

Mineral Reconnaissance Programme

Report No. 86

**Volcanogenic mineralisation in the
Treffgarne area, South-West Dyfed,
Wales**

Geology

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DATA PACKAGE

This report contains a summary of the Mineral Reconnaissance Programme project in the Treffgarne area, south-west Dyfed, Wales. A comprehensive data package is available at a cost of £1000 sterling. This includes:

A — Consultation with British Geological Survey staff involved with the project.

B — Examination of drill-core and thin-sections of surface rocks and drill core.

C — A comprehensive data package to include the items listed below. The geochemical data is available in digital form if required.

1 Cu, Pb and Zn analyses of 1360 soil samples from the Treffgarne area.

2 Ti, Fe, Ni, Rb, Sr, Zr, Mo, U, Sn, Ba, As, Cu, Pb and Zn analyses of 373 soil samples from the Haycastle area.

3 Ti, Fe, Ca, Mn, Ni, Sr, Zr, Mo, U, Sn, Ba, As, Th, Cu, Pb and Zn analyses of 20 samples collected from 5 soil profiles.

4 Ba, Sb, Pb, Zn, Cu, Ni, Fe, Mn, U, Sr, Zr and Mo analyses of 236 overburden samples collected by mechanical auger and Cobra percussion sampler.

5 Ba, Sb, Sn, Pb, Zn, Cu, Ca, Ni, Fe, Mn, Ti, Ag, U, Th, Sr, Zr, Mo, As, W and Ce analyses for 12 stream sediment samples and Cu and Zn content of 44 water samples from the Treffgarne area.

6 SiO₂, Al₂O₃, TiO₂, Fe₂O₃, MgO, CaO, Na₂O, K₂O, MnO, P₂O₅, As, Ba, Cr, Cu, Mo, Ni, Nb, Pb, Rb, S, Sb, Sr, V, Zn and Zr analyses of 202 drill core samples from 3 boreholes.

7 Summary statistics for the geochemical analyses of the drillcore.

8 Lithological site logs for the 3 boreholes.

9 Graphic lithological logs and histograms of the geochemical data for the 3 boreholes.

10 Mineralogical notes for 48 samples from the 3 boreholes.

11 Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb, Rb, Sr, Y, Zr, Nb, Mo, U, Ba and As analyses of 74 rock samples from surface exposures.

12 Summary statistics for surface rock samples.

13 List of thin-sections for 30 surface rock samples.

14 Downhole induced polarisation and resistivity plots for BH2 and BH3.

15 Gold analyses for 45 rock samples, from the boreholes and surface exposures.

16 Data sheets containing IP and resistivity data.

17 Not included in the package but available from the British Geological Survey, Keyworth, Nottingham. NG12 5GG (Regional Geophysics Group) are both regional aeromagnetic and gravity data for south-west Dyfed. Detailed helicopter-borne magnetic and VLF data are also available in a Department of Industry Mineral Reconnaissance Report, Number 84 (Cornwell and Cave, 1987).

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

Mineral investigations were carried out around Treffgarne, south-west Dyfed following palaeotectonic and metallogenic modelling studies which suggested that the area possessed appreciable metalliferous mineral potential. Geological, geochemical and geophysical surveys were carried out to investigate indications of alteration and mineralisation recorded in both sedimentary and volcanic rocks ranging in age from probable Precambrian to Ordovician.

Reconnaissance soil sampling located several anomalies but with the exception of two well defined groups, most could be attributed to secondary enrichment processes. Investigation of these two groups by deep overburden sampling, indicated that secondary enrichment processes were operative but in one of the areas coincident chargeability anomalies suggested the possibility of a metalliferous source.

Results of reconnaissance geophysical surveys revealed a zone of high chargeability and resistivity coincident with acid volcanic and associated sedimentary rocks of the Roch Rhyolite Group. Three boreholes were drilled to investigate the chargeability anomalies. Both core and surface rock samples were analysed for a wide range of elements and a selected suite of samples submitted for Au analysis.

Mineralogical and analytical data confirmed field observations in demonstrating that both the acid volcanics and the associated sedimentary rocks are highly altered. The acid volcanics are characterised by low total $\text{Na}_2\text{O} + \text{CaO} + \text{K}_2\text{O}$, high Al_2O_3 , Fe, S and locally Sr and Ba, which are reflected in the mineralogy by the presence of barite, corundum and pyrite. The associated sedimentary and pyroclastic rocks of the Nant-y-Coy Formation are locally intensely sericitised, bleached, pyritic and cut by numerous veins and stringers of quartz and pyrite.

Evidence from remapping, lithochemistry and the discovery of a trilobite fragment in mudstones from one of the boreholes suggests that the Roch Rhyolite Group are of Lower Ordovician (Arenig) age and precludes the Precambrian age previously ascribed to this group. An Ordovician age enhances the mineral potential of the Roch Rhyolite Group because of the known association of Ordovician igneous activity with volcanogenic mineralisation in the southern Caledonides.

INTRODUCTION

There has been little metalliferous mining activity in south-west Wales, but palaeotectonic and metallogenic modelling studies suggested that the area possessed appreciable metalliferous mineral potential. Of particular interest were extrusive volcanic rocks which might be associated with massive sulphide ore deposits, and high level intrusions of intermediate composition emplaced in a tectonic setting where they might be associated with porphyry style mineralisation. Any such deposits would probably be masked by the extensive drift cover. This theory was supported by the discovery of veinlet and disseminated copper mineralisation in intrusive rocks of dioritic and tonalitic composition near Llandeloy (Allen and others, 1985).

Attention was focused on the Treffgarne area by the geological setting of the acid volcanic rocks and reference to both abundant pyrite and traces of copper within them (Thomas and Cox, 1924). Further evidence was provided

by a regional study of the soils of Dyfed (Bradley and others, 1978) which showed that the Treffgarne area contained above average levels of copper in soil. According to Davies (1948) gold was apparently found during the driving of the railway through the volcanic rocks of Treffgarne Gorge, but there are no records available to substantiate this claim.

Location

The prospect lies within the Ordnance Survey 1:50 000 Sheet 157, (St Davids and Haverfordwest). It lies some 5 miles north of Haverfordwest and 7 miles south of Fishguard (Fig 1). There is no Geological Survey map covering the area available but the southern boundary is within the 1:50 000 sheet 228 (Haverfordwest).

Relief in the prospect area is subdued with the exception of a ridge, running from Roch in the west to Little Treffgarne Mountain in the east, which rises to 178 m. On the ridge outcrops of rhyolite give rise to striking tor-like masses at Roch Castle, Plumstone, Maiden Castle, Poll Carn and Treffgarne Rocks (Fig. 2). The Western Cleddau, which cuts through a deep gorge at Treffgarne, flows in a southerly direction. Other streams in the area are small and surface drainage is poor. Much of the low ground is farmland, supporting dairy herds while the higher ground is given over to rough grazing or forestry.

Previous Work

The earliest studies of the geology of the Treffgarne area are summarised on the Old Series one inch Geological Survey map sheet 40 (1845, 1857). Other early work of note was carried out by Hicks (1879, 1886) and Marr and Roberts (1885). Part of the area was covered by the Geological Survey of the South Wales Coalfield (Strachan, Cantrill and Jones, 1914). The only detailed accounts of the geology are given by Thomas and Jones (1912), who described the Hayscastle area, and Thomas and Cox (1924) who surveyed the ground between Roch and Treffgarne. There has been little information published since then, except for some descriptions of specific localities in field guides (e.g. Baker, 1982) and regional scale studies on the geochemistry, petrology and geological setting of the igneous rocks (e.g. Allen, 1982; Bevins, Kokelaar and Dunkley, 1984).

