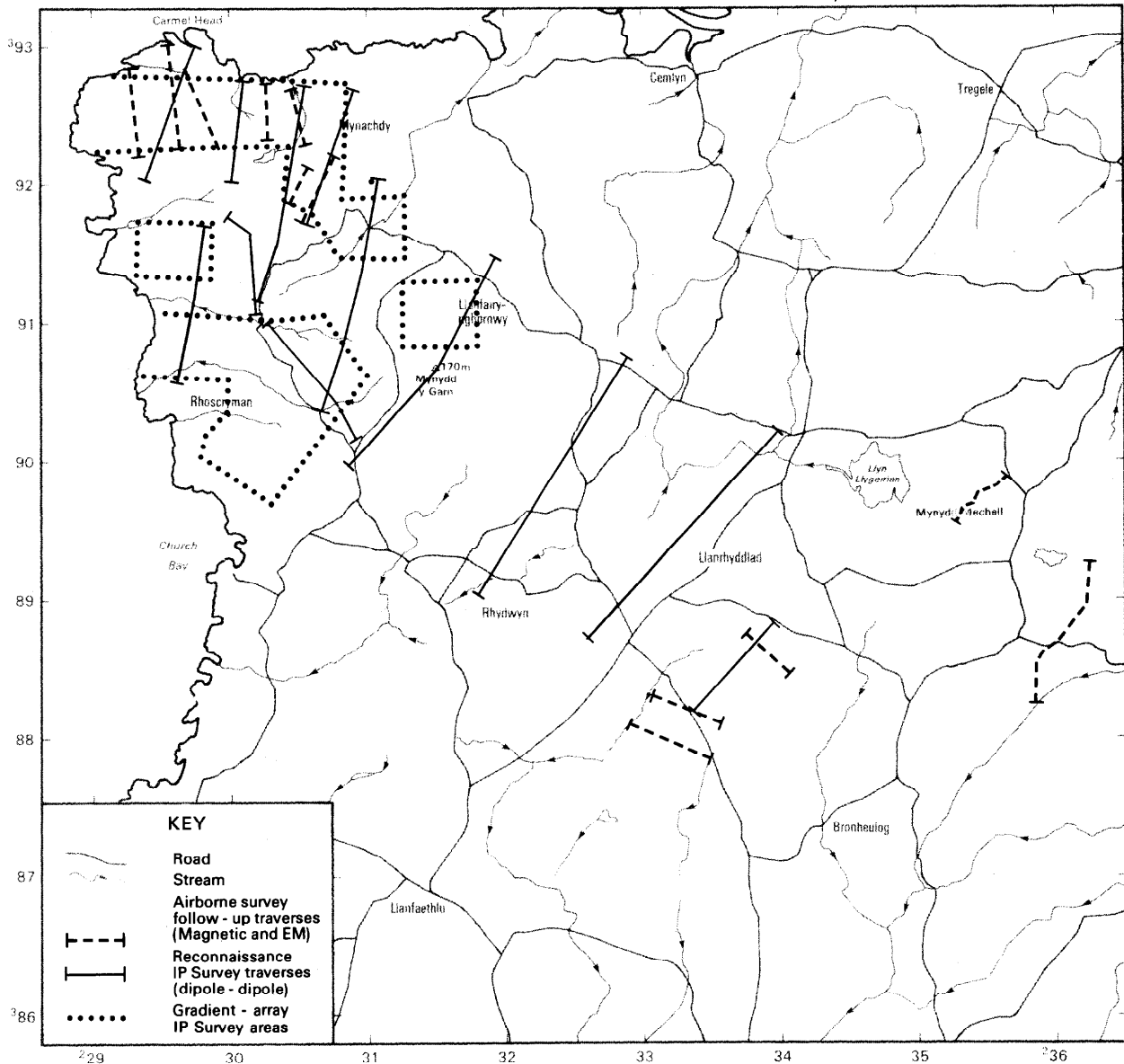
Figure 4 Location of geophysical survey traverse lines

were taken using proton precession and fluxgate magnetometers, several types of Slingram EM apparatus (Abem 35/88 EM gun, ABEM 'demigun', Geonics EM15 and Geonics EM17) and locally, Very Low Frequency (VLF) EM equipment. Those airborne anomalies which were investigated and lie within the area covered by this report are listed in Table 4 together with brief comments on their probable origin.

