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Mineral Reconnaissance Programme

The metalliferous mineral potential of the basic rocks of the Penmynydd Zone, south-east Anglesey

Department of Trade and Industry

MRP Report 127
Technical Report WF/93/3

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BRITISH GEOLOGICAL SURVEY

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SUMMARY

Geophysical and geochemical investigations have been carried out to assess the mineral potential of an area in south-east Anglesey containing positive gravity anomalies and coincident aeromagnetic anomalies. The anomalous area contains outcrops of dense, basic hornblende schist of the Precambrian Penmynydd Zone, which is a complex, fault-bounded zone of tectonised metasediments and basic schists.

The existing regional gravity survey coverage has been augmented by over 150 additional gravity stations and three detailed traverses made on lines normal to the regional strike. Over 250 soil samples have been collected on 7 traverse lines which, together with over 30 rock samples, have been analysed for a suite of up to 13 elements (soils) and up to 28 elements (rocks). Some of the rocks have been analysed also for gold and platinum.

The geophysical data suggest that the gravity and aeromagnetic anomalies over the Penmynydd Zone can best be explained by the presence of a near-surface, relatively dense body of low magnetic susceptibility underlain at around 3 km depth by a body with a much higher magnetic susceptibility. The anomalies could therefore be due to a layered basic intrusion, fault-bounded on both its north-west and south-east sides. Along-strike modelling of this body indicates that it is disrupted by block faulting along a north-west trend, with segments becoming progressively deeper towards the north-east.

The geochemistry of the basic hornblende schists indicates that they have an oceanic tholeitic basalt parentage. The soil sampling results show several barium anomalies, probably associated with thin baryte veins, and one Pb/Zn anomaly over Carboniferous Limestone. There are no immediate geological or geochemical indications of potentially economic near-surface mineralisation in the area.

INTRODUCTION

This report describes the results of geochemical and geophysical investigations carried out in south-east Anglesey to follow-up previous studies on Anglesey by the Mineral Reconnaissance Programme (Cooper et al., 1990). The previous studies identified a broad zone of strong positive gravity anomalies, with coincident aeromagnetic anomalies, in south-east Anglesey and recommended further work to determine the source. It was considered that if the anomalies were caused by a substantial body of basic igneous rock at shallow depth there might also be potential for mineralisation associated with these rocks. A reported observation of mineralisation along the Berw Fault was investigated briefly.

The island of Anglesey is separated from the north-west coast of Wales by the Menai Strait (Figure 1). Additional place names mentioned in the text can be found on the British Geological Survey 1:50 000 Anglesey Special Sheet. The island has an area of about 750 km^2 and is generally low-lying. The area (about 15 x 5 km) described in this report is situated in the south-east of the island between Newborough and Menai Bridge (Figure 1). Topographically it is a peneplain of low rounded hills rising to about 50 m with a poorly developed drainage of small streams generally flowing south-west.

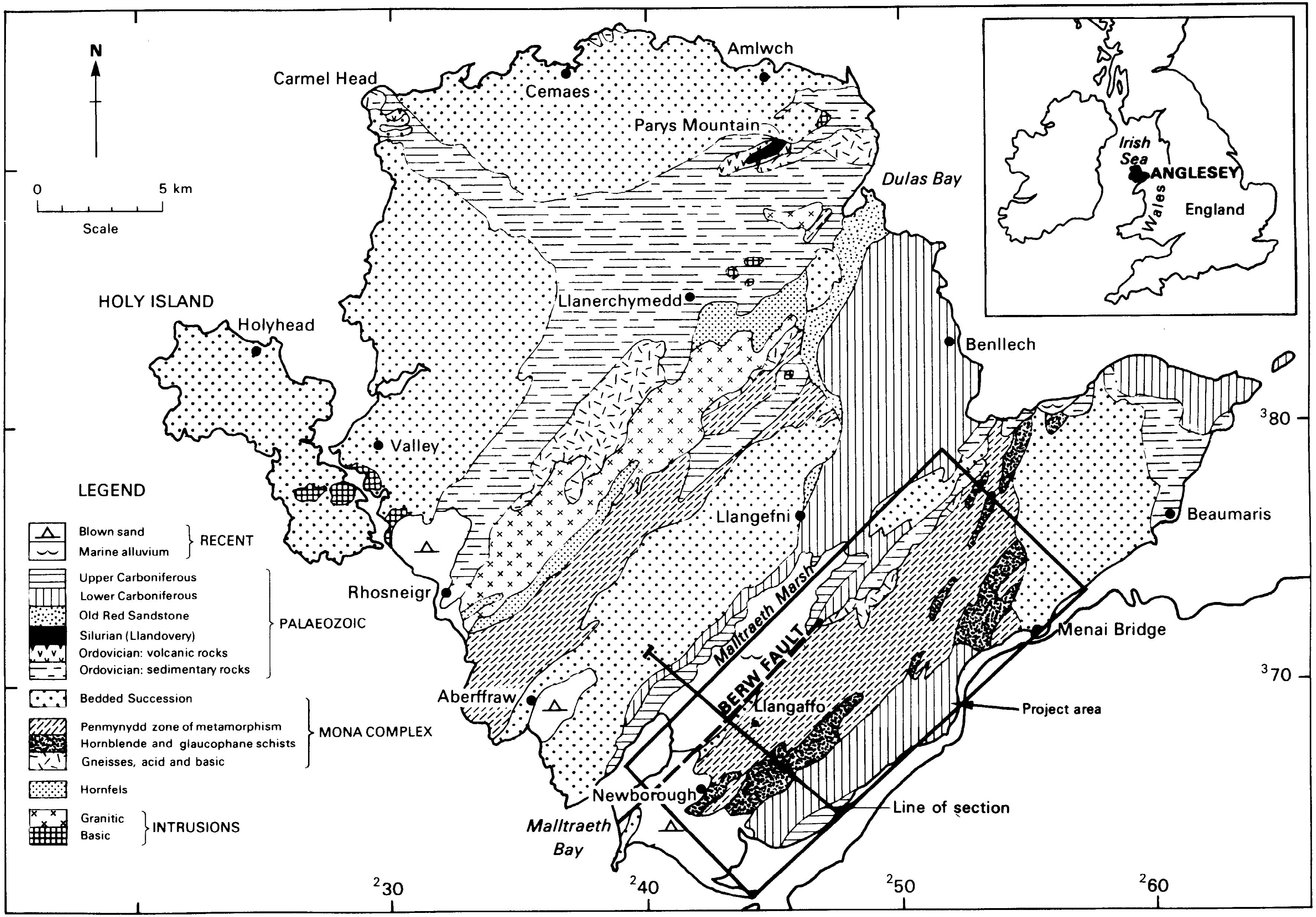

Figure 1 Geology of Anglesey and location of the report area

An area in the vicinity of the gravity anomalies has been investigated by a detailed gravity survey supplemented by several gravity, magnetic and VLF-EM traverses. Seven geochemical soil traverses have been completed and a small number of rocks collected from the few exposures in the area. The objectives of the work were to 1) determine the source of the gravity and magnetic anomalies; 2) to look for any evidence of associated mineralisation.

GEOLOGY AND MINERALISATION

Introduction

The geology of Anglesey is varied and locally complex (Figure 1). The rocks range in age from late Precambrian to Upper Palaeozoic with a metamorphic basement of metasediments with acid and basic intrusions. This basement, commonly called the Mona Complex (Greenly, 1919), includes the Monian Supergroup of low-grade metasediments overlain by the Gwna Mélange (Gibbons and Horák, 1990), gneissic and granitic rocks and the Penmynydd Zone of strongly metamorphosed sediments and basic igneous rocks. This complex is succeeded by an unconformable sequence of Ordovician sediments and volcanics followed by Devonian sandstones and a thin Carboniferous sequence of Dinantian limestones and Namurian and Westphalian sandstones, shales and coal measures. The structure of the island is dominated by a north-east - south-west Caledonide trend reflected by the major Berw and Menai Strait faults. There are also a number of major thrusts in the north of the island, such as the Carmel Head Thrust. In contrast to the adjoining mainland (Snowdonia) the topography is very subdued. This fact, coupled with the extensive superficial deposits of glacial origin on Anglesey, makes for very poor exposure over extensive areas and creates difficulties in conducting geological investigations. The geology of the island is summarised in previous MRP reports (Cooper et al., 1982; Cooper et al., 1990). The only detailed geological description of the whole island is that given by Greenly (1919).

Penmynydd Zone

The area investigated is mainly underlain by rocks of the Penmynydd Zone which was considered by Greenly (1919) to be a metamorphic and structural unit rather than a lithological one and to be composed of the metamorphosed equivalents of the adjacent Gwna Group sediments. It comprises mica schists, quartz schists and limestones together with a series of basic hornblende and glaucophane schists. A small area of basic gneiss crops out near the Berw Fault on the north-west side of the zone. Apart from the area to the north-west of Menai Bridge, where outcrops are numerous, exposure is generally sparse, being limited to a few small quarries and some natural outcrops at the tops of the low, rounded hills. The Penmynydd Zone is unconformably overlain to the south-east by flat-lying Carboniferous Limestones and is abruptly terminated against the major Berw Fault to the north-west. The fault, and associated scarp, forms the eastern boundary of the Malltraeth, a former estuary which has silted up to form very low-lying, marshy ground. This is underlain by Carboniferous sediments, including Coal Measures which were worked in a small colliery near Pentre Berw.

There are two main areas of Penmynydd rocks. The western area is on the eastern side of the Coedana Granite and extends from Aberffraw to north of Llangefni. This area contains few outcrops of basic 'hornblende schist'. The eastern area, which contains the ground described in this report, extends from Newborough in the south-west to the northern coast south of Benllech. However, only the southern section of this area, south-west of Menai Bridge, has been examined in any detail because it is underlain by the most intense gravity and magnetic anomaly. The Penmynydd Zone has generally been considered to be of late Precambrian age (Greenly, 1919). However, more recent studies (Barber and Max, 1979) have indicated that an early Cambrian age may be more appropriate. Gibbons and Horák (1990) suggest that the zone must have been in place prior to late Lower Cambrian times. Gibbons (1989) argues that the Penmynydd Zone is not part of the rest of the Monian of Anglesey and that it forms a 'suspect terrane' in tectonic contact with the Monian. These contacts are formed by the Berw Shear Zone to the west and the Menai Strait Shear Zone to the east. These shear zones may have been the locus for fluid flow and therefore could be of interest to mineral exploration.

Mica schist

The main rock type within the Penmynydd Zone is a pale to medium grey quartz-mica schist containing occasional quartz veins. It is very poorly exposed and is often covered by a light-grey gritty soil, in contrast to the darker brown, more clay-rich soil developed over the basic schists. The quartz-mica schists are interpreted as metamorphosed clastic sedimentary rocks which may contain tuffaceous horizons. The mica schists were not sampled for rock geochemical analysis, although some additional samples were collected for physical property determinations to assist in the interpretation of the geophysical data. They were, however, crossed by the soil sample traverses.

Hornblende schists

The rocks of most interest to the current investigation are the 'hornblende schists' which are mapped as a series of lenses up to 1.5 km wide throughout the eastern Penmynydd Zone from Newborough northwards. The northern part of this zone has only a few sporadic, thin lenses of hornblende schist. The hornblende schists are strongly folded and foliated and in places appear to be interlayered with the mica schists as if the two rock types were contemporaneous or the basic rocks were a series of thin sill-like intrusions. The hornblende schists are generally dark grey to grey green, fine grained, dense, tough basic rocks. They are finely laminated or layered, as at Llys Lew quarry (Rock sample OHR 5004 at [24697 36825]*), with alternating thin lighter and darker layers up to 1 cm wide which are suggestive of tuffs. They are also found as massive dark blue-green rocks, as at Newborough (OHR 5003 [24208 36506]). At Ty-Cerrig, north of Dwyran, an outcrop at [24462 36635] (OHR 5030) shows pale grey green schist folded with dark grey-green basic schist. The pale rocks have a low magnetic susceptibility (0.5-3 $\times 10^{-3}$ SI units) while the dark schists are much higher (8-15 $\times 10^{-3}$ SI units).

The impression given by the outcrops of the hornblende schist is of a series of basic tuffs or lavas, with interbedded sediments. More massive outcrops may represent either thick lava flows or high level intrusions.

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*National Grid Reference

Glaucophane schists

Considerable geological interest has been focussed on the hornblende schists of the Llanfairpwllgwyngyll area, which contain glaucophane. This is a sodium amphibole which generally forms under conditions of high pressure and low temperature which are commonly found in island arcs and in orogenic belts related to plate subduction, obduction and collision. Glaucophane schists are relatively rare in Palaeozoic rocks. Gibbons and Mann (1983) suggested that the mylonitic schists of the Penmynydd Zone were the result of metamorphism and deformation within deep-seated ductile shear zones produced by the movement of sialic basement up into low-grade melange. Thorpe (1972) suggested on geochemical grounds that the glaucophane schists were originally ocean floor basalts. This interpretation was confirmed and extended by Mann (1986) who showed that most of the basic rocks were probably ocean floor tholeiitic basalts, but there were also some alkaline basalts and basic tuffs. There is insufficient field evidence to determine whether the basic rocks were lavas or sills. Some glaucophane schists were collected and analysed as part of the current investigation for comparison with rocks from the southern end of the Penmynydd Zone.

Carboniferous rocks

Carboniferous Limestones (Asbian - Brigantian) unconformably overlie the Penmynydd rocks to the south-east towards the Menai Strait. They are exposed in a number of small quarries in the Cefn Dderwen and Quirt areas. They also occur beneath the Malltraeth on the north-west side of the Berw Fault where they are overlain by Westphalian Coal Measures. Coal was produced from a small colliery near Pentre Berw (Greenly, 1919). Greenly mentions thin baryte veins within the Carboniferous Limestone and a number of lead and barium drainage anomalies occur along the contact of the basal Carboniferous and the Penmynydd Zone (Cooper et al., 1982).

Superficial deposits

The whole area has been glaciated and a thin veneer of till has been deposited. However, soil augering showed that weathered bedrock can be observed at shallow (40 - 50 cm) depth. There are narrow sinuous spreads of alluvium associated with the south-west flowing streams. The Malltreath is a recently drained area of coastal marsh.

Structure

The dominant structural trend is north-east - south-west, parallel to the Menai Strait and Berw Faults, which is accentuated by the drainage in the same direction. The Berw Fault forms a prominent north-west facing scarp where it downthrows relatively soft Carboniferous strata against the harder Penmynydd rocks. Gibbons and Horák (1990) consider this fault to be of regional significance 'comparable in width and deformation state to crustal scale shears such as the Median Tectonic Line in Japan'. Most of the layering or foliation seen in the rocks of the Penmynydd Zone is orientated between 020° and 060° with very variable dips ranging from vertical to 10° both to east and west. Greenly's (1919) sections show a westerly dip which is reflected in Figure 2. No faults or thrusts are mapped in the main area of the southern basic schists around Dwyran due probably to lack of exposure. All contacts of the hornblende and glaucophane schists with the mica schists are shown as lensing out or indeterminate indicating the problem of investigating field relationships of the rocks in this area of poor exposure. Some small faults are shown in the basic gneiss of the Pentre Berw area and along the Berw Fault. The abrupt termination of the basic ridge south of Dwyran, which coincides with the end of the main gravity anomaly, may reflect a recent coastal platform development or indicate faulting cutting off the basic rocks to the south-west.