No previous geochemical studies specifically related to mineralisation are known. Thomas and Jones (1912) report that Cambrian conglomerates at the base of the Welsh Hook Beds were assayed for gold but 'yielded no values'. Thomas and Cox (1924) report that the Nant-y-Coy Beds contained traces of copper, but give no further details. The beds are also described as bleached and pyritous. A quartz vein bearing copper pyrites is reported from Treffgarne Quarry. Regional scale geochemical drainage maps covering the area are published in the Wolfson Geochemical Atlas (Imperial College, 1978) and both regional gravity (Griffiths and Gibb, 1965) and magnetic maps (BGS, 1965) are available. A detailed helicopter-borne magnetic and VLF survey of part of S.W. Dyfed, flown for the DTI Mineral Reconnaissance Programme (Cornwell and Cave, 1987), covers this area.

Present Investigations

Initial investigations involved geological mapping, reconnaissance soil sampling, drainage sampling and geophysical investigations within an area of some 20 km² (Fig. 2). Subsequently, two prominent soil anomalies at Prescelly View and Mountain Water were investigated by deep overburden sampling, using a power auger (Fig. 2).

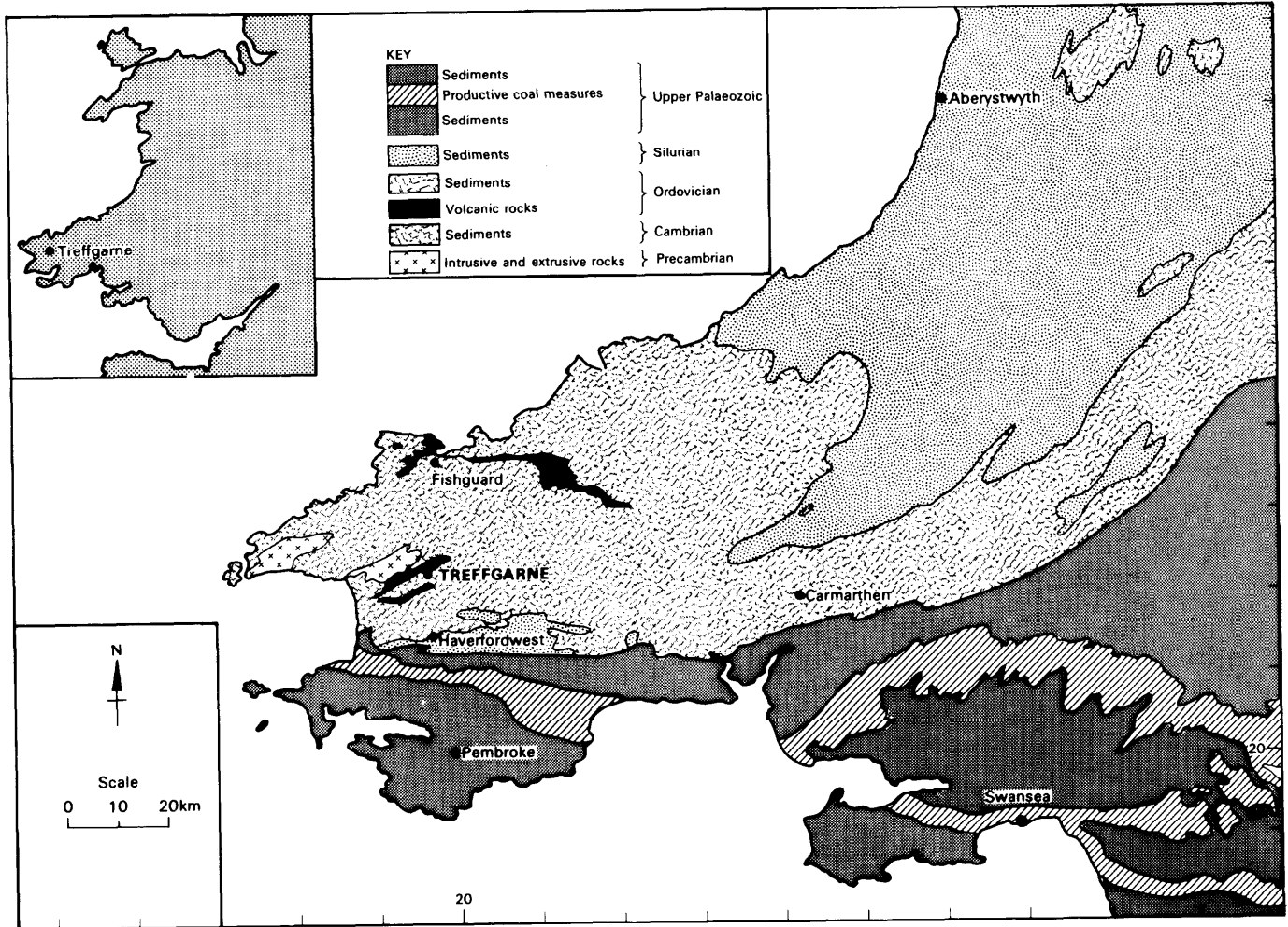


Figure 1 General geology of south-west Wales

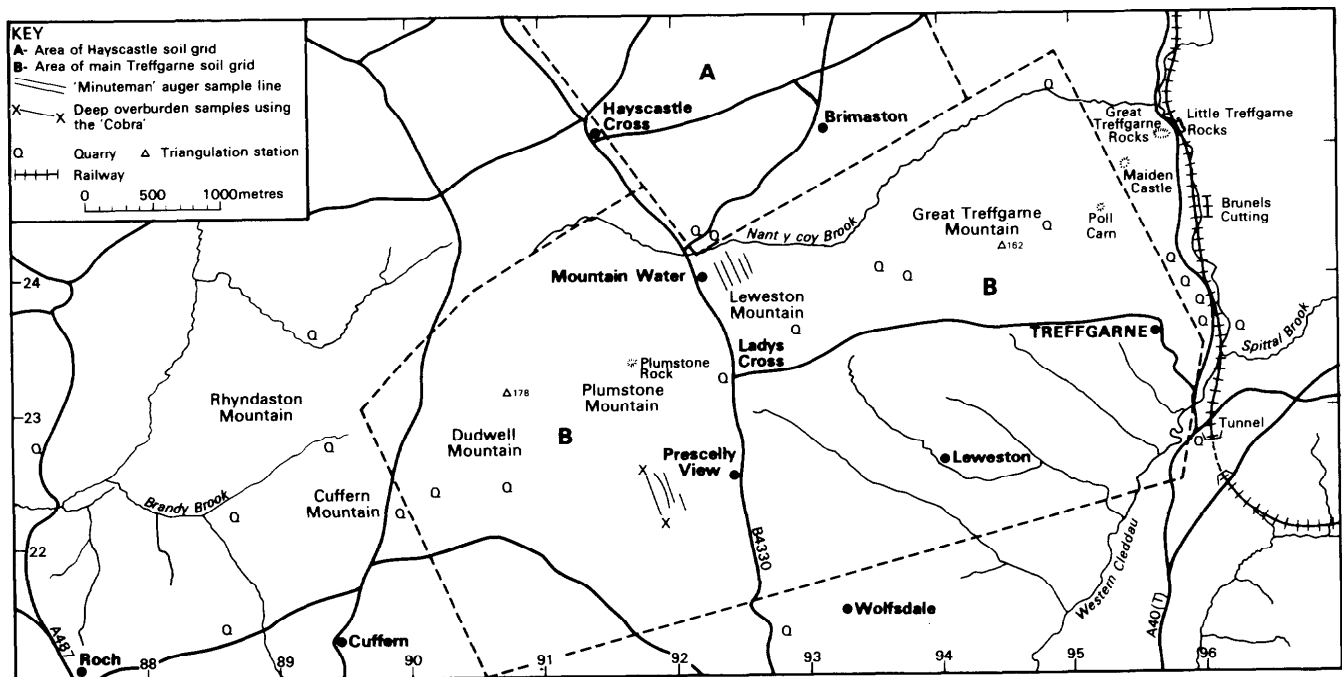


Figure 2 Detailed location map of the survey area

More detailed geophysical surveys and a revised interpretation of the geology led to the drilling of three boreholes to investigate the source of chargeability anomalies. In conjunction with the drilling, further geological mapping was undertaken, rock samples were collected from available exposures for chemical analysis, and mineralogical work was carried out on both rock and drill core samples. Reconnaissance soil sampling combined with geophysical surveys was extended to cover part of the Hayscastle Anticline.