In the Carmel Head area, airborne EM anomalies of about 100 ppm are situated within a 2 km^2 area to the west of Mynachdy farm. EM measurements were taken along seven traverses totally 3.5 km in length across these features (Figure 4). The results were inconclusive. There are irregular variations along most of the traverses, but only in one place [SH 2960 9265] does a systematic anomaly appear. It is not found on adjacent traverses

Table 4 Investigation of airborne geophysical survey anomalies

Location	Grid Ref. (centre)	Methods	Comments
Carmel Head-Mynachdy	SH 300 924	EM, Mag.	Small EM and magnetic anomalies, see text
Mynydd y Garn	SH 315 907	EM, Mag.	No anomaly found on the ground
Cefn-coch	SH 345 910	EM	No anomaly found on the ground
Gamog	SH 335 884	EM	Weak EM anomaly, see text
Bron-heulog	SH 340 875	EM	Power line and fence anomaly
Mynydd Mechell-Tyddyn Salbri	SH 355 897 SH 360 887	Mag. Mag.	Airborne magnetic anomaly confirmed on the ground, see text

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and is most apparent in the in-phase component. It may be interpreted as a conductive body of short strike length dipping at less than 30° to the south with the (low) conductivity width product of 4 mhos. At [SH 3049 9249] and [SH 3029 9254] there are two anomalies of similar shape. They differ from the normal pattern of EM anomalies and have a weak magnetic anomaly associated with them. No artificial conductors are known and the area is drift covered. Later surveys revealed no coincident IP anomaly.

In the Mynydd Mechell-Tyddyn Salbri area a complex of generally north-west trending aeromagnetic anomalies of 150 nT astride the Carmel Head Thrust was investigated. Two north-east trending traverses one kilometre apart (Figure 4) were measured with a proton precession magnetometer: both showed anomalies reaching 300 nT. There is a well-marked change in character of the magnetic profiles across the Carmel Head Thrust: to the south it is smooth, but to the north there are sizable variations. The anomalies are most probably related to dolerite dykes in the Coeden Beds (Greenly, 1919; Barber and Max, 1979), although other interpretations are possible (Smith, 1979).

Airborne EM anomalies of about 50 ppm amplitude and 300 m wavelength at Gamog were investigated by taking measurements along three west-north-west trending traverses (Figure 4) using Slingram apparatus. Although it was concluded that the airborne anomaly is most probably due to radio transmitter interference, a weak anomaly in the out-of-phase component of the ground traverse data was located east of Gamog at [SH 3387 8863]. There is no obvious artificial cause of this feature and the most likely source is considered to be local conductive overburden.

On the basis of this work and later successful trials with IP and VLF-EM it was concluded that Slingram based EM survey was generally unsuitable for use in the Carmel Head area because of its weak response, and that the airborne anomalies were generated or confused by radio-transmitter interference. No magnetic anomalies related to mineralisation or of use in tracing mineralised structures were found and further geophysical investigations were based on the IP method, supplemented locally by VLF-EM measurements.

IP surveys

Following successful trials at Parys Mountain, a reconnaissance Induced Polarisation (IP) survey was carried out across north-west Anglesey in conjunction with the reconnaissance soil sampling described above. Twelve traverses, near-coincident with the soil sampling lines and spaced at roughly 1 km intervals, were measured using the dipole-dipole array method (Figure 4). A dipole length of 50 m, with separations of up to 5 dipole lengths, was chosen.