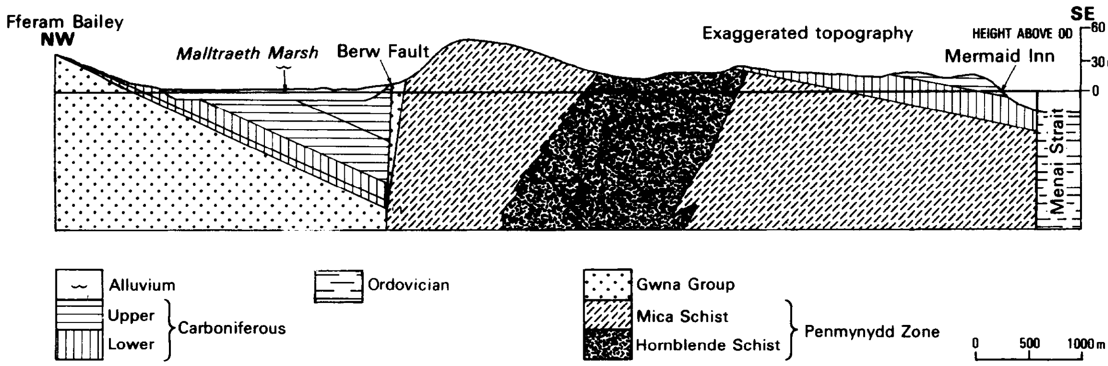


Figure 2 Cross section of the Penmynydd Zone (after Greenly, 1919)

Faulting was seen in Hengae quarry where a zone of quartz veining about 30 m wide marks a possible splay fault from the main Berw Fault. Minor quartz-sulphide veining is associated with the faulting.

Minor quartz veins are quite common in outcrops in the area. They are usually sub-parallel to the foliation. A few wider (to 5 cm) quartz veins occur, sometimes containing included clasts of the wallrock.

Mineralisation

Only minor occurrences of metalliferous mineralisation are known from the Penmynydd Zone. The only visible sulphides in the hornblende schists are occasional traces of pyrite. One loose block of hornblende schist near Bodrida farm (OHR 5015 [24687 36789]) showed extensive blue-green secondary copper mineralisation in minor carbonate veins. The sample contained 762 ppm Cu. Greenly (1919) states that 'small patches of copper-salts are not uncommon. Some from the glaucophane-schist at the Column quarry, and from about a furlong west of Dinam, Valley, were found... to be malachite'. There is reference by Greenly to a silicified zone near Llangaffo where eight analyses in 1888 - 89 of quartz, pyrite and galena showed chalcopyrite, argentiferous galena (up to 1025 dwt per ton or 1568 g/t) and up to 8 dwt (12.2 g/t) of gold. Unfortunately the 'high boss' referred to by Greenly has been removed in the enlarged Hengae Quarry and precious metal analyses from a sulphide-bearing fault zone, with minor pyrite, sphalerite and chalcopyrite, in the quarry were not encouraging (Table 2). Greenly (1919) also described the occurrence of several outcrops of strongly silicified rocks adjacent to the Berw Fault between Llangaffo and Newborough. He states (p 568) that 'thin bands of siliceous matter lie along the foliation-strike of the mica schist. They recall the silicified material of Parys Mountain, being composed of a quartz-mosaic studded with cubes of pyrite'. Several samples were taken from these rocks. Earlier surveys by the MRP found blocks of mica-schist with thin baryte veins in streams near Llangaffo (Cooper et al., 1982).

GEOPHYSICAL SURVEYS

Previous investigations

Gravity surveys

Powell's (1956) original gravity coverage of North Wales has been supplemented extensively in this area by the subsequent work of Leeds University and the BGS, resulting in increased density of coverage from about nine to 80 stations per 100 km^2.

The Bouguer anomaly contour map based on these data gridded at 500 m intervals is shown in Figure 3, while fitting a third order polynomial surface yields the regional and residual fields shown in Figures 4 and 5 respectively. The regional field shows a well defined south-east to north-west positive gradient of approximately 0.2 mGal/km, culminating in values approaching +32 mGal over Anglesey and the Irish Sea. This extensive positive feature clearly has a deep origin. It has been ascribed (Powell, 1956) to an updoming or arching of the crust by some 3 km, and hence an effective shallowing of the denser mantle material. Bott (1964) reports that a mantle rise of this order under this part of the Irish Sea is supported by results of the Eskdalemuir refraction seismic experiment.

Anomalies with relatively shallow source are shown by the residual field contours of Figure 5. Of immediate interest is the elongate positive feature occupying the south-east part of Anglesey. This displays a Caledonide trend, parallel to the Menai Strait, and has a maximum amplitude of about 16 mGal. Powell (1956) observed that this feature could be due to a shallow body of hornblende schist enclosed within mica schist, extending between 1-3 km deep. Viewed in greater detail (Figure 6) clear spatial correlation is seen between the high Bouguer anomaly values and the belt of metamorphic rocks between the Berw and Menai Strait Faults. This area is largely enclosed by the 10 mGal contour while the positive closures in the south-west are largely coincident with outcropping hornblende- or glaucophane-schist.

A further striking residual feature shown on Figure 5 is the elongate negative zone immediately south-east of Anglesey; this is believed to reflect either a concealed granitic intrusion (Powell, 1956) or a combination of thick (>2 km) volcaniclastic sedimentary rocks and co-magmatic acidic intrusions (Reedman et al., 1984).

Magnetic surveys

The aeromagnetic map of North Wales (Institute of Geological Sciences, 1978) is dominated by high intensity values reflecting shallow magnetic basement in the Blaenau Ffestiniog and Lleyn Peninsula areas (Figure 7). The area of this study is north of the latter, occupying part of a well defined north-east-trending positive linear feature.

The centres of the regional gravity and magnetic fields are clearly disparate and indicate different sources. However on a more local (and shallower) scale there is close spatial correlation between the Mona Complex rocks of the Penmynydd Zone and both the positive gravity and aeromagnetic anomalies.