GEOLOGY AND MINERALISATION

Exposure throughout the area is extremely poor with the exception of the River Cleddau gorge and some stream sections. Other exposures are limited to tors, man-made ditches and quarries. Much of the western part of the area is covered by till while elsewhere solid rock is mantled by head up to 3 m thick. The lack of exposure is largely responsible for the uncertainties surrounding the age relationships of the different lithologies throughout the area. New information from geological and geochemical investigations and borehole data reported here has enabled some of the interpretations made by Thomas and Cox (1924) to be revised. The rocks within the area investigated range from probable Precambrian to Ordovician age (Fig. 3). The revised succession based on recent work is shown in Table 1.

Precambrian rocks

Rocks of probable Precambrian age are found in the north of the area forming the Hayscastle anticline. The succession (Table 1) which is composed largely of pyroclastic rocks is divided into two groups (Thomas and Jones, 1912). The lowest (Pont-yr-Hafod) group is dominated by andesitic tuffs and the upper (Rhindaston and Gignog) group by rhyolitic and keratophyre tuffs with associated rhyolites and quartz-keratophyre lavas (Cornwell and Cave, 1987). The rocks are best exposed in quarries at Gignog (SM 8824 2470) and Rhindaston (SM 8925 2360).

A variety of intrusions are also present described as quartz porphyry, granite, granodiorite and diorite (Thomas and Jones, 1912). Relationships between the intrusions and the bedded succession are rarely seen due to

the poor exposure. The final intrusive event involved the emplacement of basic dykes. Granodiorite is exposed in the area investigated to the north of the Nant-y-Coy Brook (SM 9471 2543) and was also seen in temporary exposures to the north of Brimaston (SM 9280 2550).

Cambrian rocks

The oldest rocks of Cambrian age, the Welsh Hook Beds (Fig. 3), outcrop in the north of the area. A coarse conglomerate, containing clasts, probably derived from the Precambrian igneous rocks, forms the base of the succession and unconformably overlies highly sheared rhyolitic ashes assigned to the Rhindaston and Gignog Group. The conglomerate is overlain by a succession comprising green feldspathic sandstones, red shales, purple sandstones and quartzitic sandstones (Thomas and Jones, 1912). The Welsh Hook Beds are overlain by the Ford Beds which are exposed to the north-east of the area investigated. Rare trilobites recovered from these indicate a Middle Cambrian age (Nicholas, 1933). They comprise a thick sequence of locally pyritiferous, blue-grey shales containing flaggy and quartzitic horizons. At their base is a green/yellow feldspathic grit (Musland Grit).

The Treffgarne Bridge Beds (Cowie, Rushton and Stubblefield, 1972) occupy a large part of the survey area between Cuffern and Spittal. They comprise a poorly exposed succession of green/grey micaceous shales with sandy mudstones, black mudstones and bedded grits and contain fossils indicating an Upper Cambrian age. The beds occur within a faulted area bounded in the north by the Roch Rhyolite Group and in the south by the Treffgarne Volcanic Group and Tetraraptus Beds. They are exposed in a roadside quarry, the railway cutting south-east of Treffgarne Bridge and in stream sections to the west (e.g. SM 9534 2356) where they comprise dark grey to black carbonaceous mudstones containing sparse laminae and up to 2.5 cm bands of quartzose sandstones. Thinly bedded micaceous siltstones and flaggy sandstones are exposed in a quarry at Lady's Cross (SM 9240 2330). Elsewhere in the belt exposure is poor. In a quarry in the extreme west of the area (SM 8935 2280) there are interbedded grey siltstones and quartzose sandstones with pyritic, sericitised, silty mudstones of similar age (Thomas and Cox, 1924).

Ordovician rocks

Treffgarne Volcanic Group

This group is largely composed of basaltic andesite and andesitic lavas and tuffs. The upper part of the succession is dominated by tuffs and distinctive volcanic conglomerates. The sequence is best exposed in quarries by the A40 trunk road north of Treffgarne. At the south end of the main quarry (SM 9602 2393), an inlier of several metres of tuffaceous mudstone and an overlying feldspathic sandstone, typical of the Brunel Beds, rests on grey volcanic rocks in the core of a syncline. The rocks are altered and sparse pyroxene phenocrysts are replaced by chlorite. The precise age of the volcanics is uncertain (Williams and others, 1972) as their base is nowhere exposed. The apparently conformable overlying Brunel Beds contain fossils of early Arenig age (Thomas and Cox, 1924). On the basis of petrographic and geochemical similarities with the calc-alkaline Rhobell Volcanic Group in North Wales a Tremadoc age has been proposed by Bevins, Kokelaar and Dunkley (1984).

Exposure is very poor in the belt of volcanic rocks near the southern boundary of the area and the mapped extent

Table 1 Geological succession in the Treffgarne area

Tetraraptus Beds	} Ordovician
Roch Rhyolite Group	
Brunel Beds	
Treffgarne Andesite Group	
----- ? -----	
Treffgarne Bridge Beds	} Cambrian
?	
Ford Beds (inc. Musland Grit)	
?	} Cambrian
Welsh Hook Beds	
----- unconformity -----	
Basic Dykes	} Precambrian
Granite/granodiorite/quartz porphyry/diorite intrusions	
Rhindaston and Gignog Group	
Pont-yr-hafod Group	