Several strong chargeability anomalies were revealed by the survey. They could be divided into three groups: (a) artificial anomalies, (b) anomalies of geological origin and (c) ambiguous anomalies of possible geological or artificial origin. Most of the artificial anomalies, such as those associated with fences, had strong negative values of chargeability associated with the positive and some artificial sources gave a purely negative anomaly.

Correlation of anomalies between traverses was highly speculative because of the wide traverse spacing and five areas containing the most promising anomalies were investigated by gradient array IP mapping. For this work a transmitter dipole length within the range 600–1000 m was chosen for each area. The receiver dipole was 25 m throughout. Traverses were spaced at 100 m with infill to 25 m where additional detail was required. Station spacing was 25 m initially and 10 m for detail. Some artificial anomalies and others of uncertain origin were again recorded and in an attempt to resolve these the decay curve of the IP was measured in detail at several localities.

Eleven areas containing one or more significant gradient array anomalies were distinguished. Individual anomalies were up to 50 ms in magnitude and 0.4 km in length. The anomaly in one area was believed to be wholly artificial and caused by grounded fences. In a second area, which is on the edge of the surveyed ground, the anomaly was incompletely defined and may be related to graphitic schists. In the remaining nine areas there were either coincident geochemical anomalies, or geochemical anomalies close by which could be geologically related to the chargeability anomalies. This together with geological evidence indicated that sulphide mineralisation was the cause of at least part of the anomaly pattern in these nine areas, though in five cases evidence for an artificial component was also present.

VLF(EM) survey

Trial VLF(EM) traverses across the site of the Gadair copper mine at Carmel Head produced a strong anomaly over the vein, suggesting that the method would be useful in detecting similar structures elsewhere in north-west Anglesey. Accordingly, VLF(EM) measurements were taken in the vicinity of the more promising gradient array IP anomalies at 25 m intervals along N–S oriented traverses placed 100 m apart.

Six of the eight IP anomalies traversed were found to have significant VLF(EM) anomalies associated with them. The position and shape of five of the six VLF(EM) anomalies suggest that they are related to geological boundaries and/or faults. At the site of the sixth, where a grounded fence cast some doubt on the validity of the IP anomaly, an intense VLF(EM) anomaly was generated by the fence. However, a weak anomaly indicative of a dipping weakly conductive body was also detected.

DRILLING

Operations

Fifteen inclined cored boreholes, dipping between 45° and 80° were drilled to investigate the sources of IP anomalies. One of the boreholes was a repeat by deflection. The maximum inclined depth drilled in one hole was 122.13 m and the total depth drilled was 917.26 m. Much of the core recovered was BQ (36.4 mm diameter) in size, although some AQ (26.9 mm diameter) was obtained. Core recovery measurements were taken on each section lifted and a detailed log recorded. Thin sections and polished thin sections were made from the core to provide more detailed information on mineralisation and host-rock lithologies. X-ray diffraction was used to verify some mineral identifications. 18 samples of core were examined for microfossils.

Drill sludge (mud) samples were collected from all holes. In three holes return of water was lost, resulting in an incomplete sequence of samples. The samples, each representing 3 m of cored drilling, were mixed thoroughly and c. 500 g taken for Cu, Zn and Pb analysis by AAS.

Remaining material was panned and the resulting concentrate examined for heavy minerals.

232 metres of split drill-core, subdivided into 276 samples ranging in length from 0.4 to 3 m, were also analysed. Lengths were selected by reference to the geological logs and the drill mud data. One half of the selected core-run was crushed and milled and a sub-sample of the resulting powder analysed for Cu, Zn, and Pb by AAS following digestion in hot concentrated nitric acid. Mn, Fe, Co, Ni, Mo and Ba were determined on another sub-sample by optical emission spectrography. Arsenic was detemined on a third sub-sample by X-ray fluorescence spectrometry. 129 of the samples, including representatives from all sample runs, were analysed for Au, either by neutron activation analysis or by AAS following dissolution of a 50–60 g sample using *aqua regia*.