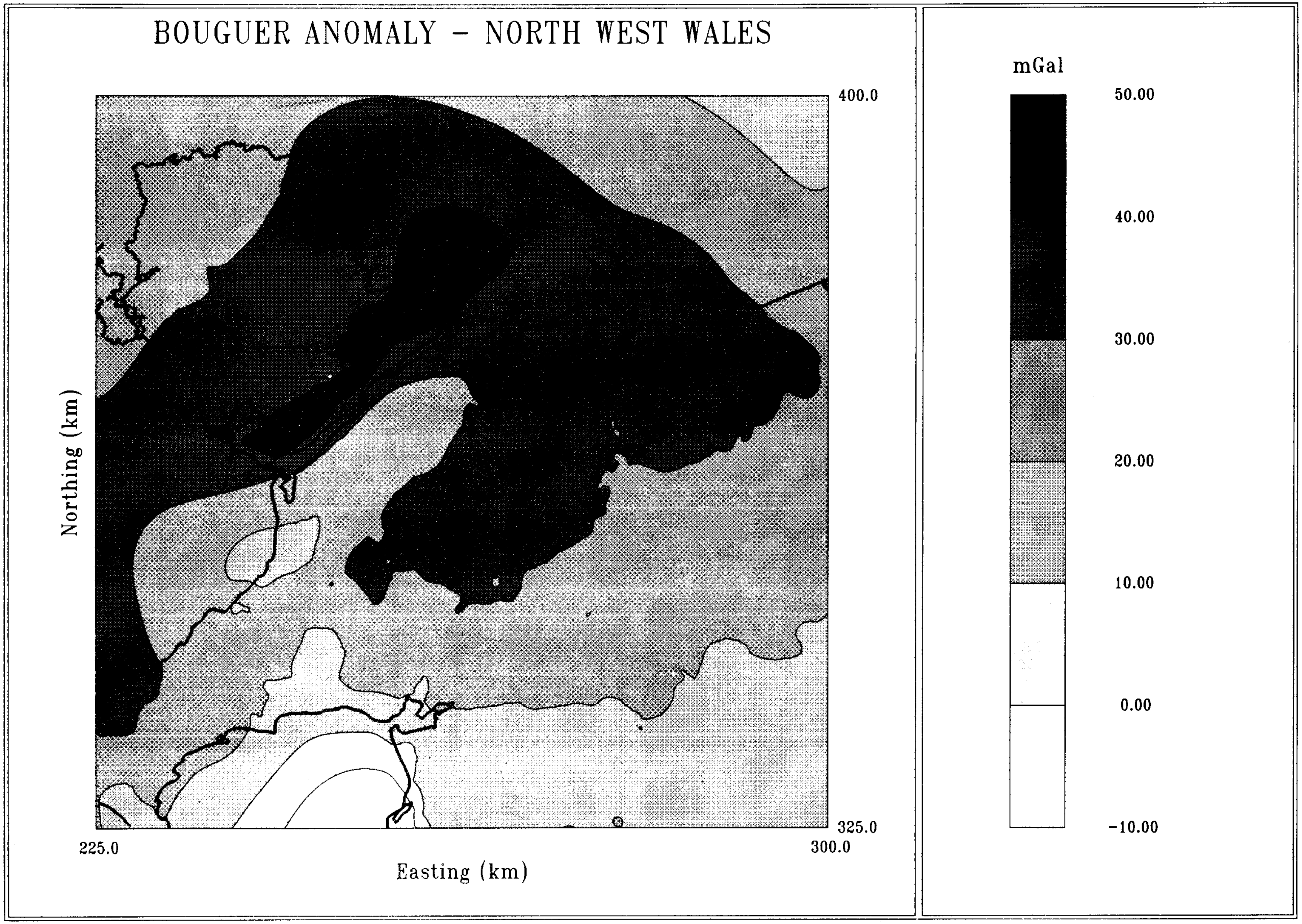


Figure 3 Bouguer anomaly map of north-west Wales

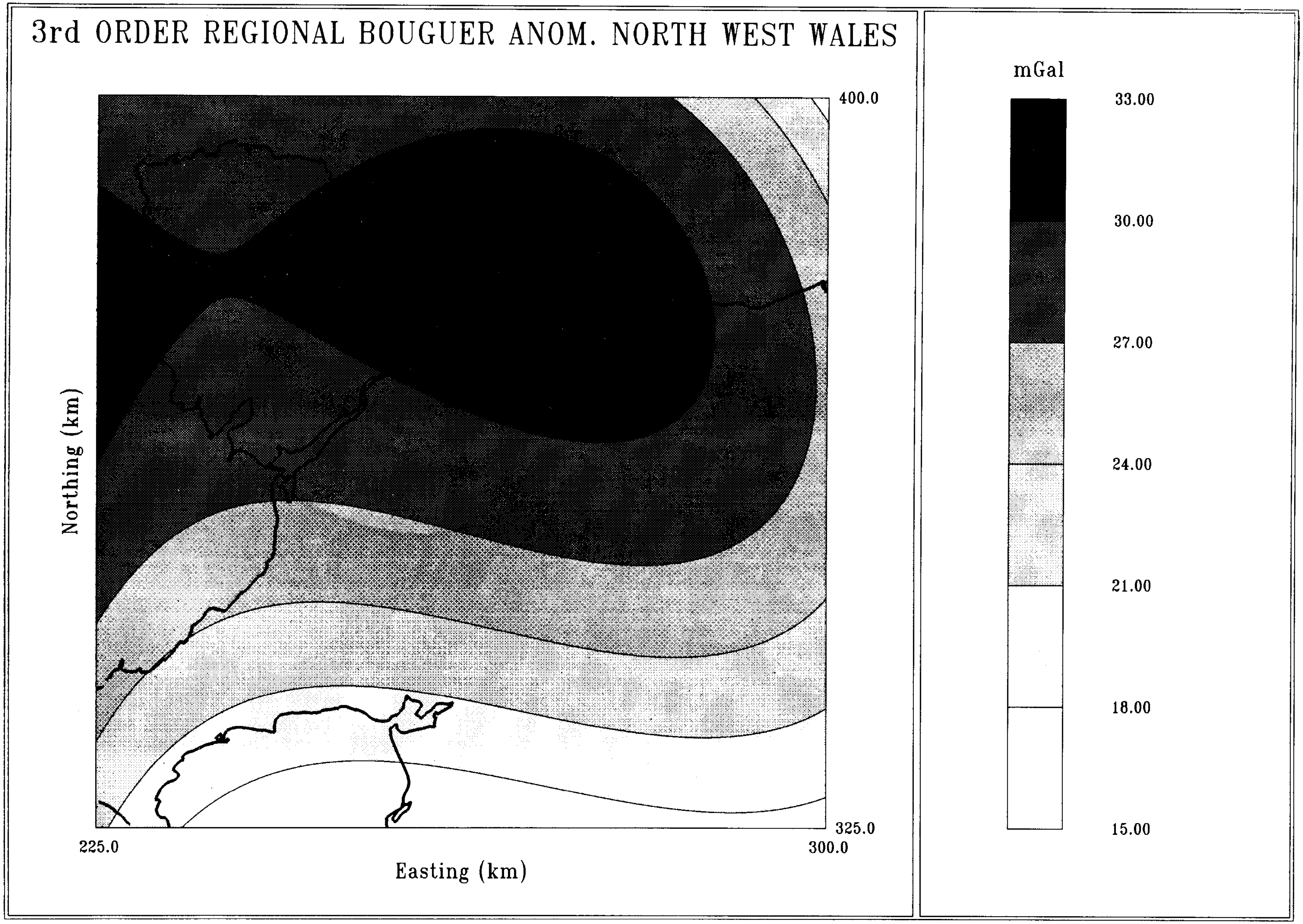


Figure 4 Third order regional Bouguer anomaly map of north-west Wales

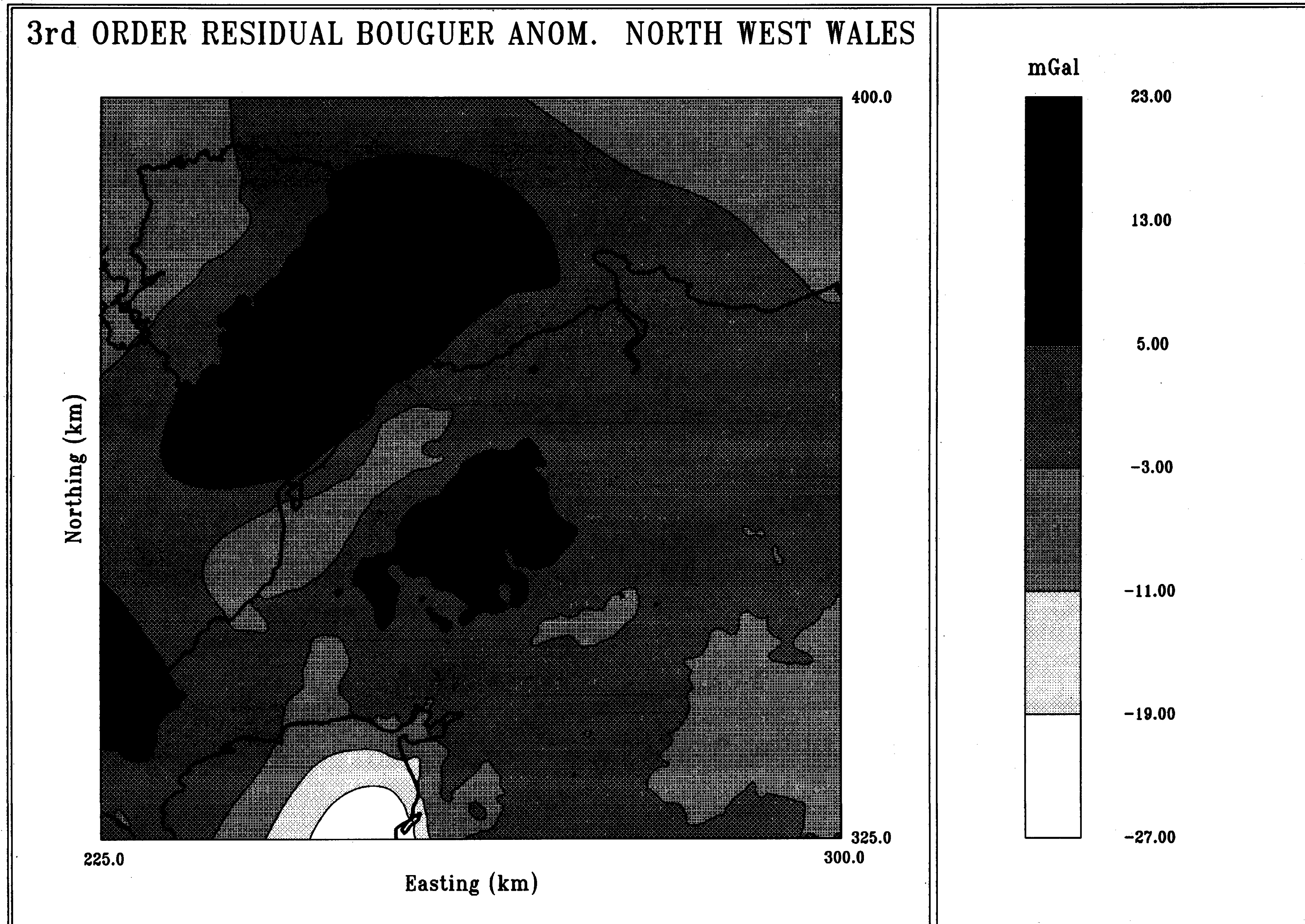


Figure 5 Third order residual Bouguer anomaly map of north-west Wales

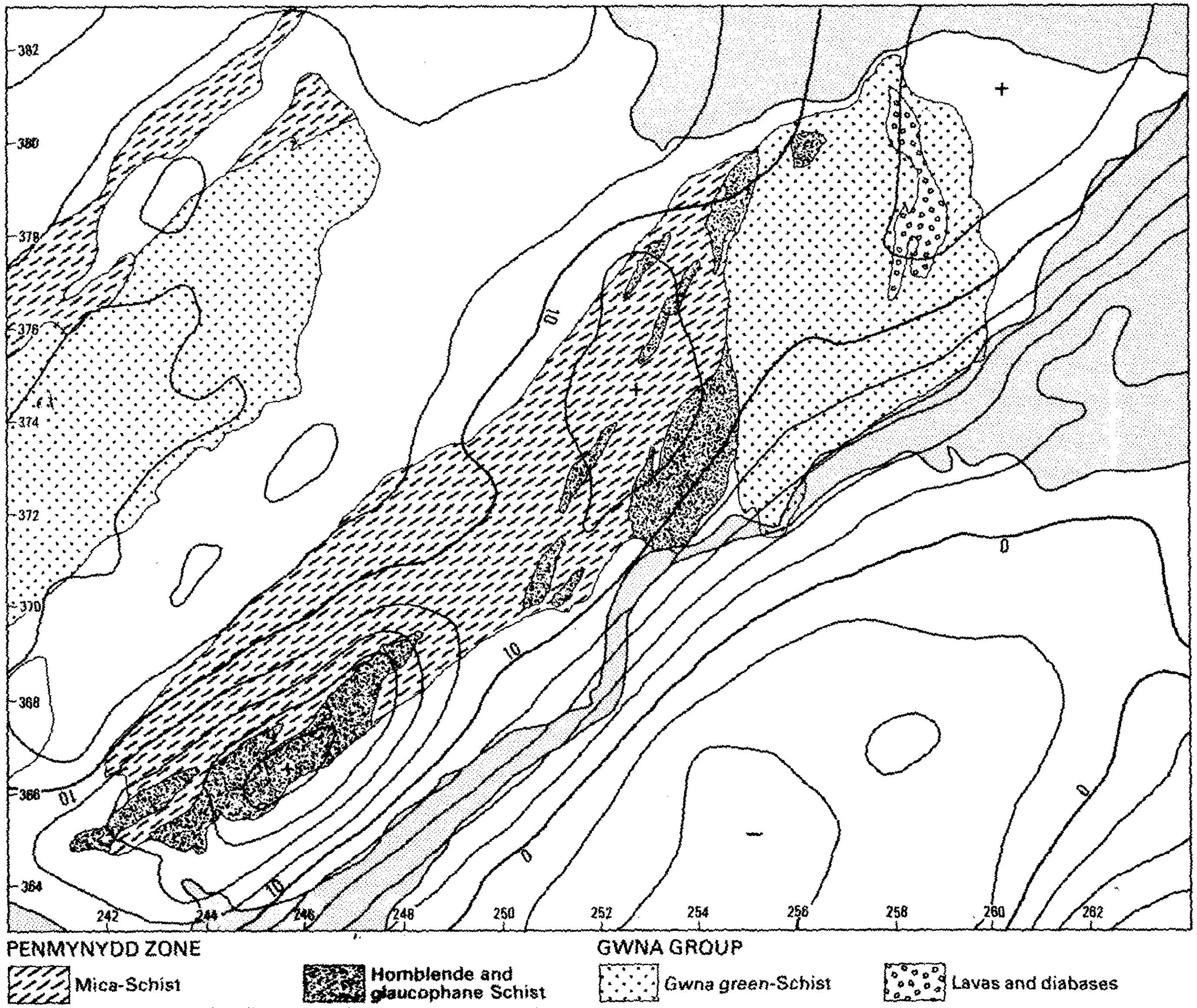


Figure 6 Residual Bouguer anomaly map of the Penmynydd Zone

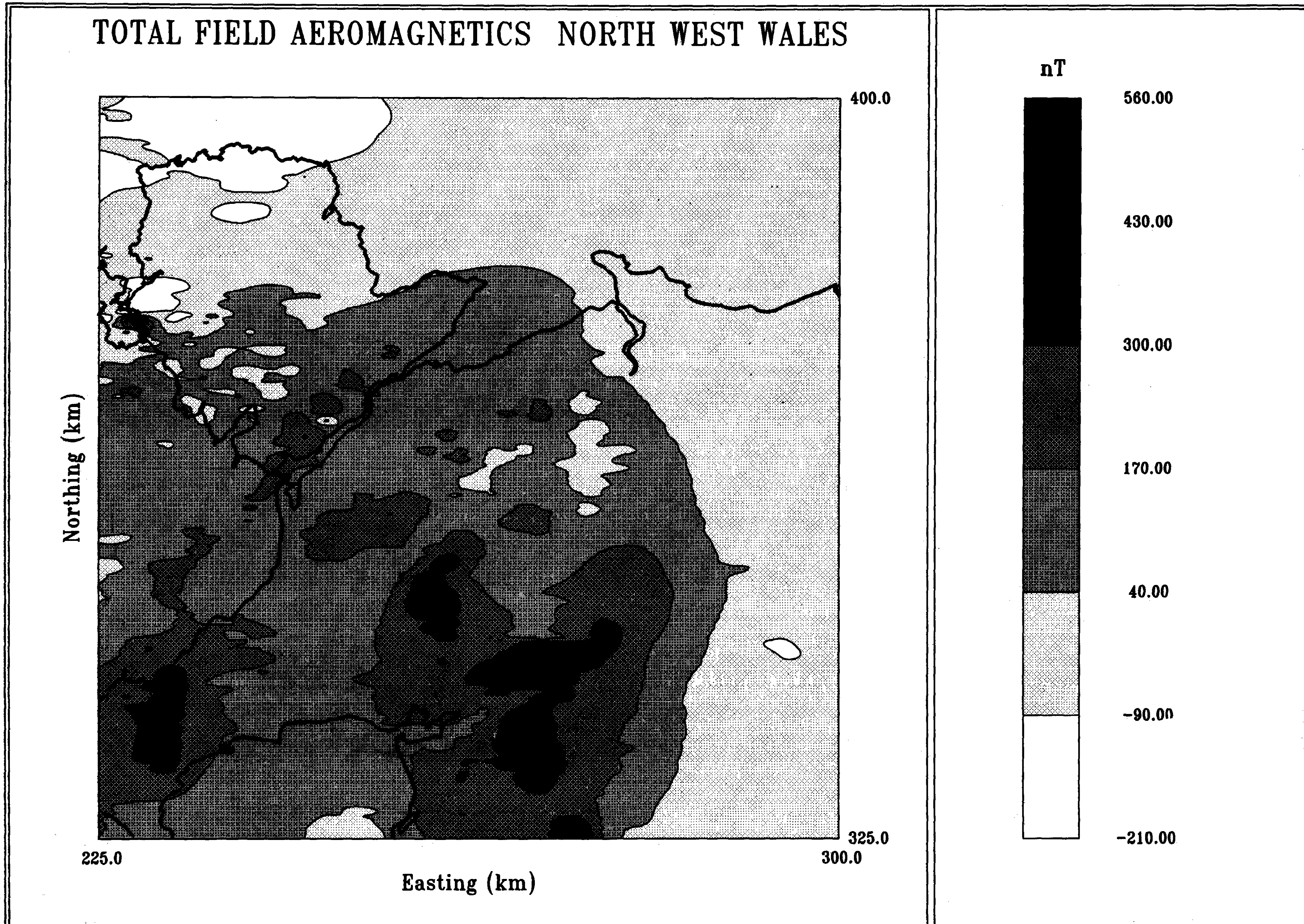


Figure 7 Total field aeromagnetic map of north-west Wales

Present work

The principal aim of the current geophysical work was to investigate the source of the residual gravity anomaly associated with the Mona Complex rocks in south-east Anglesey, deducing, if possible, its likely lithology and origin thus giving some constraints on its mineral potential.

Fieldwork comprising gravity, magnetic and Very Low Frequency (VLF) electromagnetic measurements was carried out across the Dwyran anomaly, the south-westernmost closure within the Penmynydd gravity feature (Figures 6 and 8). Additional infill gravity observations were made in the vicinity of the central closure near the village of Penmynydd.

Gravity

The absolute gravity value of a convenient local base station was determined by repeated looping to the National Gravity Reference Net (1973) Primary Base Station at Bangor. A total of 153 infill gravity readings were made, concentrated in zones of sparse cover and/or steep Bouguer anomaly gradients. Where possible these readings were made adjacent to either bench marks or spot heights but occasionally station elevations were established by contour intersection.

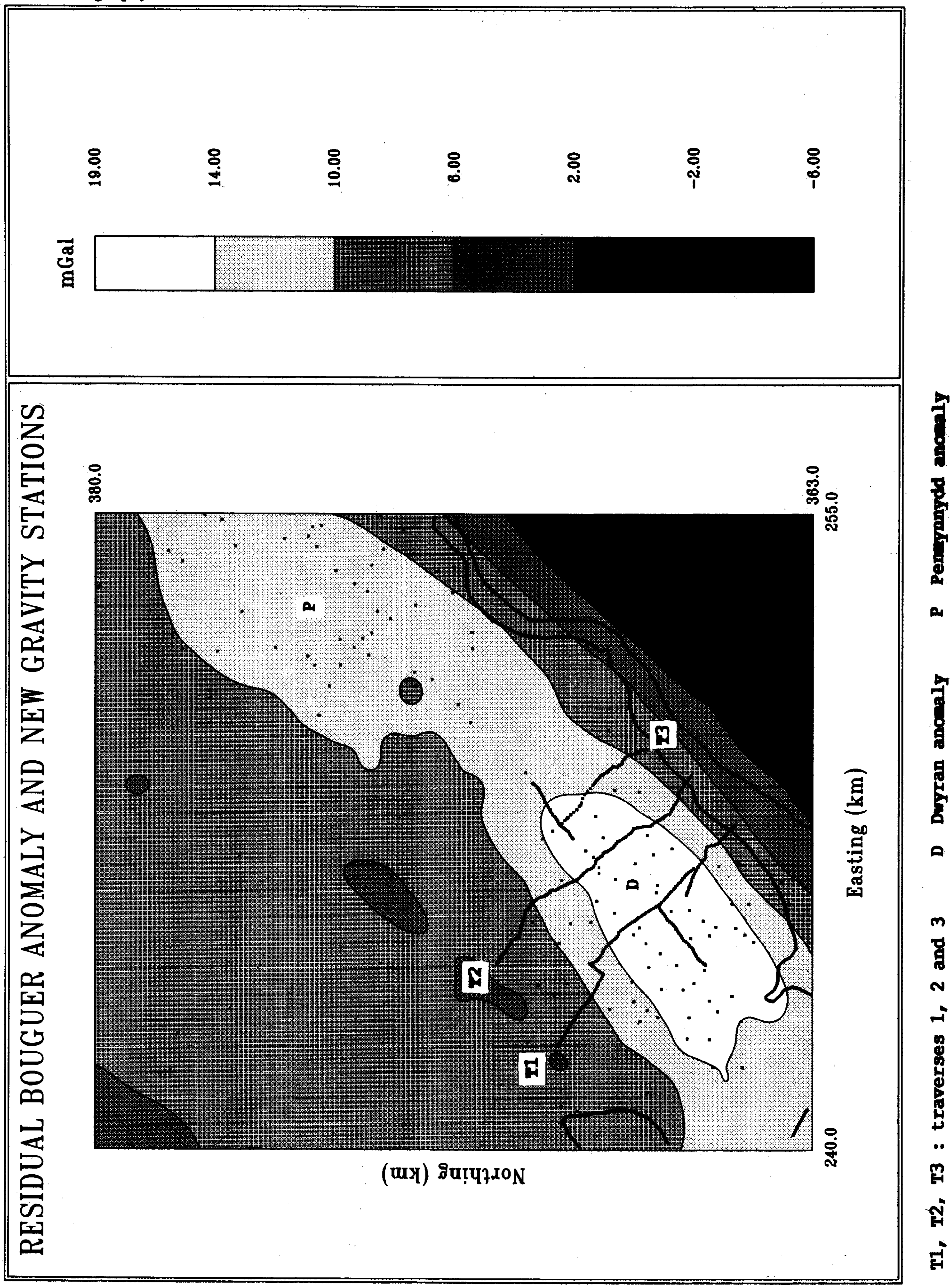
In addition to this infill coverage, five detailed traverses totalling 20.7 km were completed. Gravity observations were made generally at 50 m intervals (415 stations) along roads and tracks, deviating from these (following a compass bearing) where necessary to maintain a reasonably straight line. In these cases progress was hampered by the numerous hedges bordering small fields. Distances were taped and station locations were checked by reference to 1:10,000 scale maps. Heights were determined by concurrent optical levelling with tying-in to spot heights etc where practicable. Errors between points of known elevation (spot heights, sea level etc) were distributed through the traverse and were usually less than 1 m over 2 km. The locations of all the current gravity observations, including the traverses, are shown in Figure 8.

The gravity measurements were subjected to standard reduction procedures; the density value (2.7 Mg/m^3) applied is shown to be appropriate by the lack of correlation between reduced values and topography. Five readings were made at stations occupied during the earlier surveys and these showed discrepancies of Bouguer anomaly values in the range 0.02 - 0.17 mGal which is considered acceptable. All gravity values (including those from earlier surveys) have been terrain corrected to the X-zone (42 km) following the construction of a digital terrain model using height data supplied under licence by the Ordnance Survey (Rollin, 1990). In the area of current interest these terrain corrections are always less than 0.3 mGal.

Magnetics and VLF

A total of 10.1 km was covered on Traverses 1 and 3 using these techniques. Measurements were made at 25 m intervals, parallel to the gravity traverses but at least 50 m from roads and tracks where practicable. Despite this precaution both the magnetic and VLF data are strongly influenced by noise arising from cultural features such as fences and power lines. VLF measurements on Traverse 1, for instance, were influenced by high tension overhead power lines up to 300 m from the traverse. The total field magnetic values have been corrected for diurnal drift and tied to a base value of 48586 nT.

Figure 8 Residual Bouguer anomaly map of the Penmynydd Zone with gravity stations and geophysical traverses



VLF measurements comprised both the in- and out of- phase components of the vertical magnetic field and the horizontal field strength of the primary field. Transmitters used initially were Carlisle and Rugby; subsequently Oxford was substituted for Rugby following an unscheduled stoppage. These stations should provide optimum coupling with both along- and cross-strike conductors respectively.