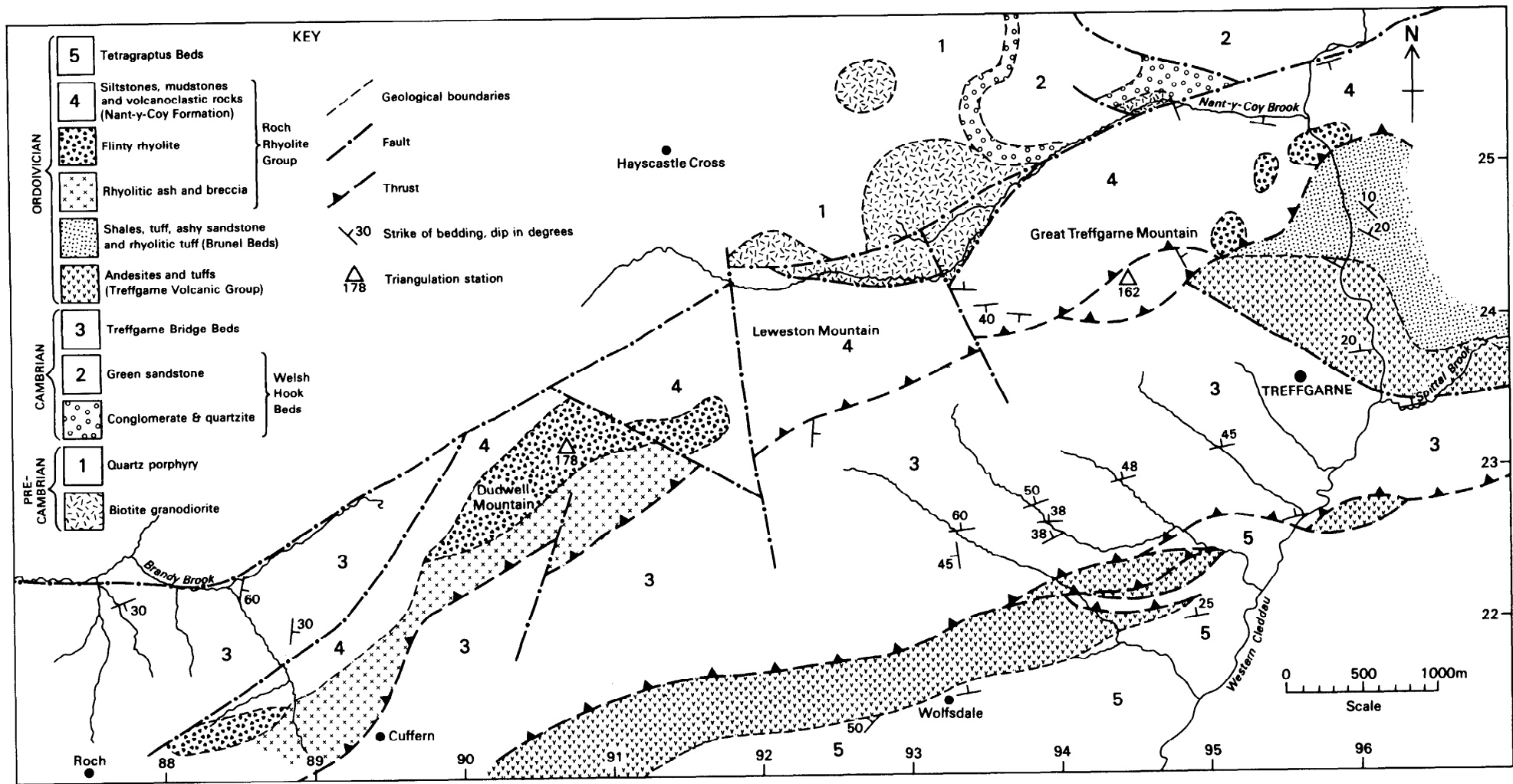


Figure 3 Geology of the Treffgarne area

of the Treffgarne Volcanic Group is that determined by Thomas and Cox (1924), largely on the basis of the distribution of weathered float. The only exposure of this southerly belt of rocks was found in a quarry near Wolfsdale (SM 9270 2140).

Brunel Beds

These rocks, which appear to follow the Treffgarne Volcanic Group conformably, are best exposed in an abandoned railway cutting in the Treffgarne Gorge (SM 9602 2450) and in the Spittal Brook. They contain fossils of Arenig age (Thomas and Cox 1924). The succession, as seen in Brunel's cutting (Fig. 2), comprises dark grey shales and tuffs passing upwards into blue ashy bedded sandstone with laminae of micaceous shale, rhyolitic tuff and black ashy mudstone.

Roch Rhyolite Group

Included in this group are the volcanic rocks of Roch, Dudwell, Plumstone, Poll Carn, Maiden Castle, Great Treffgarne Rocks and Little Treffgarne Rocks (Fig. 2), together with the associated sedimentary rocks of the Nant-y-Coy Formation (Fig. 3). The age of this group, previously referred to as the Roch Rhyolite Series, is uncertain as no diagnostic fossils have been found. The junction with other rocks is either faulted or not exposed. Previous authors have accepted the suggestion of Hicks (1886), and Thomas and Cox (1924) that the rocks are of Precambrian age, but this is now precluded by the discovery of a trilobite fragment in drillcore from the Nant-y-Coy Formation (*see* 'Drilling' section). It is suggested that the group is most probably of Arenig age and may be contemporaneous with the Brunel Beds. The reasoning for this is that: 1) although the objectively undeterminable fossil does not preclude a Cambrian age, the absence of appreciable Cambrian volcanism in Wales makes it unlikely; 2) there are lithological similarities between the Brunel Beds and the Roch Rhyolite Group which are partly obscured by the highly altered nature of much of the Roch Rhyolite Group and 3) in the Cleddau valley the rhyolites follow an ascending succession of Brunel Beds and it is reasonable to assume, despite faulting, that there is no great disconformity between them. Elsewhere Brunel Beds appear to be followed by Tetragraptus Beds (Thomas and Cox, 1924) but this may be explained if the rhyolitic lavas are of limited lateral extent and the Nant-y-Coy Formation, at least in part, is the altered equivalent of the Brunel Beds.

RHYOLITIC BRECCIAS These rocks are only seen on Dudwell and Cuffern Mountains where they dip northwards below the flinty rhyolites. They are best exposed in a number of quarries north of Rock Farm (SM 9000 2220). The main rock types are laharic breccias, composed of angular to subangular blocks up to 1m long of acid volcanic rocks in a muddy matrix. Also present are volcanic breccias consisting of closely packed blocks of various rhyolitic rocks, and rhyolitic breccias in which blocks of mudstone and laharic breccia, more than 1 m in length, are incorporated in brecciated silicified rhyolite. Black siltstone and muddy tuffite are minor components.

FLINTY RHYOLITES The flinty rhyolites form a prominent line of tors from Roch Castle in the west to Little Treffgarne Rocks in the east. The rock is a yellowish-grey, white weathered silicified rhyolite with a blocky, pseudobrecciated texture on weathered surfaces. Relict flow texture is recognisable in some specimens. The rock

contains small, recrystallised quartz and less common pseudomorphed feldspar phenocrysts in a quartz dominant matrix. At Poll Carn, Maiden Castle and Great Treffgarne Rocks the rock is brecciated and there are veins of intrusion breccias forming a network in parts of the crags. In many outcrops the rocks appear to be highly altered, silicified and deeply weathered. The rhyolite outcrops may represent the eroded remnants of one or several flows, or form a series of separate tholoidal extrusions.

NANT-Y-COY FORMATION These sedimentary and pyroclastic rocks appear to rest conformably on the rhyolites seen in a railway cutting (SM 9577 2521) below Little Treffgarne Rocks. Elsewhere exposures suggest that at least locally they dip beneath the rhyolites (e.g. SM 9166 2334) leading to the view that the rhyolites form lenses within the sedimentary sequence. The Formation comprises a sequence of thinly laminated siliceous siltstones with thin muddy bands and included volcanoclastic material. They are frequently altered and bleached and contain abundant disseminated pyrite which, on weathering, gives rise to a characteristic yellow-brown sand. The rocks are well exposed in the lower part of the Nant-y-Coy Brook where they comprise thinly bedded sericitised siltstone, quartz-sericite rock and quartzite with abundant pyrite. The quartzite beds do not usually exceed 15 cm thick with some showing ripple marks and lensed bedding. The pelitic rocks are strongly cleaved. Sericitisation masks most primary textures, but there is evidence, in thin section, of volcanoclastic debris in some of the rocks. In a temporary excavation at Plumstone reservoir (SM 9185 2345) grey mudstone and siltstone was seen thinly interbedded with volcanoclastic rocks.

Tetragraptus Beds

These dark-grey to black graptolitic shales are to be found on the southern boundary of the area but exposure is poor. Their junction with the underlying Brunel Beds is not exposed but it is thought to be a conformable transition (Thomas and Cox, 1924).

Structure

Due to poor exposure the structure and age relationships of the different lithologies is difficult to interpret. The Precambrian rocks of the Hayscastle Anticline form a horst-like structure to the north. Aeromagnetic data (Cornwell and Cave, 1987) suggest that the southerly margin of the horst, at the boundary with the Roch Rhyolite Group, is steeply dipping but has a more shallow dip towards the south in the south-west of the area (Fig. 7). Dips of strata recorded suggest that the Roch Rhyolite Group form an anticline with the Cambrian rocks to the south thrust over the southern limb. Most faults have a Caledonian trend and are thus near-strike faults. The Cambro-Ordovician rocks have undergone low-grade metamorphism mainly within the prehnite-pumpellyite facies (Bevins and Rowbottom, 1983).