Six boreholes were logged using a geophysical method in order to identify the source of the IP anomalies. The system used was one developed by BGS for measuring induced polarisation in slim boreholes, based on the Huntec Mk.3 receiver and 'Lopo' transmitter. It utilised purpose-built sondes with non-polarising electrodes configured either in the 'pole-pole' ('normal') or the 'pole-dipole' ('lateral') mode. In addition Self Potential (SP) was measured. In general logging was carried out at 0.5 m intervals from the bottom of the hole up to casing level.

Results

Base-metal sulphide mineralisation (major and minor) was encountered in the boreholes as follows: Cu, Zn and Pb in eleven boreholes; Cu in two boreholes. The remaining two boreholes, one of which was not sited on an IP anomaly, revealed only pyrite.

In addition, chemical analysis showed that appreciable amounts of Au are present in some sections. Arsenic is enriched locally and shows a statistically significant correlation with Au (Spearman-rank correlation 0.68), but the relationship is not sufficiently close to make As a reliable pathfinder for Au.

The correlation between visible mineralisation in the core, sulphide in panned drill-mud concentrates and high levels of Cu, Zn and Pb in the drill mud analyses is generally good, suggesting an absence of any appreciable very fine-grained base-metal mineralisation.

Significant anomalies were detected on all the geophysical logs. As expected the apparent resistivity and chargeability measured on the lateral sonde are noisier but have greater amplitude and better depth resolution than the normal logs. Correlations between the chargeability logs is fair but not consistent. The chargeability and apparent resistivity logs usually show an inverse correlation but this is neither strong nor consistently clear. The SP logs show good correlation with the lateral chargeability logs, although the polarity of the SP appears to alter between boreholes. Comparison with the lithological logs suggests that the lateral induced polarisation method provides a sensitive indication of mineralisation. Noise causes some interpretational difficulties on this log, but when used in conjunction with SP some discrimination is possible and the more significant intersections of polarising minerals can be identified.

Correlation coefficients (Table 5) generated from the drill-core analyses confirmed visual observations by showing a closer relationship between Zn and Pb than between either of these metals and Cu. Variations in Mn, Fe, Co, Ni and Mo content are caused in part by mineralisation

Table 5 Summary of the inter-element correlation matrix for 276 drill-core analyses

Element	Correlation coefficient 0.3–0.49	0.50–0.69	>0.70
Mn	Fe		
Fe	Mn	Co, Ni	
Co	As	Fe	Ni
Ni	As	Fe	Co
Cu	Zn	Pb	
Zn	Cu		Pb
As	Pb, Co, Ni		
Mo			
Ba			
Pb	As	Cu	Zn

and in part by changes in lithology. Maximum levels of these elements (Mn:0.8%, Fe:26%, Co:101 ppm, Ni:184 ppm, Mo:38 ppm) are too low to be of economic interest, although detailed variation in mineralised sections suggest that (as well as Fe in pyrite) minor amounts of Mn, Co, Ni and possibly Mo are held in sulphide phases. Lithologies containing high background levels of these elements include greenstone, basaltic lava and tuffs and some mudstone horizons. Ba levels (max. 1515 ppm) indicate that little or no baryte is present and variation is related mainly to bedrock lithology and alteration associated with mineralisation.