The in-phase profiles were despiked to remove the cultural effects and then subjected to KHFILTER (Ogilvy and Lee, 1989) to generate current density pseudo depth sections as first described by Karous and Hjelt (1983). Ogilvy and Lee (1991) have recently shown that such sections yield reliable information on the lateral position and direction of dip of single, steeply dipping conductive plates. Further details of the field methods and data processing are included in Appendix 1.

Physical properties

Density and magnetic susceptibility measurements were made on one inch diameter core plugs cut from 19 samples selected to be representative of the principal rock types expected at surface in the survey area. Average values for the main lithologies found in the study area, resulting from this and earlier work (Forster, 1974) are shown in Table 1; generally accepted density values for the other lithologies present but not determined in this work are also included. Appendix 2 lists the results of all the individual determinations. In addition numerous in situ susceptibility determinations were made with a Kappameter at each of 18 different locations. It should be noted that such determinations (made on irregular rock faces, etc.) are likely to be underestimates by at least a factor of two.

Table 1 Initial density values used in modelling

Lithology	**Saturated density (Mg/m^3)**	**Lithology**	**Saturated density (Mg/m^3)**
Drift/Alluvium	2.00	Carboniferous Limestone	2.69
Red Beds	2.50	Gwna Group schist	2.80
Coal Measures	2.50	Penmynydd mica-Schist	2.70
Millstone Grit	2.50	Penmynydd horneblende-schist	3.01

Gravity and Magnetic Modelling

The physical property values have been used in modelling selected profiles using GRAVMAG (Pedley, 1991), an interactive computer programme developed in BGS for the 2.5 D interpretation of both gravity and magnetic data. The traverse results have been projected onto straight lines and local irregularities are preserved; elsewhere profiles have been extracted from the databank using GMPROF which process may involve some smoothing.

In addition, iterative 3-D gravity modelling was attempted using GM3D (Rollin, 1988). Vertical square prisms (of side 250 m) were assigned various densities and projected to various heights from a plane base at 3 km until a match was obtained within specified limits between the observed and calculated gridded Bouguer values.

Traverse 1

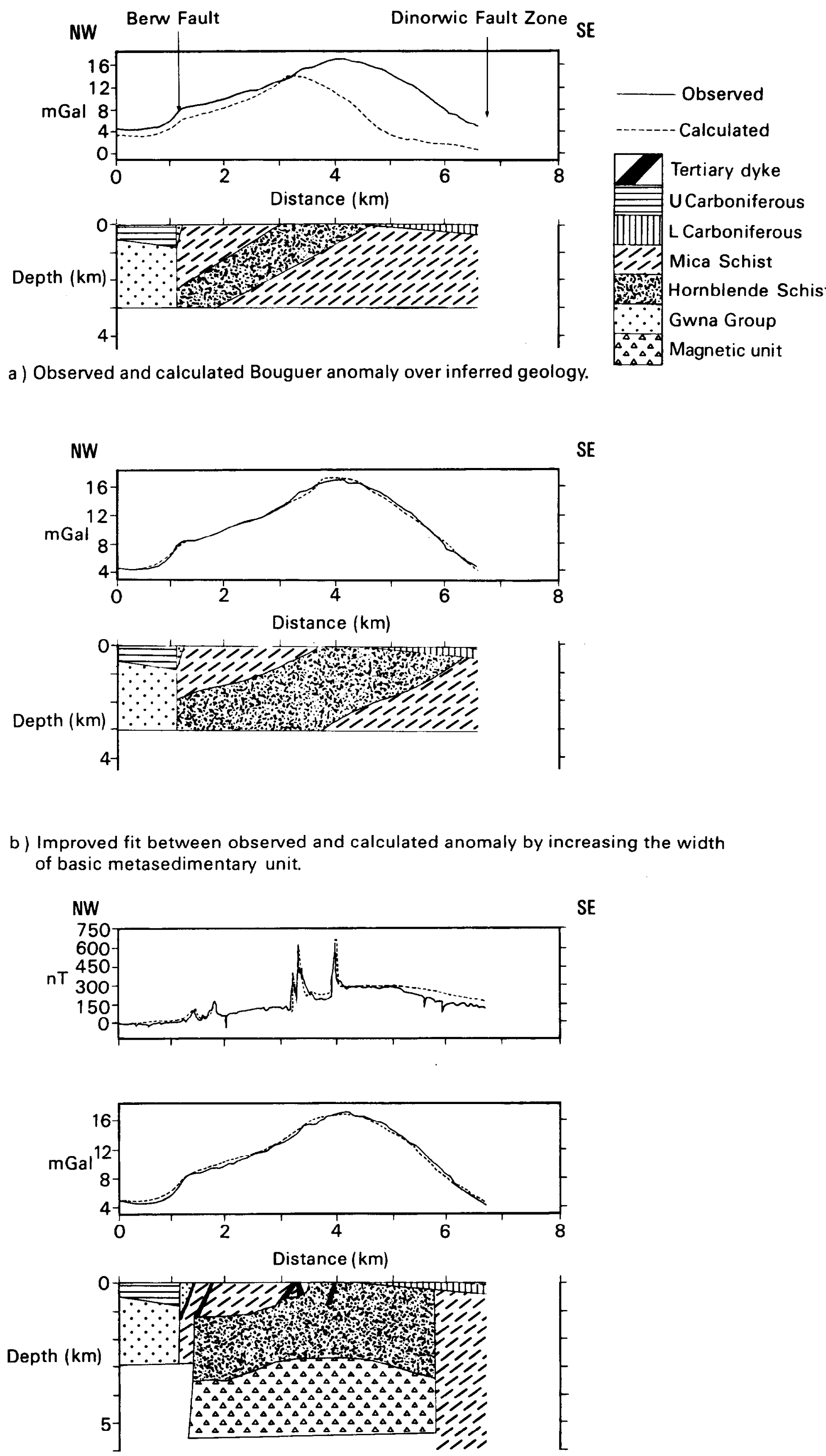
The initial 2.5 D gravity model of Traverse 1 (Figure 9a) is based on the section (Figure 2) abstracted from the Anglesey Special Sheet geological map, incorporating additional information from Greenly (1919). Briefly, at its north-west end the section comprises Gwna Group sediments overlain by a series (up to 800 m thick) of Carboniferous sedimentary rocks dipping at a shallow angle to the south-east. The basal limestone unit cannot be clearly resolved at this compressed vertical scale. The Carboniferous units, preserved in a downfaulted block by the sub-vertical Berw Fault, are in turn overlain by up to 30 m of marine alluvium and boulder clay in the low-lying Malltraeth Marsh area.

A wedge of Gwna Group rocks is enclosed within the Berw Fault zone, while immediately to the south-east, mica- and hornblende schists of the Penmynydd Zone are exposed in a belt some 3.5 km wide. These units are shown as roughly conformable with their cleavage/schistosity dipping at c. 50 degrees north-west, the metabasic unit terminating against the Berw Fault at a depth of about 3 km. These Mona Complex rocks are overlain to the south-east by Carboniferous sedimentary rocks and at its south-east end the section is bounded near the Menai Strait by the vertical Dinorwic Fault.

The observed Bouguer profile is dominated by a large, smoothly varying positive feature with only very minor local irregularities. The main difference between the observed profile (minus the computed regional effect of between 30 mGal in the north-west and 31.4 mGal in the south-east) and the computed profile for this initial section is the mass deficit in the south-east part (Figure 9a). In addition the calculated anomaly peaks almost 1 km further to the north-west than does the observed. Figure 9b shows a better match, achieved by increasing the thickness of the dense metabasic unit from c. 1 km to 2.2 km, by reducing its density slightly (from 3.01 Mg/m^3 to 2.95 Mg/m^3) and by moving the north-west edge of the body some 500m towards the south-east. This latter adjustment would imply that the occurrence of hornblende schist mapped at 3 km along the traverse has little depth extent. Similarly good fits can be found for this dipping-layer or slab model by increasing the density of the surrounding mica schist (to 2.8 Mg/m^3) and reducing the thickness of the dense body, with concurrent increase in its density (to a minimum thickness of about 600 m with a density of 3.01 Mg/m^3).

A weakness with this model is that it does not readily account for the observed long wavelength magnetic anomaly, for which the inclusion of a deep (lying between 3 and 6 km) and broad body extending beyond both the Berw and Dinorwic Fault zones is required. An alternative (preferred) model that does yield a good fit with both the observed gravity and magnetic profiles is shown in Figure 9c. This suggests an intrusive type of feature, fault bounded at both its north-west and south-east ends, while the suggestion of "doming" may indicate lateral compression. The position of the fault bounding the south-east end of this model (and the models for Traverses 2 and 3) lies not beneath the Menai Strait but some 1.5 km to the north-west of it under the Carboniferous. The rectilinear nature of the Menai Strait indicates that it may be controlled by two parallel north-east trending faults and the modelled edge may reflect an extension of the northernmost of these. A feature of this model is the conformable nature of the bodies responsible for the gravity and long wavelength magnetic anomalies.

Figure 9 Gravity and magnetic profiles and modelling - Traverse 1



a) Observed and calculated Bouguer anomaly over inferred geology.

b) Improved fit between observed and calculated anomaly by increasing the width of basic metasedimentary unit.

c) Good fit between observed and calculated magnetic and gravity profiles over (layered?) intrusive - like body with shallow magnetic units.

The upper body, extending from the surface to about 3.3 km depth, is relatively dense (2.92 Mg/m^3) compared with the surrounding mica schists (2.7 Mg/m^3) but of similarly low susceptibility (2×10^{-3} SI) as displayed by much of the hornblende schist in both laboratory and field tests. The density of the lower body, extending to about 5.5 km depth, is set at 2.7 Mg/m^3; it can, however, assume any greater value provided there remain no significant lateral density contrasts in its depth range (i.e. it could be assigned a greater density value than the upper body). The susceptibility of the lower body is set at 70×10^{-3} SI. While this value is typical of lithologies such as basalt, diorite etc, in this area only Tertiary dolerite has yielded such a high susceptibility reading.

The high amplitude, short wavelength magnetic anomalies of Figure 9c are ascribed to shallow (subcropping), generally north-west dipping magnetite-rich layers in the mica schists. Their susceptibilities lie in the range 5 to 20×10^{-3} SI; such values were commonly observed during in-situ measurements of the darker, more basic schists. Subsequent limited infill magnetic traversing in the Maesoglen Farm area (at 3 - 3.5 km along the traverse on Figure 9c) has shown at least some of these features to be of very limited strike extent, characterised by almost circular plan-view anomalies. It should be mentioned that the abundance of power lines and fences in the vicinity of 1.7 km along Traverse 1 (Figure 9c) may be responsible for the magnetic anomaly recorded here. Supporting evidence for the proposed model (Figure 9c) is that, when continued upwards to 300 m, the calculated magnetic field resembles closely the extracted aeromagnetic profile in terms of both amplitude (250 nT) and shape. Hence the aeromagnetic map (Figure 7) suggests a south-westerly extension of the layered unit, while the very limited gravimetric evidence for this may reflect lack of cover. Lastly, this model suggests that the hornblende schist mapped near 3 km, that cannot readily be incorporated with the main dense body, may represent a more basic layer within the mica schist.

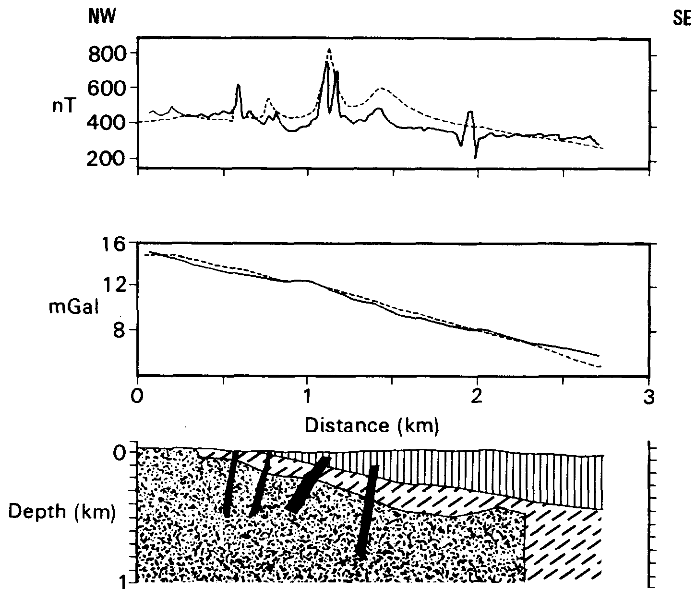
Other traverses and sections

The Bouguer profiles of Traverses 1 and 2 are very similar and the match between observed and calculated profiles in Figure 10b was achieved by minor adjustments to the geometry of the preferred Traverse 1 model. It is noteworthy that on Traverse 2 there is almost exact correspondence between the modelled and mapped locations of hornblende schist and Carboniferous Limestone, between which is shown a small wedge of mica schist at c 4.1 km along the traverse.

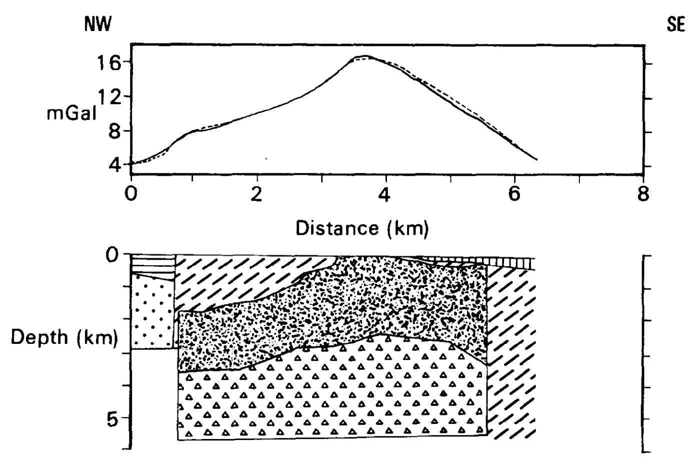
A close correspondence exists between the mapped subcrop and model results over the incomplete Traverse 3 (Figure 10a). The magnetic field in the vicinity of Traverse 3 is strongly affected by an intense local anomaly, probably related to cross-cutting Tertiary dykes. After applying an arbitrary correction for this influence (the addition to the observed field of between 0 nT in the north-west and 200 nT in the south-east), the short wavelength ground magnetic anomalies of Figure 10a are matched satisfactorily by steeply north-west dipping units of susceptibility in the range 10 - 80×10^{-3} SI. The magnetic anomaly between c. 1.9 and 2 km along the traverse reflects cultural features.

An attempt was made to model the Bouguer profile along strike of the Penmynydd Zone, from a point on the coast at Newborough Warren [2410 3630] to some 22 km north-east [2570 3780] (Figure 10c). The dense basic body has been assigned a half-strike length of 3 km and a density of 2.9 Mg/m^3, against a background density of 2.7 Mg/m^3, and a uniform regional value of 30 mGal has been removed from the observed profile. The steep sides on the upper surface of this model suggest that the dense body may be displaced vertically by block faulting.

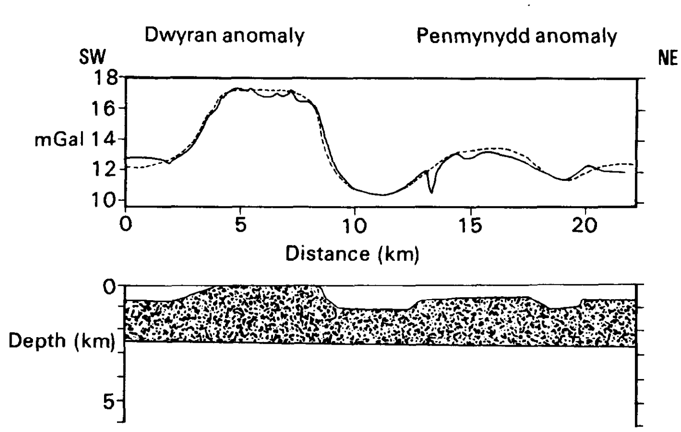
Figure 10 Gravity and magnetic profiles and modelling - Traverses 2 and 3, plus along-strike gravity profile and model



a)The match between observed and computed magnetic and gravity profiles of Traverse 3.



b)The intrusive body model yields a good match along Traverse 2.



c) Along strike variation in depth to dense body.