Mineralisation

There are few records of mineralisation in the area. Perhaps of most interest is the reference to the possible occurrence of gold at Treffgarne (Davies, 1948). Minor occurrences of pyrite and quartz veining are present throughout the area but the only significant indications of mineralisation were found in the Roch Rhyolite Group. The rocks of the Nant-y-Coy Formation are pyritic and locally sericitisation is intense. The acid volcanics are also

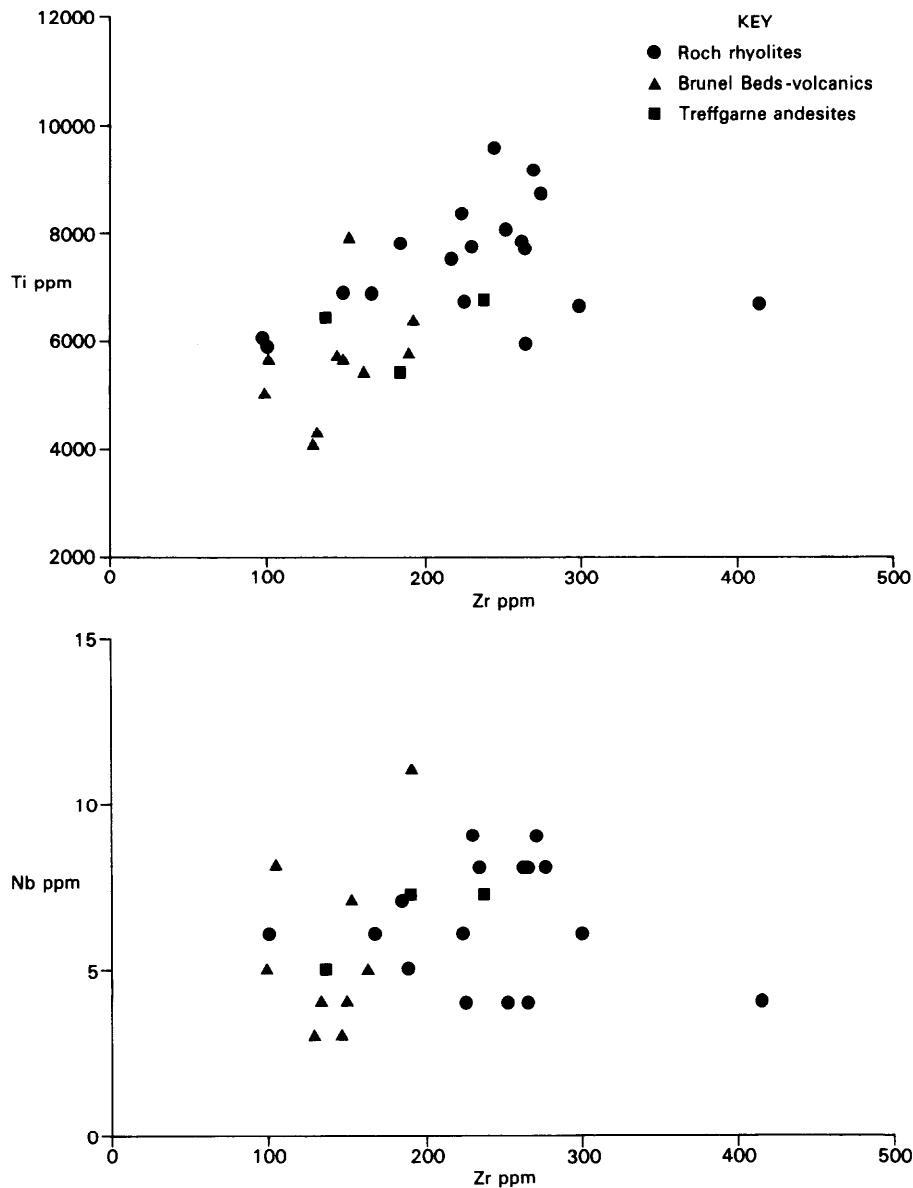


Figure 4 Plots of Zr against Ti and Zr against Nb for volcanic rocks from the Treffgarne area

altered and locally mineralised. Sericitisation in some rhyolites is almost complete where pseudomorphs of coarse-grained sericite are set in a fine-grained sericite groundmass. Specularite is locally abundant in the brecciated rhyolites at Maiden Castle and hematite and limonite after pyrite are common. Silicification and quartz veining are common and several phases of quartz veining are evident. In the railway cutting in Treffgarne Gorge (SM 9577 2518) a prominent quartz vein a metre thick, cutting rhyolite, contains rich pockets of pyrite. Traces of copper within the Nant-y-Coy formation have been recorded by Thomas and Cox (1924).

LITHOGEOCHEMISTRY

Sampling and analysis

A total of 74 rock samples were collected from outcrops within the area under investigation. Rock samples were crushed, mixed and a 150 g split then milled, in agate barrels. Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb, Rb, Sr, Y, Zr, Nb, Mo, U, Ba and As were determined in all samples by X-Ray Fluorescence Spectrometry (XRF).

Analyses and summary statistics, for the surface rock samples, are listed in the Data Package

Interpretation

The principal feature of the acid volcanic rocks of the Roch Rhyolite Group is the very low Na, K, Ca and Rb content such that $\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO}$ totals less than 0.5% in most of the samples analysed. This unusual feature is illustrated by comparing the analyses of the Roch Rhyolite Group with analyses of other acid volcanic rocks of Ordovician age from the southern Caledonides (Table 2). This comparison also indicates that the acid volcanics of the Roch Rhyolitic Group also contain relatively low levels of Nb.

For volcanic rocks from both surface exposures and drillcore major and trace elements plots against Zr indicate that only Ti has a relatively good correlation with Zr (Fig. 4). Volcanic rocks in the Brunel Beds have a lower median Ti/Zr ratio than those of the Roch Rhyolite Group, but they appear to conform to the same trend with some degree of overlap (Fig. 4). Samples from the Treffgarne Volcanic Group plot within this area of overlap and contain lower levels of Zr (andesites shown on Fig. 4) than

those of the Roch Rhyolite Group. Outlying samples on the Ti-Zr plot may be due to the effects of alteration. The high degree of scatter evident for the plot of Nb against Zr indicates the probable mobility of Nb.

Geochemical features have been widely used to characterise the tectonic setting of basic lavas (Pearce and Cann, 1973) and some of the same principles can be extended to more acid rocks (Pearce, 1982). However, the lack of basic rocks in the area and the additional problem that elements considered relatively immobile during alteration processes, such as Nb, may have been enriched or depleted in the Roch Rhyolite Group has made it impossible to relate the volcanic rocks to a particular tectonic setting with any degree of certainty.

Table 2 Comparison of the mean composition of rhyolitic rocks from Treffgarne with those of the Fishguard Volcanic Group and the Borrowdale Volcanic Group

Element	Rhyolites & tuffs BH1 Treffgarne n = 57	Roch Rhyolite Group n = 17	Rhyolites Fishguard Volcanic Group (Bevins, 1982) n = 2	Rhyolites Borrowdale Volcanics Group (Fitton, 1972) n = 7
%				
SiO ₂	70.40		76.85	72.21
TiO ₂	0.90	0.87	0.18	0.31
Al ₂ O ₃	16.80	—	13.45	14.72
Fe ₂ O ₃	2.50	1.45	0.38	3.17
MnO	<0.01	<0.01	0.74	0.75
MgO	0.02	—	<0.01	0.58
CaO	0.18	<0.01	5.91	2.36
Na ₂ O	0.34	—	3.34	5.55
K ₂ O	<0.01	—	0.01	0.06
P ₂ O ₅	0.17	—	0.02	0.21
ppm				
Nb	9	6	23	27
Rb	2	2	81	237
Sr	1085	61	62	85
Y	—	4	20	65
Zr	188	159	79	282

— not determined

GEOCHEMICAL INVESTIGATIONS

Drainage sampling

A total of 12 stream sediments and 42 water samples were collected from small streams, ditches, wells and seepages to the north and south of the Dudwell-Treffgarne interfluvium (Fig. 5). Stream sediment samples were wet sieved at site and the -100 mesh BSS fraction (150 μm) collected, dried and then milled prior to analysis by XRF for Ba, Sb, Sn, Pb, Zn, Cu, Ca, Ni, Fe, Mn, Ti, Ag, U, Th, Sr, Zr, Mo, As, W and Ce. Water samples (30 ml) were acidified on collection with 0.3 ml perchloric acid and analysed for Cu and Zn by Atomic Absorption Spectrophotometry (AAS) without further treatment.