The principal ore minerals are chalcopyrite, sphalerite and galena. Arsenopyrite was not seen but chemical levels of As (up to 1800 ppm) suggest that it is present locally. Similarly, no Au bearing mineral was identified. Pyrite is the commonest sulphide, occurring in bands, veins and disseminations with and without other sulphides. It appears to be polyphase and to be both syngenetic/diagenetic and epigenetic in origin. Locally it contains exsolved galena. In some sections disseminated pyrite mineralisation appears to be associated with sericitisation and pre-date vein mineralisation. In veins, there is evidence for pyrite pre-dating and post-dating base-metal sulphides. Chalcopyrite, galena and sphalerite are usually closely associated and sphalerite often contains exsolved chalcopyrite. In one vein chalcopyrite forms marginal rims on fractured euhedral pyrite with infillings of galena and sphalerite, giving an order of crystallisation of pyrite, chalcopyrite, galena, sphalerite. Locally chalcopyrite is altered at grain margins to covellite, digenite or chalcocite and pyrite to iron oxides. Gangue minerals in veins consist largely of quartz, chlorite and carbonates. Veins are polyphase with evidence locally of at least three generations.

The original mineralogy of the host rocks was affected by metamorphism, tectonism (shearing) and hydrothermal alteration. In the borehole sections sericitisation is widespread and often intense. Carbonate and chlorite alteration is also widespread whilst silicification, epidotisation and clay alterations (kaolinite, illite, montmorillonite) are found in places.

A basic intrusion associated with a mineralised structure is altered to a quartz-clay (illite, montmorillonite, kaolinite)-mica (fuschite, muscovite, sericite) rock with minor epidote, iron oxides and carbonate. There appears to be a correlation between the highest gold values and this lithology. Whether this is because the rock had a high pre-alteration gold content, the host rock exerted a control on gold precipitation from hydrothermal fluids, and/or

the fluids that affected the rock had particular physio-chemical properties is not known. It is relevant, however, to note that fuschite has been reported from gold prospects in Ordovician and Silurian rocks of the Irish Caledonides (Romer and Cazalet, 1988).

The mineral textures and relationships seen in the core samples suggest the following sequence of mineralising events:

iii Syngenetic/diagenetic sulphide (pyrite) deposition.
ii Disseminated (pyrite) mineralisation, ? associated with sericite alteration, ? accompanying vein mineralisation.
iii Hydrothermal vein-style mineralisation; (a) quartz-pyrite-chlorite; (b) quartz-carbonate-pyrite-chalcopyrite-sphalerite-galena.
iv 'Late' carbonate and quartz veining.
v Local oxidation and leaching of sulphides.

The location of the anomalies and accompanying mineralisation found in the boreholes confirms the validity of the geological model and indicates the presence of at least five separate mineralised structures in the area. Although the intention of the drilling was not to delimit the extent of the mineralisation, surface anomalies suggest that some of the structures may extend to over 1 km in length. The location of the mineralised structures and the position of IP and soil anomalies not investigated suggest the presence of further mineralised structures and extensions to those already proven. Details are contained in the Data Package.

CONCLUSIONS

1 Geochemical and geophysical (IP) surveys followed by shallow drilling confirmed the validity of the geological model which suggested the presence of polymetallic mineralisation in north-west Anglesey. The potential for base-metal deposits similar to that exploited at Parys Mountain is confirmed.
2 Drilling showed that the principal IP anomalies, most of which have coincident metal anomalies in soil, are caused by sulphide mineralisation.
3 The newly discovered mineralisation contains Cu, Zn, Pb and, locally, As and Au. The principal ore minerals are chalcopyrite, galena and sphalerite; pyrite is ubiquitous. There is some evidence for host rock control on the distribution of gold.
4 Brief studies of the drill-core show that mineralisation is polyphase, occurring as disseminations and veins which may locally form extensive anastomosing structures.
5 As well as hydrothermal mineralisation the host rocks have been affected by metamorphic and tectonic events. Sericite, carbonate and chlorite alteration is widespread in the host rocks. Silicification, epidotisation, sulphide oxidation and alteration to clay mineral assemblages are present locally.
6 Further work in the area could usefully involve drilling of geochemical and geophysical anomalies not so far investigated and additional drilling of mineralised structures already detected. More detailed study of the alteration and mineralisation and comparison with the Parys Mountain deposits is also merited.

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