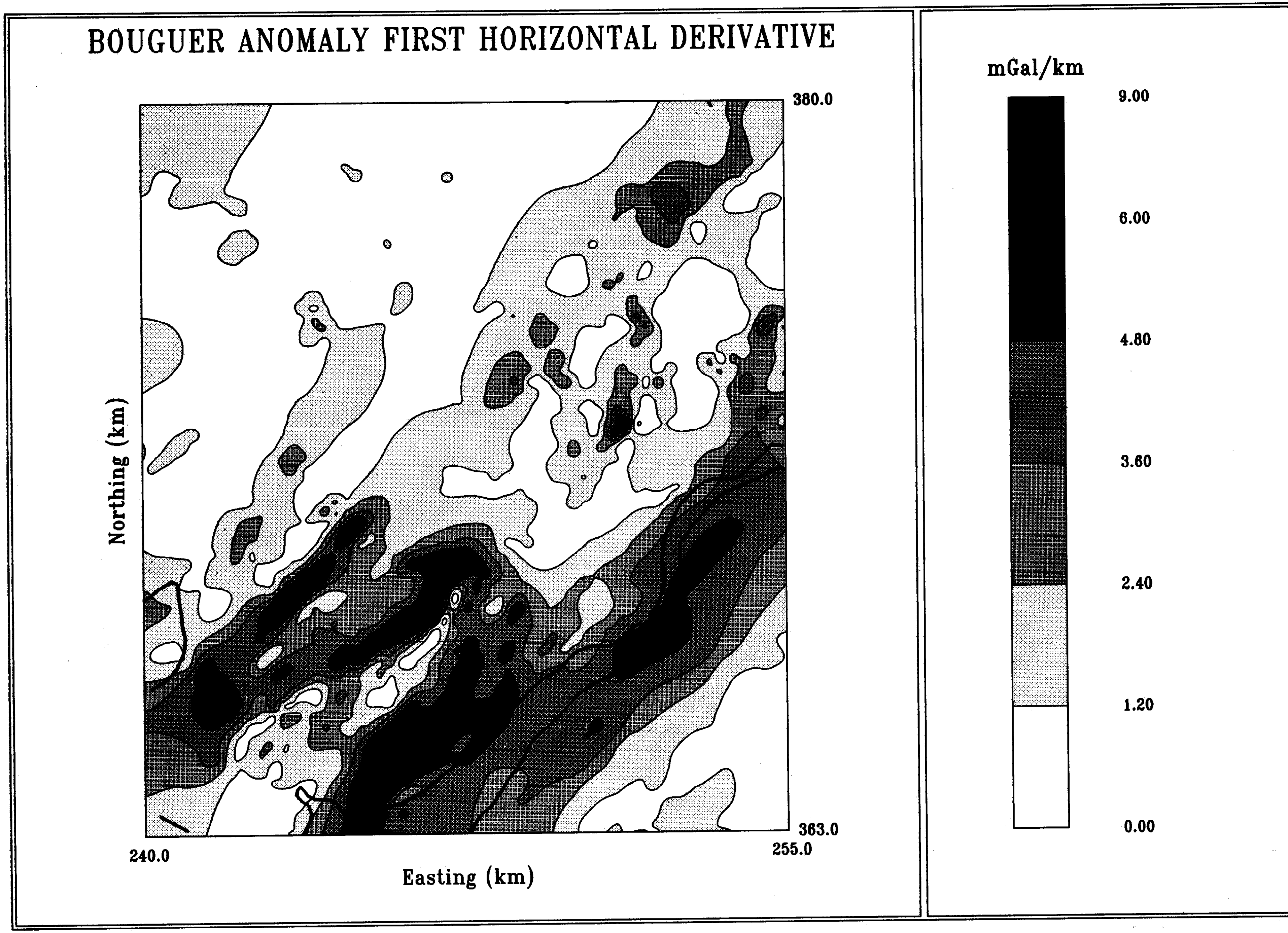
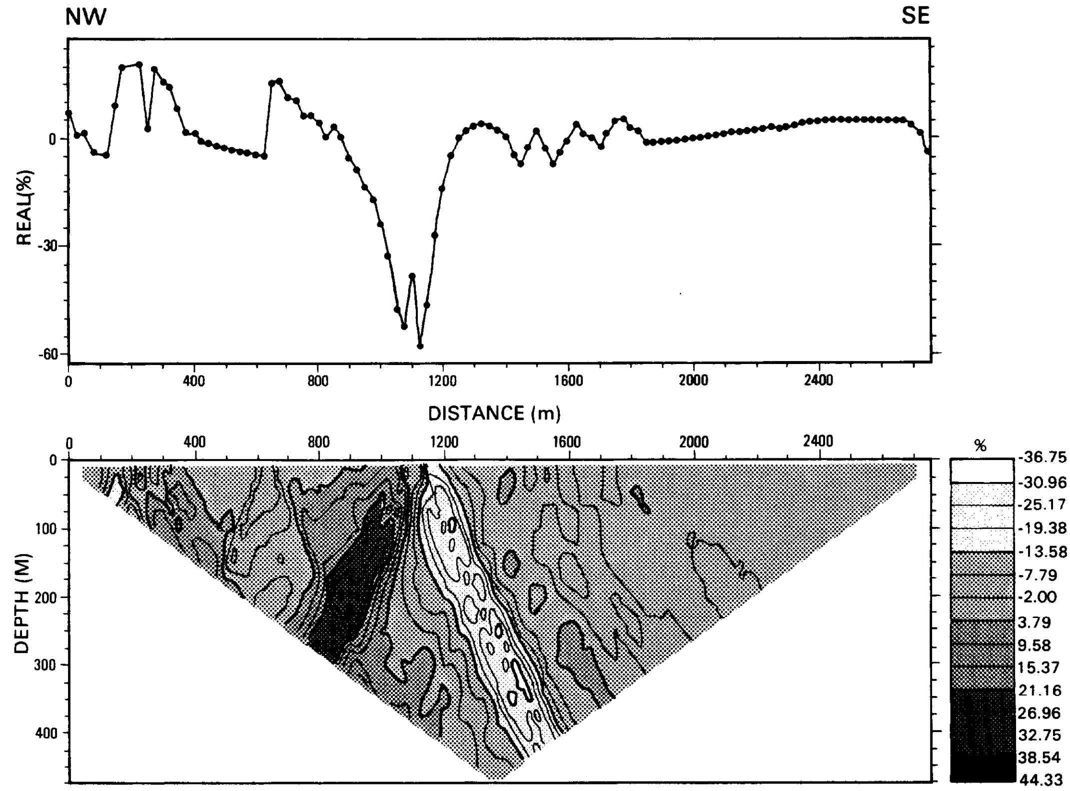


Figure 11 Bouguer anomaly - first horizontal derivative

Figure 12 VLF-EM (19 KHz) in-phase profile and apparent current density pseudo-section - Traverse 3



The in-phase component of the vertical field expressed as a percentage of the horizontal primary transmitted field is shown top. These values are subjected to linear filtering to give the apparent current density pseudo-section shown bottom. Darker tones indicate increasing current density (i.e. conductive body); the negative values have no physical meaning.

The regional aeromagnetic map (Figure 7) supports the presence of such faults, occupied by north-west trending Tertiary dykes. The model of shallow dense rocks in the Dwyran area is confirmed by the observed surface geology and also by the first horizontal derivative of the Bouguer anomaly of south-east Anglesey (Figure 11). Shallow features yield steep gradients and these are seen to predominate in the south-west quadrant with only isolated occurrences elsewhere. The indication of a north-west trending fault terminating the Dwyran block at its north-east edge is particularly strong in this presentation.

Attempts were made to model several other geological options; these included a pile of alternating lavas and sediments, both steeply dipping and tightly folded. Since all such models yield an undulating Bouguer profile with a high frequency component, at variance with that observed, these models were discounted.

VLF surveys

The contact between conductive and resistive environments at the edge of the Malltraeth Marsh is well displayed by both frequencies on Traverse 1 (not shown). Further to the south-east the 16 kHz measurements reveal a conductive zone, probably associated with the magnetic body within the hornblende schist at c. 3.9 km (Figure 9c).

A significant conductive zone, dipping to the north-west, is indicated by both frequencies in the vicinity of 1.1 km along Traverse 3 (Figure 12). This zone is further characterised by marked differences in the horizontal field strength extending to either side; this in turn probably reflects the contact between Carboniferous Limestone and Mona Complex rocks. This conductive body too is probably associated with the magnetic body indicated at 1.1 km (Figure 10a).

Discussion

Infill gravity observations combined with detailed gravity and magnetic traversing have confirmed the presence of a large, smoothly varying gravity and associated magnetic anomaly in south-east Anglesey, related apparently to hornblende schists of the Penmynydd Zone of metamorphic rocks.

Gravity modelling suggests that the dense metabasic unit, initially considered as a conformable, dipping layer, must be considerably more extensive than anticipated from its outcrop pattern. A preferred model matching both observed gravity and magnetic fields, suggests a layered intrusive feature, fault bounded at both its north-west and south-east margins, its upper part (0 km to c. 3.3 km) being relatively dense and its lower part (c. 3.3 km to 5.5 km) relatively magnetic. Along-strike modelling of this body indicates that it is disrupted by block faulting along a north-west trend, with faulted segments becoming successively deeper towards the north-east. It was not possible to match the observed gravity field with a model of steeply dipping/tightly folded alternating lavas and sediments (a favoured geological option).

Conclusions and recommendations

The observed gravity and long wavelength magnetic anomaly of the Dwyran area have been modelled successfully as a layered intrusive. It is relatively dense in its upper part and relatively magnetic below. High frequency magnetic anomalies indicate the presence of more basic zones within the metasediments. An extensive conductivity / magnetic feature associated with the contact between the Carboniferous Limestone and the Penmynydd Zone may be worthy of follow up.

GEOCHEMICAL SURVEYS

Previous investigations

The low relief and poorly developed drainage of the area presented a problem during the earlier reconnaissance stream sediment sampling survey of Anglesey (Cooper et al., 1982). No samples were collected from the area around Newborough, and north-east along the Berw Fault past Llangaffo, because of the absence of surface drainage. Only nine stream sediment and panned concentrate samples were taken from the area bounded by Llangaffo, Newborough and Brynsiencyn (Figure 13). Some anomalies were found around Llangaffo, notably in a panned concentrate sample from Dinam Bridge [24540 36830] which contained nearly 2% Ba. This was caused by baryte, believed to be derived from metamorphic basement and Carboniferous rocks containing thin veins of baryte. Two weak Pb anomalies were found to the south-west of Llangaffo near Glan Morpha at [24320 36780] and near Ty-mawr at [24240 36680] along strike from the mineralisation recorded by Greenly (1919) at Llangaffo. These anomalies in themselves were not particularly encouraging, but the experience gained by this initial survey showed that, in the area of the Dwyran gravity anomaly, soil sampling could be more effective than drainage sampling in detecting metal anomalies.

Current survey

The aims of the geochemical work were a) to assist the geophysical interpretation of the Dwyran gravity anomaly by determining the origins of the basic rocks and b) to provide information on the mineral potential of the area. The first objective was achieved by interpretation of the major and trace element analyses of the basic rocks. The second by the analysis of soil samples collected along reconnaissance traverses across the area and by analysis of rocks from the silicified zone to the south-west of Llangaffo described by Greenly (1919).

Rock sampling

A total of 35 rock samples were collected, mainly from natural outcrops. They were predominantly of metabasic rocks, but included some silicified samples from the zone adjacent to the Berw Fault recorded by Greenly (1919). Twenty samples were taken from the area of the Dwyran gravity anomaly between Newborough and Llanfairpwllgwyngyll of which 14 were analysed for major elements. The sample locations are shown on Figure 13. Eleven samples (Figure 14) were taken from the area north of the Bangor - Holyhead railway line between Llanfairpwllgwyngyll and Pentraeth, all were analysed for major elements. Three samples were taken from two small quarries south-east of Gwalchmai, west of the Malltraeth, where Greenly (1919, p 114) noted pyritic hornblende schist, two of which were analysed for major elements. All the rock samples (1 - 4 kg) were crushed to -10 mm, and 150 g splits were Tema-milled to -150 μm. 12 g splits were mixed with 3 g of Elvacite binder and milled in a P5 ball mill for 30 minutes.

The resultant powder was pressed to make a pellet for X-Ray Fluorescence (XRF) analysis at Keyworth. 21 elements were determined using a Phillips 1480 spectrometer; Ca, Ti, Mn, Fe, As, Ba, Ce, Co, Cr, Cu, La, Nb, Ni, Pb, Rb, Sb, Sr, V, Y, Zn and Zr. A smaller number (28) of unmineralised basic rock samples, with one silicified sample from Llangaffo, were analysed for major elements and Loss on Ignition (LOI) using fused borax beads with a 1 g sample, also by XRF. 17 samples (Tema milled powder) were analysed for precious metals by Acme Laboratories of Vancouver either because they contained visible sulphides or to provide background data for unmineralised rocks. Au, Pt, Pd and Rh were determined on 30 g samples by an ICP/Graphite Furnace analysis. All the analysed samples, together with excess material, are held in the National Geosciences Data Centre (NGDC) at Keyworth and the geochemical data held on the MRP (ORACLE) database at Keyworth.

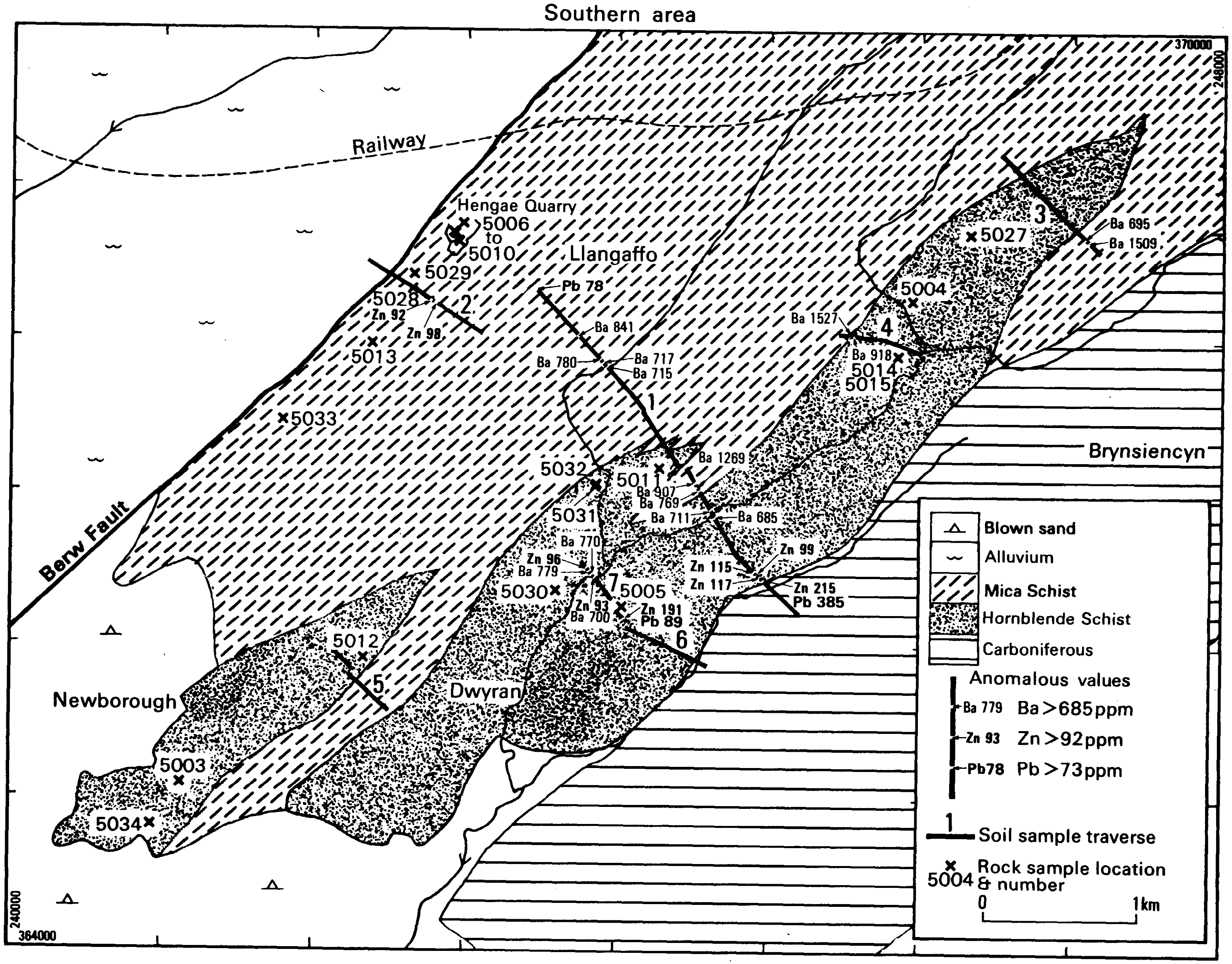


Figure 13 Geology, rock sample locations, soil sample traverses and anomalies, Southern Penmynydd Zone

Results

The samples have been separated into five sets on spatial and geological (not geochemical) grounds and summary statistics are shown in Table 2.