Water results were all close to or below the detection limit of 0.02 ppm for both elements determined. Comparison with earlier work in SW Dyfed (Cameron and

others 1984) indicated that the stream sediments contained no anomalous concentrations of any element determined with the possible exception of Cu.

Soil sample collection and analysis

A total of 1360 soil samples from the Treffgarne area were collected at 25m intervals along 11 traverse lines perpendicular to the regional strike between Cuffern and Treffgarne Gorge (Fig. 5). During a later stage of the programme 373 soils were collected from the Hayscastle area (Fig. 2) along 6 traverse lines normal to the regional strike 600 m apart. Samples of approximately 200 g were taken, using a 1.2 m hand auger, from as great a depth as possible. The soils in the area are mainly brown earths on the lower ground with humic gleys and peats on wetter ground and the hilltops. Most samples consisted of B or C horizon soil developed on bedrock, till or head deposits. A few consisted of river alluvium and others contained organic rich material from the A and H horizons (Hodgson, 1976). All samples were dried, sieved and a 0.5 g sub-sample of the -85 mesh fraction (180 μm) analysed by AAS following dissolution in hot concentrated nitric acid for 1 hour.

Results and interpretation

Analytical results are summarised in Fig. 6. Anomalous results for the 1360 reconnaissance soils were defined by cumulative frequency curve analysis (Lepeltier, 1969; Sinclair, 1976). Copper and lead results produce plots (Fig. 6) which indicate the presence of a lower lognormal population containing most of the samples and a higher population of uncertain form. The trace for Zn differs in that the lower sample population has a normal distribution. For all three elements the small upper group of results was defined as anomalous and the threshold set where a significant deviation of the trace from the lower population indicated an input of the upper population samples (Sinclair, 1976). This method produced threshold levels of Cu 51 ppm, Pb 51 ppm and Zn 81 ppm (Fig. 6).

Anomalous samples are sited in distinct groups except for a few containing near threshold metal concentrations which probably represent outlying members of the background sample population (Fig. 6). A brief inspection of the anomalous sites and others close to the threshold showed that most high values are located in boggy ground, near springs, seepages or streams. Most of the samples from these sites contained either grey gley or a high proportion of peat, suggesting that the anomalies represent secondary concentrations formed by the precipitation or adsorption of metals from groundwater in response to Eh and pH changes. Most anomalies are enrichments in Cu and Zn only, suggesting that Pb is not concentrated here by these secondary processes. The secondary anomalies are relatively weak compared with those formed by similar processes from metalliferous sources.

Only two substantial anomalies, at Mountain Water (SM 9200 2400) and Prescelly View (SM 9190 2240) appeared not to be due to secondary concentration processes or contamination. The anomalies at Prescelly View are sited close to a stream, but the samples were collected from a well drained area. At Mountain Water the anomalies are in a gently sloping well drained field, coincident with an IP chargeability anomaly. Both were investigated by deep overburden sampling.

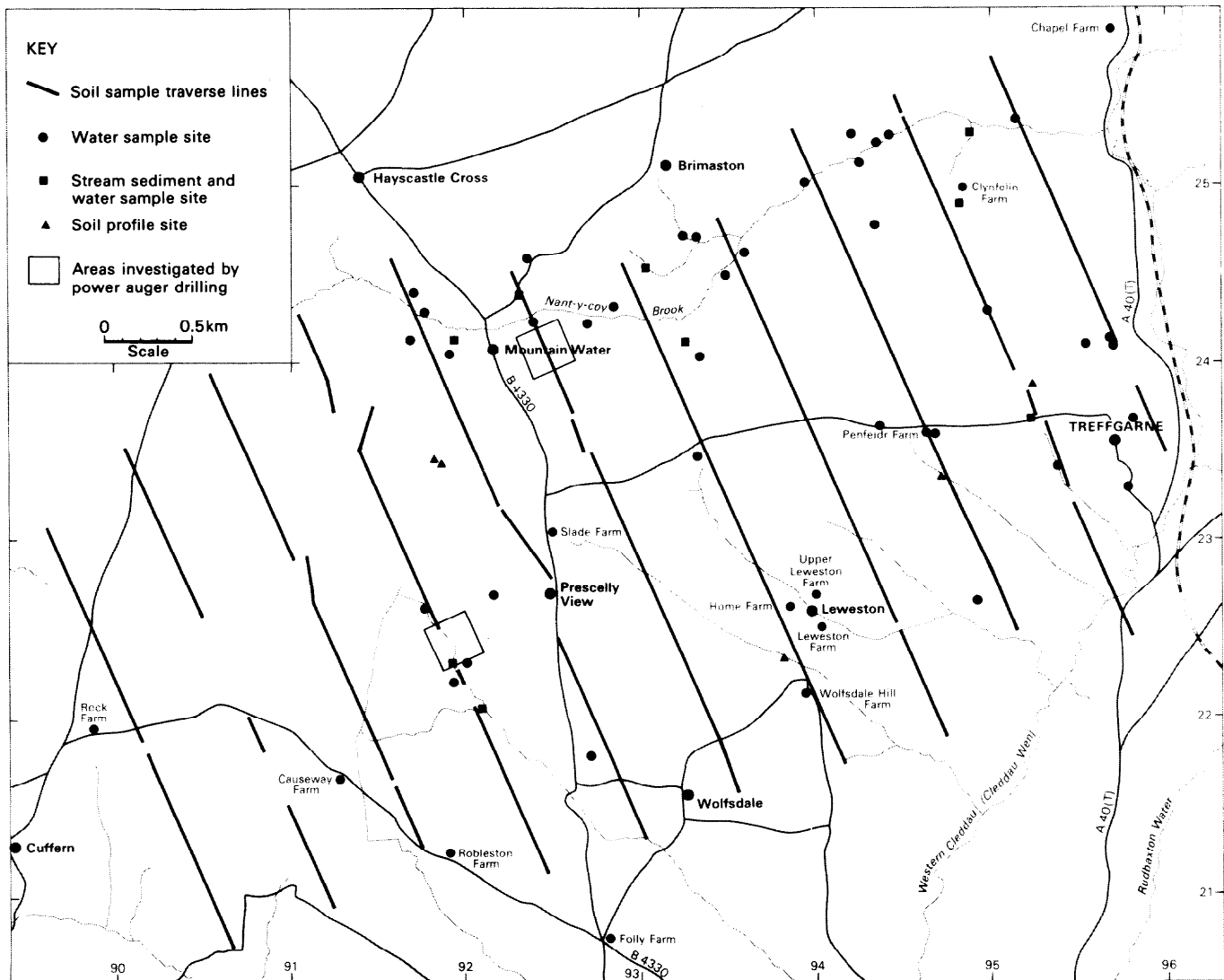


Figure 5 Location of stream sediment, water and soil sample sites

Background levels of Cu (5–20 ppm) and Zn (10–30 ppm) in soil are relatively low over the high ground compared with the remainder of the area. This variation is attributed to the leaching of metals from the high ground by acid groundwater and redeposition at seepage lines on the slopes. The process is promoted by the acid peaty soil on the high ground; inert, siliceous volcanic bedrock; the presence of highly pyritiferous rocks and the absence of carbonate rocks. Pearson product correlations (Cu-Zn 0.46, Pb-Zn 0.26, Pb-Cu 0.26) demonstrate the closer dispersion pattern of Cu and Zn, believed to be largely caused by similar responses to changes in the secondary environment. There is no close relationship between either background or anomalous Cu, Pb and Zn concentrations in the soil samples and the geology. This is attributed to the strong influence of secondary redistribution processes. The soil results show a tenuous relationship to the geophysical data. Secondary geochemical anomalies along the Nant-y-Coy may be related to a prominent belt of chargeability anomalies to the south-east, both of which may reflect buried mineralisation. There is also some correspondence of relatively high Cu values (40–50 ppm) and occasional Pb-Zn anomalies with the high IP chargeability zone at Leweston and a similar relationship between anomalies south of West Ford, but the only coincident IP anomaly and geochemical anomaly is that at Mountain Water (Fig. 2).