1. Fourteen samples from the area of Newborough to Llanfairpwllgwyngyll ('Southern' set).

2. Three samples from the glaucophane schist of Greenly (1919) to the north-west and north of Llanfairpwllgwyngyll ('Glaucophane' set).

3. Five samples from the basic hornblende schist to the north of the railway line ('Northern' set).

4. Three samples of 'basic gneiss' of Greenly (1919) ('Basic gneiss' set).

5. Three samples from the hornblende schist at Gwalchmai ('Gwalchmai' set).

Petrogenesis

The chemistry of the metabasic rocks is consistent with a basaltic parentage (Table 2). Comparison with a Mean Ocean Ridge Basalt (MORB) normalised spidergram (Pearce, 1982) for all the sets (Figure 15a) shows the enrichment in Large Ion Lithophile (LIL) elements such as K, Rb and especially Ba. The rest of the elements, however, show very similar values to MORB with the exception of Nb, Ce, P and Zr which are considerably depleted in the three samples of 'basic gneiss'. This could be due to an absence of apatite, a common host for these elements, in these rocks, compared to the other samples. Ce is also slightly depleted in the glaucophane schist samples, though not the other elements mentioned above. The base metals Cu and Zn are slightly depleted and enriched respectively in all the lithologies. Other elements of potential economic interest, such as Cr and Ni (not shown) are generally well below MORB values. Two of the three samples from the Gwalchmai area, which contain minor pyrite, do show some enrichment in the LIL elements K, Rb and Ba, but are otherwise similar to the other samples.

The analyses of the rocks show no evidence of metasomatic alteration, the spidergram indicating normal levels of the elements most likely to be affected by hydrothermal alteration - Na, Ca and Sr. The 'igneous spectrum' plot (Hughes, 1972) which relates to depletion and/or enrichment in the alkali elements K and Na (Figure 16), also shows that almost all the samples plot within the spectrum and have therefore not suffered major changes to the contents of alkali elements. The only exception is a sample from Gwalchmai which contains minor pyrite.

Immobile element bivariate plots, such as that for TiO_2/Zr (Figure 15b), show that all the sets form a continuum without obvious separate fields. The TiO_2/Zr plot shows a constant gradient for most of the samples, with only some of the southern set diverging from this gradient at high levels of Zr. This may reflect separation of a Ti phase from the parent magma. The northern basics show a particularly compact grouping.

Other tectonic setting discrimination plots (e.g. Winchester and Floyd, 1977) indicate that all the basic rocks show the chemical characteristics of Oceanic Tholeiitic Basalts (e.g. Figure 15c).

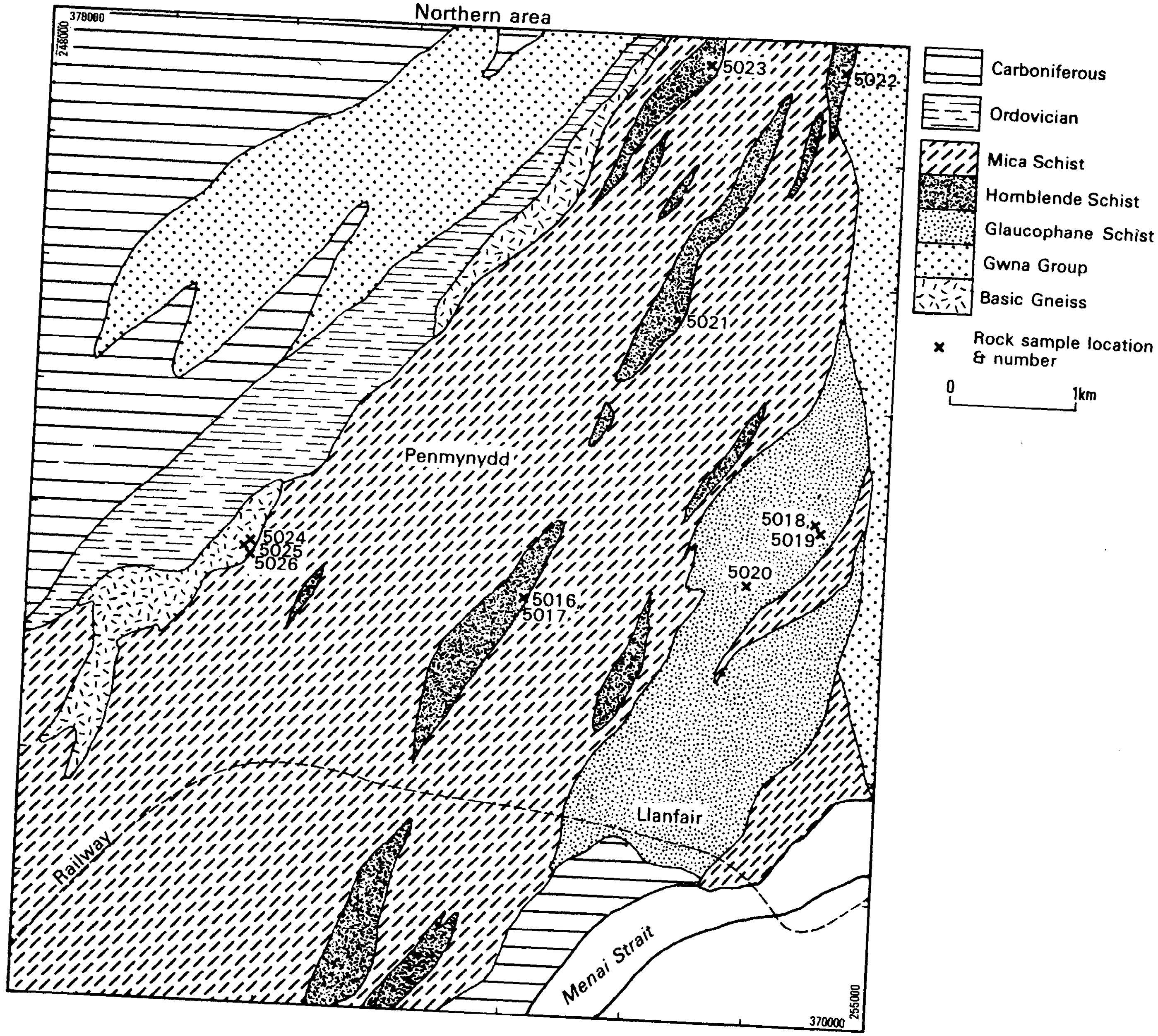


Figure 14 Geology and rock sample locations - Northern Penmynydd Zone

Table 2 Summary Statistics of the five sets of rock samples

		SiO2 %	Al2O3 %	TiO2 %	Fe2O3 %	MgO %	CaO %	Na2O %	K2O %	MnO %	P2O5 %	As	Ag	Ba	Ce
Southern	Median	48.94	13.56	2.03	13.51	6.63	9.02	2.45	0.28	0.26	0.16	0	4	99	11
basic	Mean	48.88	13.40	2.12	13.74	6.28	8.91	2.53	0.39	0.27	0.23	1	4	124	14
	Max.	50.81	15.28	3.72	18.36	7.11	11.61	4.08	1.31	0.33	0.52	4	5	473	42
n=14	Min.	46.25	12.21	1.13	11.25	4.13	6.54	1.15	0.10	0.24	0.05	0	0	50	0
	SD.	1.30	0.87	0.76	1.75	0.94	1.42	0.77	0.34	0.03	0.17	1	1	111	14
Northern	Median	48.08	14.15	1.55	11.38	7.00	10.32	2.95	0.30	0.24	0.13	0	3	72	13
basic	Mean	47.61	14.25	1.71	12.03	6.83	10.36	3.01	0.39	0.24	0.14	0	3	71	12
	Max.	48.86	14.89	2.37	14.74	7.40	11.67	3.31	0.56	0.27	0.20	2	5	88	20
n=5	Min.	45.63	13.49	1.51	11.09	5.89	9.07	2.64	0.27	0.22	0.11	0	2	52	3
	SD.	1.24	0.60	0.37	1.53	0.56	0.96	0.27	0.15	0.02	0.03	1	1	16	6
Glaucophane	Median	46.94	13.17	1.88	14.01	6.56	10.57	2.06	0.21	0.26	0.13	2	4	60	4
basic	Mean	47.44	13.32	2.04	14.32	6.53	10.51	2.21	0.19	0.27	0.14	1	4	64	31
	Max.	49.04	13.82	2.42	15.29	7.03	10.67	2.58	0.30	0.27	0.17	2	5	85	85
n=3	Min.	46.33	12.97	1.83	13.65	5.99	10.30	2.00	0.07	0.26	0.12	0	4	48	3
	SD.	1.43	0.44	0.33	0.86	0.52	0.19	0.32	0.12	0.01	0.03	1	1	19	47
Basic	Median	46.98	13.77	1.30	11.97	8.52	10.11	2.57	0.18	0.23	0.08	2	4	59	1
gneiss	Mean	47.26	14.29	1.33	11.47	8.62	10.02	2.85	0.23	0.22	0.08	2	3	70	1
	Max.	48.59	15.75	1.77	13.54	9.12	11.60	3.48	0.34	0.27	0.12	4	4	95	2
n=3	Min.	46.22	13.35	0.92	8.91	8.22	8.36	2.51	0.16	0.18	0.05	1	1	56	0
	SD.	1.21	1.28	0.43	2.35	0.46	1.62	0.54	0.10	0.05	0.04	2	2	22	1
Gwalchmai	Median	47.68	13.50	1.71	11.39	5.76	8.70	2.01	1.20	0.27	0.16	12	4	224	6
basic	Mean	47.68	13.50	1.73	11.55	5.76	8.35	2.01	1.20	0.26	0.16	11	4	243	7
	Max.	51.81	14.27	2.12	12.81	6.66	9.19	2.03	2.11	0.27	0.16	21	4	431	11
n=3	Min.	43.55	12.72	1.35	10.45	4.85	7.15	2.00	0.30	0.25	0.16	0	4	75	4
	SD.	5.84	1.10	0.39	1.19	1.28	1.07	0.02	1.28	0.01	0.00	11	0	179	4

Table 2 Summary statistics of the five sets of rock samples

		Co	Cr	Cu	La	Nb	Ni	Pb	Rb	Sb	Sr	V	Y	Zn	Zr
Southern	Median	43	119	63	4	5	44	2	5	0	106	294	39	117	132
basic	Mean	41	114	62	7	8	39	7	7	0	130	311	38	123	152
	Max.	51	285	109	23	25	65	65	35	3	324	429	67	224	281
n=14	Min.	30	7	26	0	1	14	0	0	0	66	233	25	85	49
	SD.	6	68	20	8	7	16	17	9	1	71	59	11	38	77
Northern	Median	47	157	68	5	8	63	0	5	0	179	219	22	85	96
basic	Mean	44	148	64	5	8	68	1	6	1	178	237	24	91	114
	Max.	50	199	84	7	12	96	2	13	4	212	317	33	116	188
n=5	Min.	36	90	40	4	6	39	0	3	0	152	210	20	77	94
	SD.	6	50	19	1	2	22	1	4	2	24	45	5	16	41
Glaucophane	Median	47	109	39	5	4	35	3	4	0	116	333	38	108	129
basic	Mean	47	114	62	4	4	35	2	3	0	115	349	41	107	135
	Max.	49	128	121	5	5	39	4	5	1	122	381	49	116	159
n=3	Min.	44	105	27	3	3	31	0	1	0	108	332	36	97	117
	SD.	3	12	51	1	1	4	2	2	1	7	28	7	10	22
Basic	Median	43	195	64	3	1	59	3	5	0	114	247	27	204	64
gneiss	Mean	42	268	55	2	1	82	3	4	0	117	251	25	173	64
	Max.	43	423	73	3	2	129	4	6	0	138	314	33	261	85
n=3	Min.	40	186	27	0	1	57	3	2	0	100	192	16	54	42
	SD.	2	134	24	2	1	41	1	2	0	19	61	9	107	22
Gwalchmai	Median	41	125	57	3	6	31	2	71	0	132	342	33	113	129
basic	Mean	43	159	46	3	6	36	3	54	0	138	337	37	102	132
	Max.	49	241	65	3	6	49	6	85	1	153	380	44	114	140
n=3	Min.	38	112	16	2	5	29	0	6	0	128	289	33	80	127
	SD.	6	71	26	1	1	11	3	42	1	13	46	6	19	7

Table 2 Continued:-

Metalliferous enrichments in the basic rocks

Levels of elements, such as Fe, Mn, Ti, Cr, Ni and Co, which are likely to be concentrated in the basic igneous rocks are generally low and are well within the background ranges for oceanic basalts (Table 2). Cr values have a mean of 139 ppm and a maximum of 423 ppm in a basic gneiss. Ni reaches 129 ppm from a mean of 47 ppm. TiO_2 varies from 0.9 % to 3.43 %. V has a mean of 289 ppm and a maximum of 429 ppm. Base metals (Cu, Pb and Zn) also show no abnormal enrichments apart from one loose block with malachite veining (OHR 5015) near Bodrida which contains 762 ppm Cu. Greenly (1919) states that this is not uncommon in the area, although no other similar samples were seen during the present survey. Arsenic is uniformly very low with a maximum of 21 ppm in a pyritic hornblende schist from Gwalchmai. Ba reaches a maximum of 503 ppm, with 109 ppm Cu, in a hornblende schist from Hengae Quarry which is veined with quartz, pyrite and a trace of chalcopyrite. A quartz-pyrite lens in a shatter zone in the same quarry showed no base-metal enrichment with 16 ppm As, 13 ppm Cu, 8 ppm Pb and 107 ppm Zn. Two outcrops of silicified schist and pyritic silica rock also contained very low levels of base metals.

Precious metals

The reference by Greenly to gold and silver values in samples from the Hengae Quarry near Llangaffo, and the occurrence of silicified, pyritic rocks adjacent to the major Berw Fault zone, suggested the possibility of precious metal mineralisation in the area. The possible resemblance to the structural setting and the quartzose rocks of the Hope Brook gold deposit in Newfoundland (Yule et al., 1990) was also a factor influencing the investigation of this zone. Accordingly, seventeen samples from a variety of locations and rock types were analysed for Au, Pt, Pd and Rh. The results are shown in Table 3.

Table 3 Precious metal results for rock samples

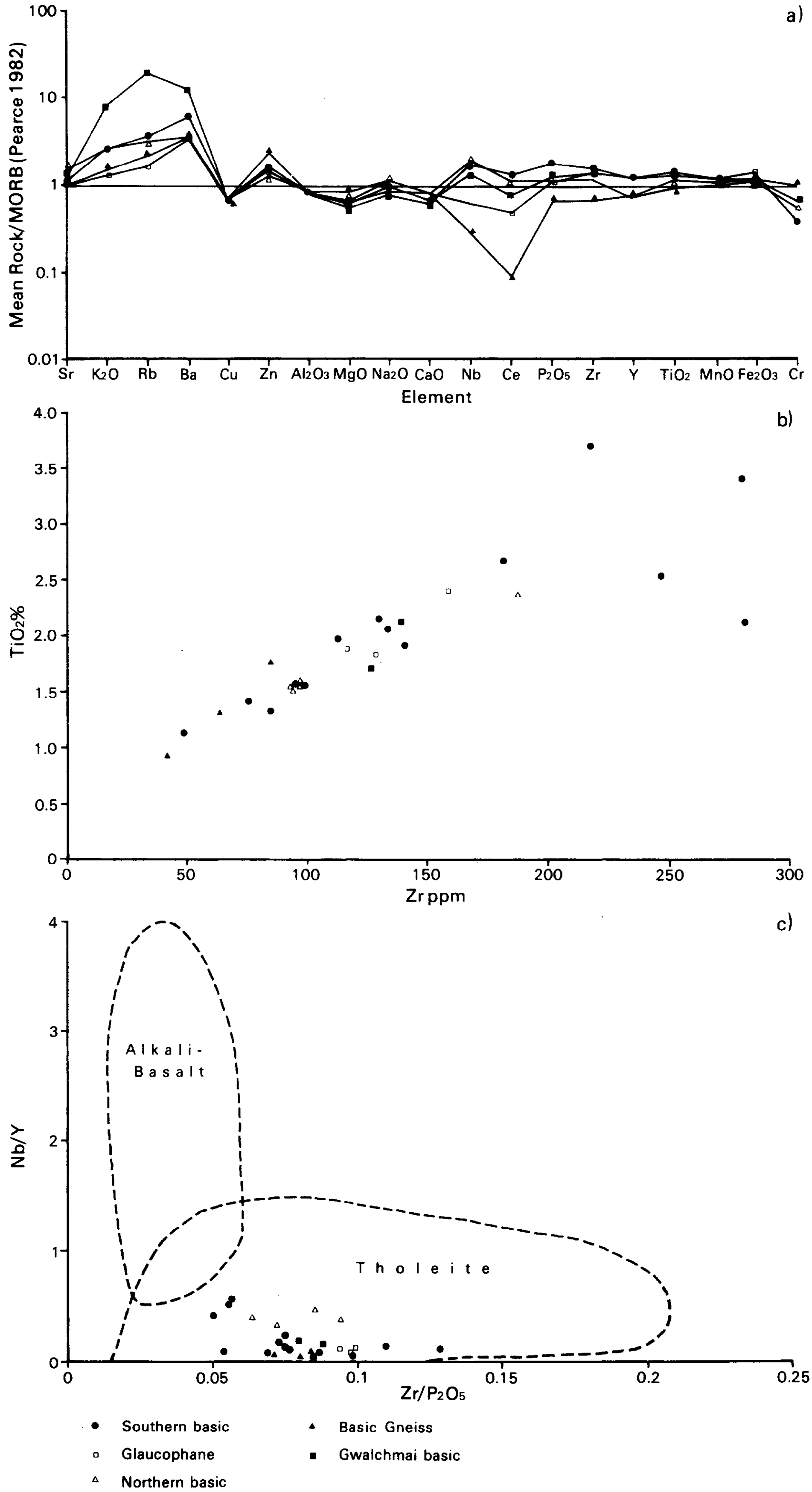
Sample No	Au ppb	Pt ppb	Pd ppb	Rh ppb	Area	Lithology
OHR 5001	2	3	3	3	Gwalchmai	Mica schist with pyrite
OHR 5003	4	2	2	4	Newborough	Hornblende schist
OHR 5004	1	1	2	2	Llangaffo	Hornblende schist
OHR 5005	1	1	2	2	Dwyran	Hornblende schist
OHR 5006	8	3	3	2	Hengae Quarry	Quartz-pyrite-sphalerite vein
OHR 5009	5	3	3	2	Hengae Quarry	Hornblende schist
OHR 5011	3	1	2	2	Llangaffo	Hornblende schist
OHR 5012	1	3	2	2	Dwyran	Hornblende schist
OHR 5013	2	2	2	2	Berw Fault	Silica rock
OHR 5014	4	1	2	2	Brynsiencyn	Hornblende schist
OHR 5015	1	1	2	2	Brynsiencyn	" " Cu stained
OHR 5016	1	4	2	2	Llanfair	Hornblende schist
OHR 5019	6	3	2	2	Llanfair	Glaucophane schist
OHR 5020	1	1	2	2	Llanfair	Glaucophane schist
OHR 5021	2	3	3	2	Llanfair	Glaucophane schist
OHR 5028	5	24	2	2	Berw Fault	Silicified schist
OHR 5033	1	14	2	2	Berw Fault	Silica rock

Figure 15 Lithogeochemical plots of the basic rocks

a) Spidergram showing variation from MORB

b) Plot of TiO_2 versus Zr

c) Nb/Y versus Zr/P_2O_5 discrimination plot (after Winchester and Floyd, 1977)



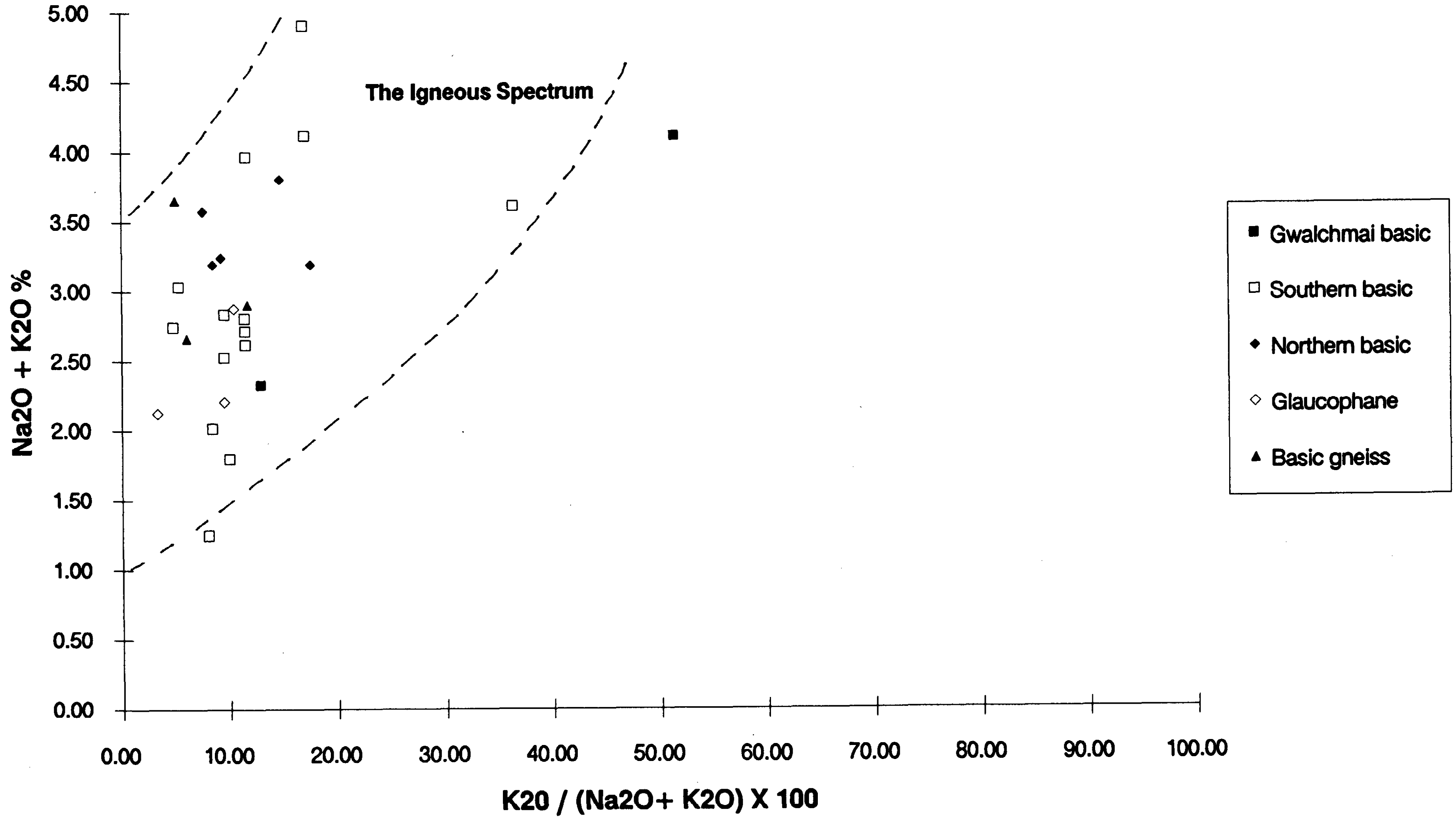


Figure 16 Igneous spectrum (after Hughes, 1972)

Rh and Pd levels are uniformly low at <4 ppb. Au levels are also low reaching a maximum of 8 ppb in a sample of a pyrite / sphalerite vein from a 30 m wide quartz - veined zone in Hengae Quarry. A sample of unmineralised hornblende schist from the same quarry contains 5 ppb Au. Five other samples contain >3 ppb Au, but there appears to be no spatial or chemical correlation with these slightly elevated results. Platinum values show more variation. The maximum value of 24 ppb Pt (and 5 ppb Au) was recorded in a sample (OHR 5028) of highly siliceous rock (82.84 % SiO_2) on the Berw Fault scarp 1 km south-west of Llangaffo. It may be significant that the only other sample which contains >4 ppb Pt is also on the fault scarp, 3 km to the south-south-west at Glyn Teg (OHR 5033). This contains 14 ppb Pt and is probably the outcrop described by Greenly (1919, p 568) as 'siliceous'. However it only contains 48.92 % SiO_2 and is geochemically similar to the other basic rocks. The siliceous rock zone is only sporadically exposed and appears to be of no great width. Another silicified, pyritic rock (OHR 5013) contained only 2 ppb of each of the four elements. There are no indications of enhanced base-metal values in the silicified rocks.

Soil sampling

A total of 269 soil samples were taken at 25 m intervals during September 1990 on seven traverses approximately normal to the strike of the rocks and covering the full range of lithologies present in the area, concentrating on the area of the Dwyran gravity anomaly underlain by the basic schists (Figure 13). Sampling was by hand auger with sample depth varying from 25 to 100 cm. All the samples were dried at 110° C, disaggregated in an agate mortar and sieved to -150 μm. A 12 g subsample was added to 3 g of Elvacite binder and milled in a P5 rotary ball mill for 30 minutes before being pressed into a pellet for subsequent XRF analysis. All the samples were analysed at Keyworth using the Phillips 1404 XRF spectrometer for Ba, Cu, Pb, Zn, Fe, Mn, Ti, V, Zr. A smaller number of samples, which crossed the silicified zone of Greenly near the Berw Fault, were also analysed for As (using the Phillips 1480 XRF Spectrometer) as a possible pathfinder for gold. The analytical results, subdivided into groups on the basis of the underlying rock types, are summarised in Table 4 and those for each element in Table 5.

Results

The results are remarkably uniform with the exception of Fe and Mn. The log-probability plots (not shown) generally indicate one population, with the exceptions of Ba, Fe, Mn, Pb and Zn.

There is little variation with lithology; for example Traverse 1 (Figure 17b) shows that Cr and V levels remain unaltered, or even increase slightly, from the basic rocks of the Penmynydd Zone to the Carboniferous Limestone as though the variations do not coincide with the mapped contact. This may indicate that sampling did not penetrate the blanket of drift deposits which cover the area. However, there are local, well defined Ba anomalies e.g. Traverses 1 (Figure 17a) and 3 (Figure 17c) which indicate a very local source - perhaps a thin vein - which suggests that the soil sampling would have revealed near-surface metalliferous mineralisation if it had been present.

Figure 17 Soil sample traverses: a) Traverse 1; i) Ba Pb Zn; ii) V Cr; b) Traverse 2 Cu Pb Zn; c) Traverse 3 Mn Ba