Soil lines were extended, at a later stage, to cover some of the volcanic and granitic rocks of the Hayscastle Anticline (Fig. 2). Exposure is particularly poor in this area but several quarries within the volcanics contain abundant disseminated pyrite (i.e. Rhindaston Quarry SM 8920 2360). To the north of Brimaston fragments of granite were apparent in the soil samples and outcrops of rotten granite were visible in several drainage ditches (SM 9280 2550). Although previously mapped as quartz porphyry (Thomas and Jones, 1912) this outcrop may be a separate small intrusion or form part of the granodiorite body to the north of the Nant-y-Coy Brook (Fig. 3). Determinations of Cu, Pb and Zn in the soils was undertaken by AAS. Ti, Fe, Ni, Rb, Sr, Zr, Mo, U, Sn, Ba and As were determined by XRF. No significant base metal anomalies were detected.

Soil Profile Analysis

Five profiles in natural and man-made temporary exposures were sampled to examine metal variation in relation to soil, drift and bedrock lithology. The –85 mesh fraction (180 μm) of the twenty samples collected was analysed for Ba, Sb, Pb, Zn, Cu, Ni, Fe, Mn, U, Sr, Zr and Mo. Two profiles were collected from reservoir excavations on Plumstone Mountain (SM 9185 2345) where the bedrock consists of pyritic, siliceous rocks of the Roch Rhyolite Group. Two more were collected from natural

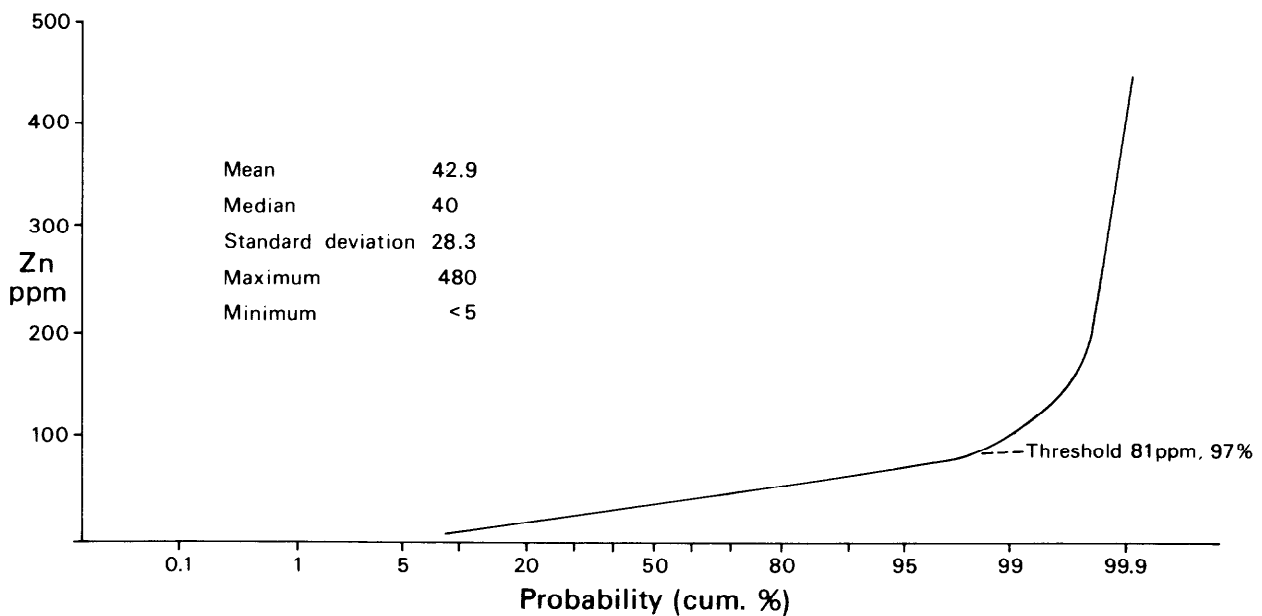
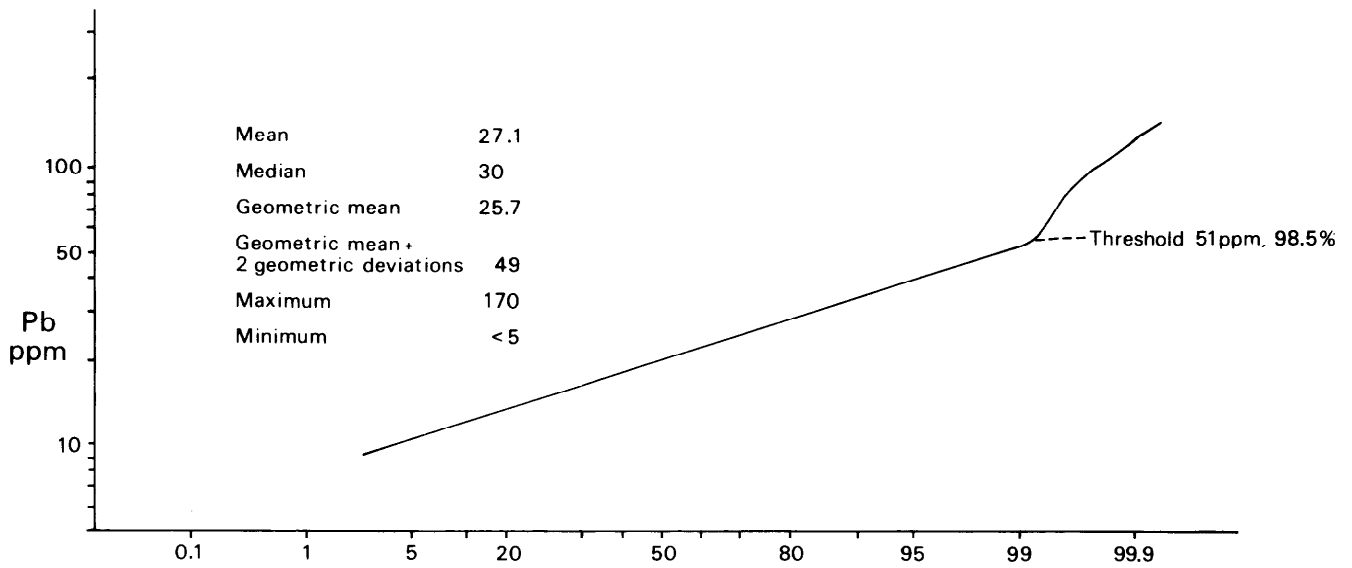
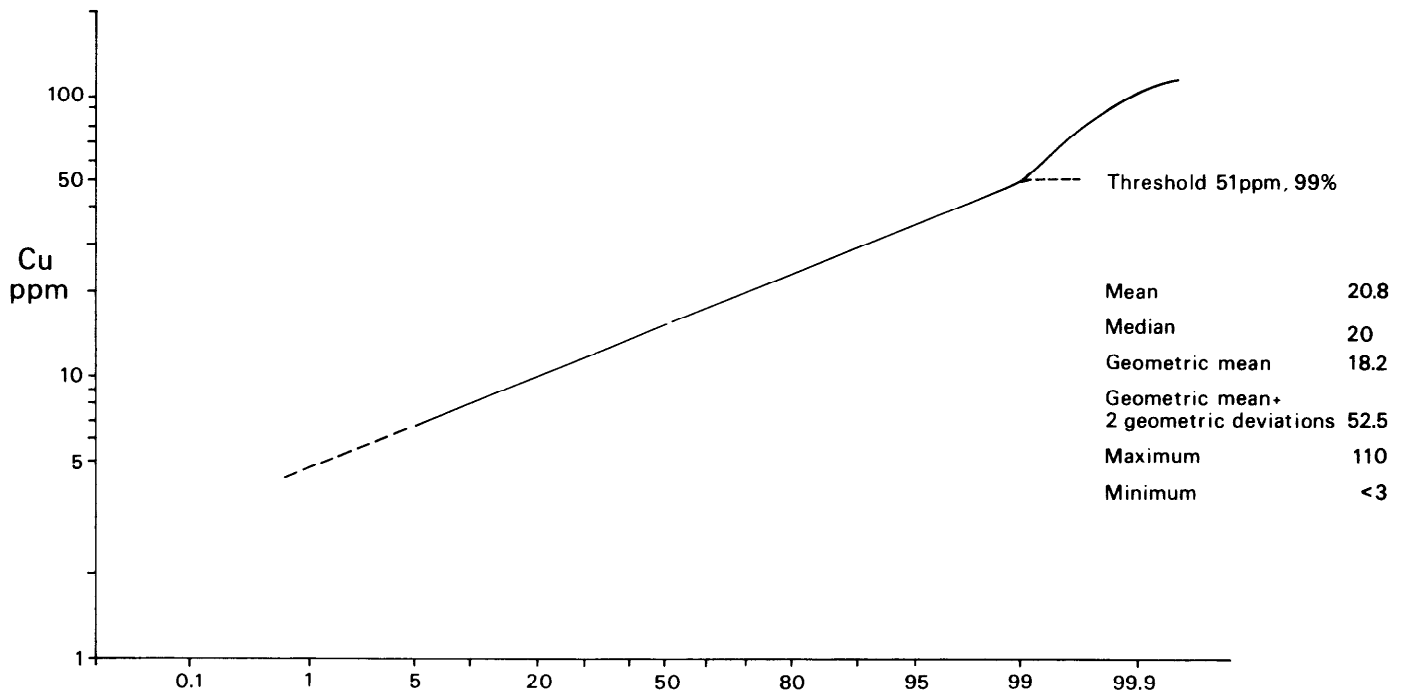