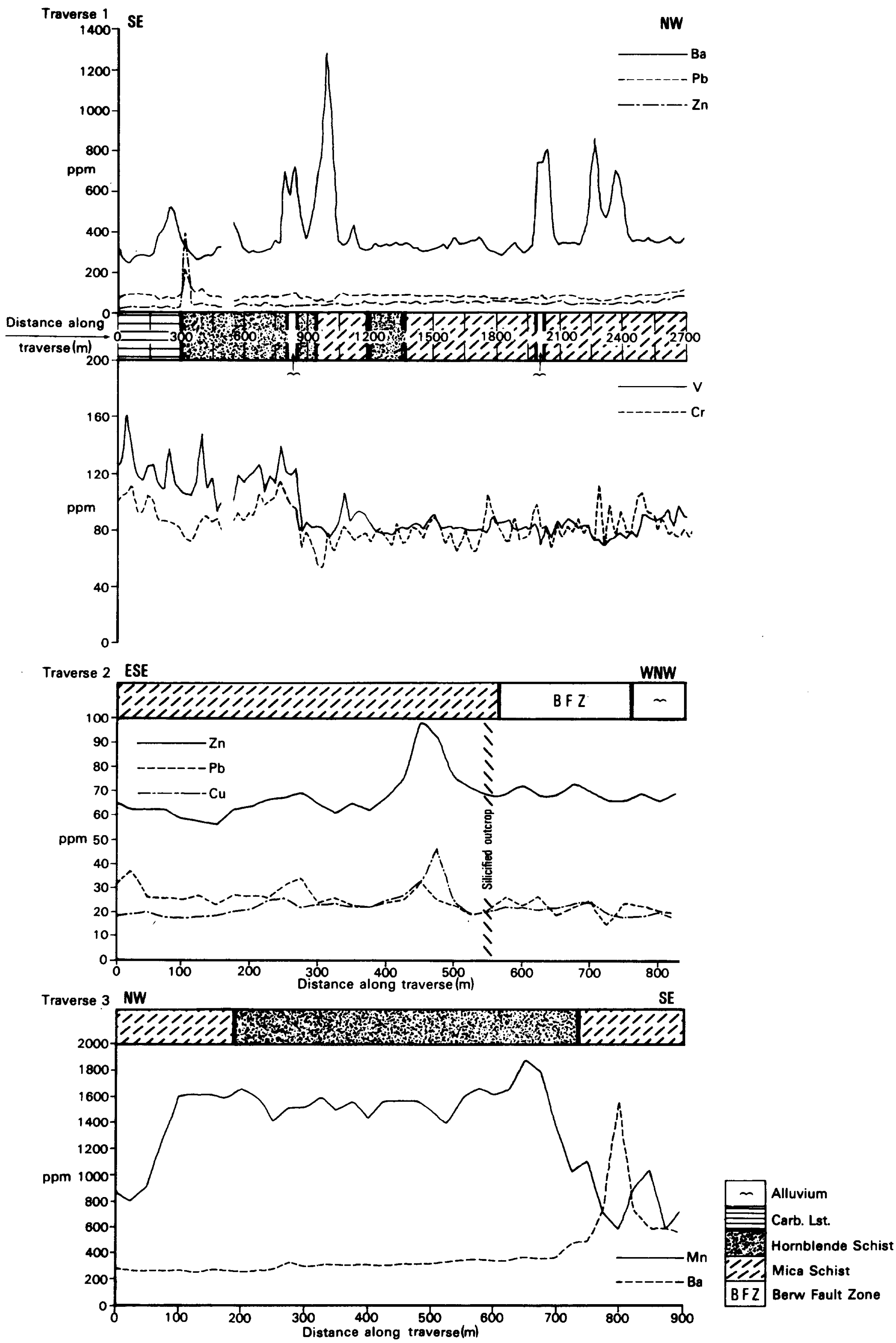


Figure 18 Soil sample geochemical scatterplots: a) Zn/Pb; b) V/Cr

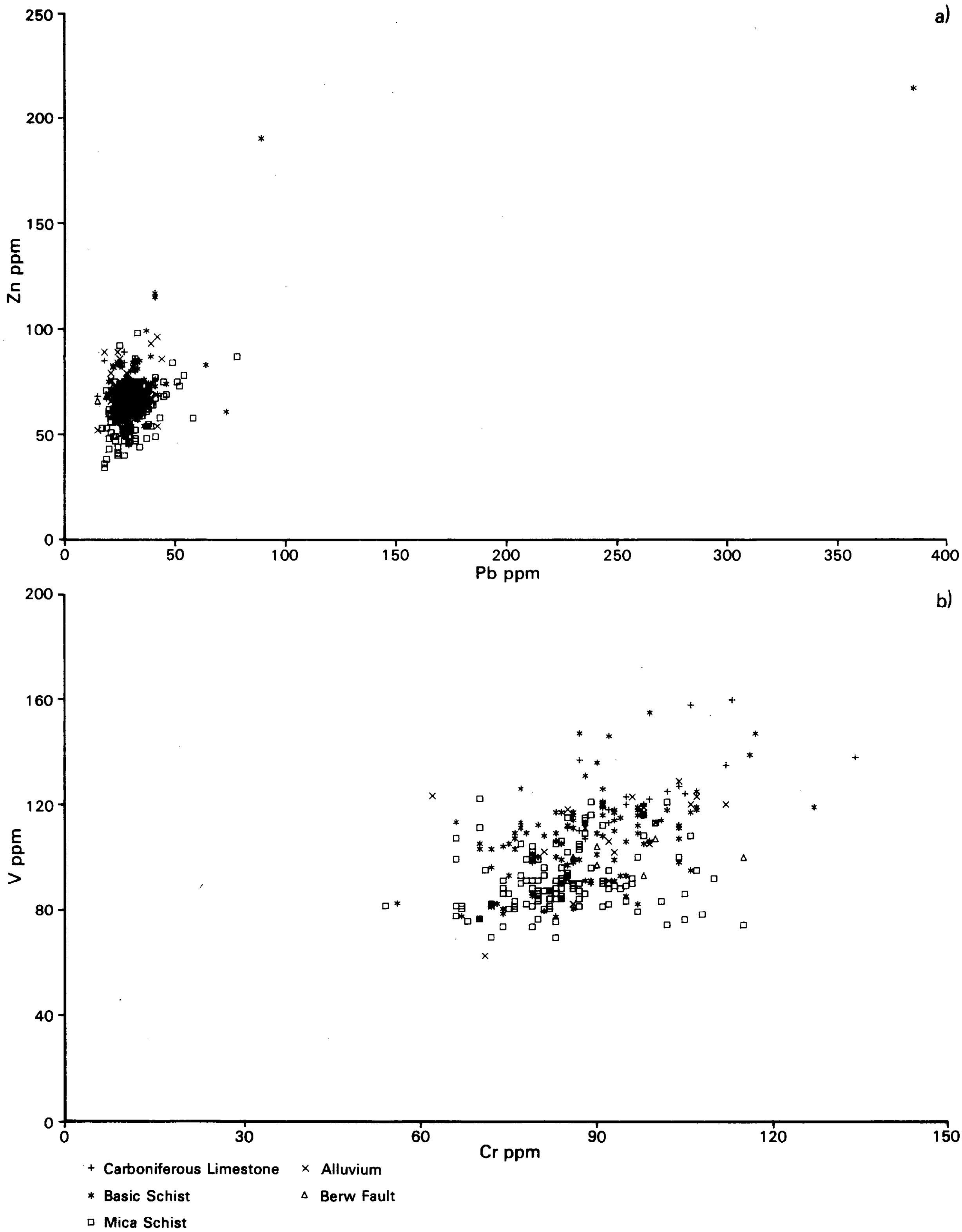


Table 4 Mean and mean plus 2 Standard Deviations for soil samples from each lithology

Lithology		Ba	Co	Cr	Cu	Fe	Mn	Ni
Carboniferous	mean	341	17	100	27	45756	1470	25
Limestone	mean + 2SD*	522	23	125	38	47704	2478	33
Basic Schist	mean	308	12	88	20	38787	1575	14
	mean + 2SD	408	15	112	28	45133	2450	19
Mica Schist	mean	393	11	84	18	35689	1206	15
	mean + 2SD	829	14	105	29	43123	2036	20
Alluvium	mean	515	16	92	20	43340	1523	22
	mean + 2SD	884	27	116	28	68348	4261	33
Berw Fault	mean	308	11	94	22	35450	1035	20
	mean + 2SD	340	13	114	26	38356	189	22
Lithology		**Pb**	**Sr**	**Ti**	**V**	**Zn**	**Zr**	**No of samples**
Carboniferous	mean	25	64	5892	128	78	294	16
Limestone	mean + 2SD	34	77	6512	159	95	334	
Basic Schist	mean	35	64	5452	108	72	348	106
	mean + 2SD	105	72	6256	140	114	389	
Mica Schist	mean	31	67	4974	93	61	354	119
	mean + 2SD	49	73	5718	117	83	400	
Alluvium	mean	27	72	5450	110	75	314	20
	mean + 2SD	43	90	6822	144	103	418	
Berw Fault	mean	20	69	4565	100	69	340	8
	mean + 2SD	31	75	4707	111	74	360	

All values in ppm. * - 2 Standard Deviations

The soil results show minor variations from the rock sample data. Mean Ba, Pb and Zr are enhanced by 2 to 5 times in the soils while the remaining elements are depleted in the soils by similar amounts except for Cr which remains at about the same level in both media. Two plots of Pb/Zn (Figure 18a) and Cr/V (Figure 18b) illustrate the lack of any anomalous trends in the samples.

The only variations of interest are a small number of anomalous Ba values which reach up to 1500 ppm from an overall mean of 363 ppm. 26 Ba values (10% of the total samples) exceed the mean + 2 SD (530 ppm). The anomalous thresholds were taken from the cumulative frequency plots and are 685 ppm for Ba (95 percentile), 92 ppm for Zn (97.5 percentile) and 73 ppm for Pb (99 percentile). Anomalous sites for these elements are shown on Figure 13. There is one sample on Traverse 1 which has anomalous Pb (385 ppm) and Zn (215 ppm) from a flat background without any other anomalous values. The barium anomalies can best be seen on Traverse 1 (Figure 17a) where they rise from a background of around 300 ppm to >750 ppm over hornblende and mica schists. On Traverse 7 there is a single point moderate Ba, Pb, Zn anomaly near its eastern end and a wider anomaly of up to 800 ppm Ba, without enhanced Pb or Zn, from alluvium samples in a small river floodplain downstream from the stream sediment anomaly at Dinam Bridge (Cooper et al., 1982). This anomaly was ascribed to thin baryte veins, loose blocks of which were found on the river bank. The isolated Pb/Zn highs, and the Ba anomalies, which are generally 3 - 4 samples wide (100 m) can be ascribed to a similar veining and are unlikely to have major metallogenic significance. The alluvium samples, e.g. Traverse 1 and Traverse 7, show marked enrichment in Ba, Co, Fe, Mn, Sr, Ti and Zr consistent with retention of heavy minerals containing these elements within the catchment.

The single traverse (2) which crossed the Berw Fault Zone passed within 10 m of OHR 5028 which is a silicified schist or rhyolite adjacent to the mapped trace of the fault. It contained no significant metal values. However, there is a distinct Cu and Zn anomaly of about 1.5-2 times background about 100 m east of the outcrop (Figure 17b). Arsenic results from this line are uniformly low at < 40 ppm.

Discussion

The results from the rock sampling show that the basic rocks in the Penmynydd Zone are of tholeiitic oceanic basaltic origin. This type of setting is not particularly favourable to synchronous mineralisation, although if they were injected as high level sills into a thick sedimentary pile (the origin of the enclosing mica schists) they could have set up hydrothermal circulation promoting development of Besshi-style deposits in the sediments. However, there is no indication of hydrothermal alteration in the basic volcanics and the soil sampling has shown no evidence of base-metal enrichments in the schists, other than that due to later Ba+Pb-Zn vein-style mineralisation perhaps of Hercynian age. There is field evidence supporting the thesis that at least some of the metabasic rocks formed as basic tuffs, but the majority are probably lavas or intrusions but lack of outcrop makes this difficult to determine. The geophysical evidence indicates that the basic rocks may form part of a major intrusion. There is no evidence for any unusual or anomalous

concentrations of elements in the basic rocks. In particular Ti, Cr, Cu, Pb and Zn are around MORB levels while V is only slightly enhanced. The precious metals, Au, Pt, Rh and Pd, are also present at very low concentrations and there is no significant enhancement in silicified samples from the Berw Fault zone.

The soil analyses generally show little variation except for Fe and Mn and also occasional Ba and Pb/Zn anomalies, which are probably due to minor baryte vein mineralisation.

Table 5 Summary statistics for each element

Element	Mean	Median	SD*	25th percentile	75th percentile
Ba	363	312	168	288	345
Co	12	12	3	10	13
Cr	87	86	12	79	94
Cu	20	20	5	16	22
Fe	38070	37400	5630	35300	39600
Mn	1386	1440	577	940	1690
Ni	16	15	4	13	17
Pb	31	28	23	25	34
Sr	66	66	5	63	69
Ti	5240	5140	505	4850	5590
V	103	101	17	88	114
Zn	68	67	17	59	73
Zr	345	347	30	328	362

All values in ppm. 269 samples. * - Standard Deviation

MINERAL POTENTIAL

The mineral potential of the south-east Anglesey area was not considered to be high before the current investigations. However the presence of the major positive gravity anomaly and the few references to mineralisation in the area by Greenly (1919) provided the encouragement to initiate the current project. This has enabled the form of the gravity anomaly to be more closely delineated and the suggestion that it is due to a layered intrusion does create additional possibilities for mineralisation. However, the absence of distinct targets in the form of mineralised horizons or outcrops means that any further investigations will have to be mainly geophysical, followed by drilling.

CONCLUSIONS AND RECOMMENDATIONS

1. The geophysical evidence suggests that a layered basic igneous complex may underlie the positive gravity anomaly in the Dwyran area. This type of body can be prospective for a number of metals and minerals including Cu, Ni, Ti, V, PGE, Cr and magnetite mineralisation. However, the soil and surface rock geochemistry does not indicate any near-surface mineralisation.

2. The zone 1.5 km south-east of Llangaffo on Geophysical Traverse 1, which has a significant magnetic and VLF-EM response, could indicate a conductive magnetic body at shallow depth parallel to the main strike of the Penmynydd Zone. However, there is no coincident geochemical anomaly.

3. A number of Ba in soil anomalies occur. One or two Pb and/or Zn anomalies are also recorded, sometimes coincident with Ba. These are ascribed to thin veins within bedrock or detrital baryte in alluvium similar to those described in MRP 112 and appear to be of little economic interest.

4. There appears to be no significant mineralisation associated with the Berw Fault Zone although only a few outcrops of the silicified zone adjacent to the fault were analysed and only one soil geochemical traverse completed across it.

5. The soil sampling methods employed may not have been effective in penetrating the drift cover over parts of the area. However, the rock sample results do not indicate that there is any reason to suspect that deeper sampling would lead to more encouraging results, and the soil sampling did show that thin baryte veins could be detected.

6. Any further surface work should involve investigation of the conductive body on Geophysical Traverses 1 and 3. This could include more detailed geophysics, including magnetics and EM, and deep overburden geochemistry.

7. Testing for the presence of a layered intrusive would require a substantial drilling programme. From the information gathered by the current project, this would not be justifiable.

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APPENDIX 1 Further details of geophysical field work and data processing

Gravity:

Gravimeters used	: LaCoste/Romberg G456 and G280
NGRN(73) Primary Base Station	: Bangor, BM at NGR 258402 373158
Gravity value at Primary Base	: 981384.96 mGal
Present survey base station	: BM at NGR 244880 369000
Gravity value at local base	: 981380.08 mGal
Normal gravity calculated from	: GRS(67)
Reduction density	: 2.7 Mg/m^3
Free air correction	: 0.3086 mGal/m
Bouguer constant	: 0.041929 mGal/m

Magnetics:

Magnetometers used	: 2 Scintrex IGS2 proton precession (1 at the base station), total field and vertical gradient (across 1m sensor separation).
Base value (IGRF at centre of area)	: 48586nT

VLF:

Equipment	: Scintrex IGS2
Transmitters	: Rugby (112deg) 16kHz 750kW
	: Oxford (126deg) 19.6kHz 500kW
	: Carlisle (26deg) 19.0kHz ?kW

APPENDIX 2a Physical properties determined during present work

Sample No	**NGR**	**Lithology**	**Saturated density (Mg/m^3)**	**Magnetic susceptibility ($SI \times 10^{-3}$)**
5011B	2453 3672	hornblende schist	3.00	0.85
5014B	2469 3679	hornblende schist	2.95	0.87
5031B	2449 3670	hornblende schist	2.91	1.02
5032B	2449 3670	hornblende schist	3.00	41.57
5036	2433 3659	hornblende schist	3.05	0.95
5037A	2431 3658	hornblende schist	3.04	1.52
5037B	2431 3658	hornblende schist	3.00	1.31
5030B	2446 3664	basic schist	3.09	1.51
5009A	2440 3686	basic schist	2.92	0.80
5039	2440 3686	basic schist	2.89	0.63
5035A	2456 3672	quartz mica schist	2.71	0.35
5035B	2456 3672	quartz mica schist	3.00	0.88
5038	2440 3686	quartz mica schist	2.70	0.39
5042A	2484 3689	mica schist	2.80	0.36
5042B	2484 3689	mica schist	2.83	0.53
5043A	2471 3692	mica schist	2.67	0.26
5043B	2471 3692	mica schist	2.61	0.40
5041A	2470 3662	Carboniferous limestone	2.68	0.05
5041B	2470 3662	Carboniferous limestone	2.69	0.19

APPENDIX 2b Physical properties determined during earlier work *

Sample No	NGR	Lithology	Saturated density (Mg/m^3)	Magnetic susceptibility (SI x 10^{-3})
BP93	2420 3650	hornblende schist	3.07	1.08
BP94	2420 3650	hornblende schist	3.05	1.08
BP95	2420 3650	hornblende schist	3.02	1.08
BP96	2450 3662	hornblende schist	2.98	0.77
BP97	2450 3662	hornblende schist	3.01	1.08
BP98	2450 3662	hornblende schist	3.04	0.99
BP99	2469 3683	hornblende schist	2.99	1.08
BP100	2469 3683	hornblende schist	2.97	0.72
BP101	2469 3683	hornblende schist	3.00	0.80
BP102	2518 3739	mica schist	2.73	0.31
BP103	2518 3739	mica schist	2.72	0.33
BP104	2518 3739	mica schist	2.72	0.45
BP105	2467 3714	mica schist	2.67	0.35
BP106	2467 3714	mica schist	2.69	<0.20
BP107	2467 3714	mica schist	2.68	0.21

* Measurements on samples collected within the survey area during 1974 and reported in Forster (1974).