Figure 6 Percentage cumulative frequency (probability) plots and summary statistics for Cu, Pb and Zn in soil samples

exposures in stream banks near Wolfsdale (SM 9380 2233) and Penfeidr (SM 9475 2333) where the bedrock is formed of the Treffgarne Bridge Beds. The fifth profile was collected from an excavation south of Mountjoy (SM 9522 2388) where the rocks are also mapped as Treffgarne Bridge Beds but the drift contained abundant clasts of volcanic rock.

In all the profiles elements of limited mobility in the weathering zone, such as Ti and Zr show relatively little variation compared with the more mobile elements such as Mn and Zn. There are no well defined metal rich horizons in the generally poorly developed soils or the underlying till and head deposits. Pb concentrations, however, are highest in the A horizon of 3 profiles. At Plumstone Mountain metal enrichments in the bedrock are reflected in the overlying till and soil with metal concentrations generally increasing with depth.

Elements least susceptible to secondary redistribution do not show strongly contrasting levels in profiles collected over the Roch Rhyolite Group and Treffgarne Bridge Beds indicating that such analyses would be of limited use as an aid to geological mapping across a large part of the area where secondary redistribution effects are strong. Elsewhere, Ba, Sr and to a lesser extent Zr, Ni and Zn in soil may prove useful for this purpose.

Deep Overburden Sampling

Soil anomalies at Mountain Water and Prescelly View were investigated by deep overburden sampling (Fig. 2). A Minuteman Power Auger with 8 cm diameter flights was used, except in inaccessible scrub at Prescelly View where a hand-held Cobra Percussion sampler with a 2.5 cm diameter sampler was employed.

Where possible samples were collected below the organic rich A horizon at each major change of soil or drift type and at the base of each hole. At several sites, only one sample was obtained, due to relatively shallow overburden, or large impenetrable boulders being encountered. From each power auger sample approximately 500 g was removed for chemical analysis and the remainder washed, panned and examined in the field for heavy minerals. The whole of the Cobra samples were retained for analysis. The samples were dried, disaggregated and sieved at -85 mesh (180 μ m) then milled, pelletised and analysed for Ba, Sb, Pb, Zn, Cu, Ni, Fe, Mn, U, Sr, Zr and Mo by XRF.

At Mountain Water, 5 traverse lines spaced at 60 m intervals were laid out parallel to the original soil survey traverses (Fig. 2). A total of 46 holes were augered at 20 m intervals along the traverse lines, with a mean depth of 4.6 m and ranging from 0.7 m to 11.7 m. At Prescelly View (Fig. 2), 21 Minuteman and 18 Cobra holes were sampled at 20 m intervals along 4 traverses, nominally spaced at 60 m apart. The mean depth for the holes sunk was 6.6 m, with a range of 2.8 m to 12.1 m.

At Mountain Water a contoured plot of the basal Cu results showed a south-west, north-east trend, corresponding to the local strike. There is a strong correlation between the Cu, Fe and Mn content of the overburden samples, which is most probably of secondary origin, but could reflect the presence of pyrite or other sulphides in the bedrock as the anomalies lie within the zone of high chargeability (Fig. 7). Examination of the panned overburden samples revealed few heavy minerals and only minor pyrite was noted. The Prescelly View results were broadly similar with a contoured plot of the basal Cu results showing a possible south-west, north-east trend.

Again a strong correlation between Cu, Fe and Mn is evident, which is most probably the product of secondary redistribution processes. The panned overburden samples contained very few heavy minerals and only rarely were trace amounts of pyrite or pyrite pseudomorphs noted.

GEOPHYSICAL INVESTIGATIONS

Introduction

Geophysical investigations were carried out at Treffgarne in five stages:

- 1 Examination of available airborne, VLF and magnetic data.
- 2 Reconnaissance ground surveys along the same 600 m spaced traverse lines as the geochemical soil survey and covering a strike length of 6 km.
- 3 Detailed follow-up of anomalous areas to determine possible drilling targets.
- 4 Extension of the reconnaissance survey grid east and west to define the strike extent of the anomalous zones. The traverse lines over which geophysical measurements were taken are shown in Figure 9. Further extensions of the reconnaissance survey grid were made along the geochemical soil traverses in the Hayscastle area (Fig. 2).
- 5 Geophysical measurements were taken in two of the three boreholes (*see* 'Drilling' section).

Methods

The primary geophysical method employed was induced polarisation (IP).

Measurements of chargeability and apparent resistivity were made using a constant separation dipole-dipole array with a dipole length (a) of 50 m and a dipole centre separation ($n \times a$) of 100 m ($n = 2$) along all reconnaissance traverse lines and extensions of the grid. The majority of these traverses were also surveyed with Very Low Frequency electromagnetics (VLF-EM) and a proton magnetometer using a station interval of 10 m. The initial reconnaissance survey defined four areas with closed chargeability maxima in excess of 35 milliseconds (ms). Subsequent investigation of these sites was made principally with IP profiling using expanding dipole-dipole arrays ($a = 50$ m and $n = 2-5$), depth soundings (Schlumberger array) and some gradient array mapping. Self potential and VLF-EM traverses were also made over the first site, but as results showed no features of interest these techniques were abandoned.

Results

Magnetics

The Treffgarne area is covered by a detailed helicopter-borne magnetic and VLF-EM survey of south-west Dyfed, flown for the DIMRP during 1978 (Cornwell and Cave, 1987). The national aeromagnetic map (BGS, 1965) shows that the survey area lies on the northern flank of one of the east-west elongated magnetic highs, of unknown origin, which extend along the South Wales coast. North of the survey area is a smaller magnetic high which, is seen on the more detailed airborne survey (Fig. 7) to be associated with the biotite granites, granophyres and tuffs in the Hayscastle Anticline. The only magnetic anomaly not obviously associated with these rocks or with man-made sources, is an isolated 140 nT high on the south side of Plumstone mountain ('a' in Fig. 7). This coincides with a strong VLF-EM anomaly and additional magnetic and VLF-EM traverses were undertaken here

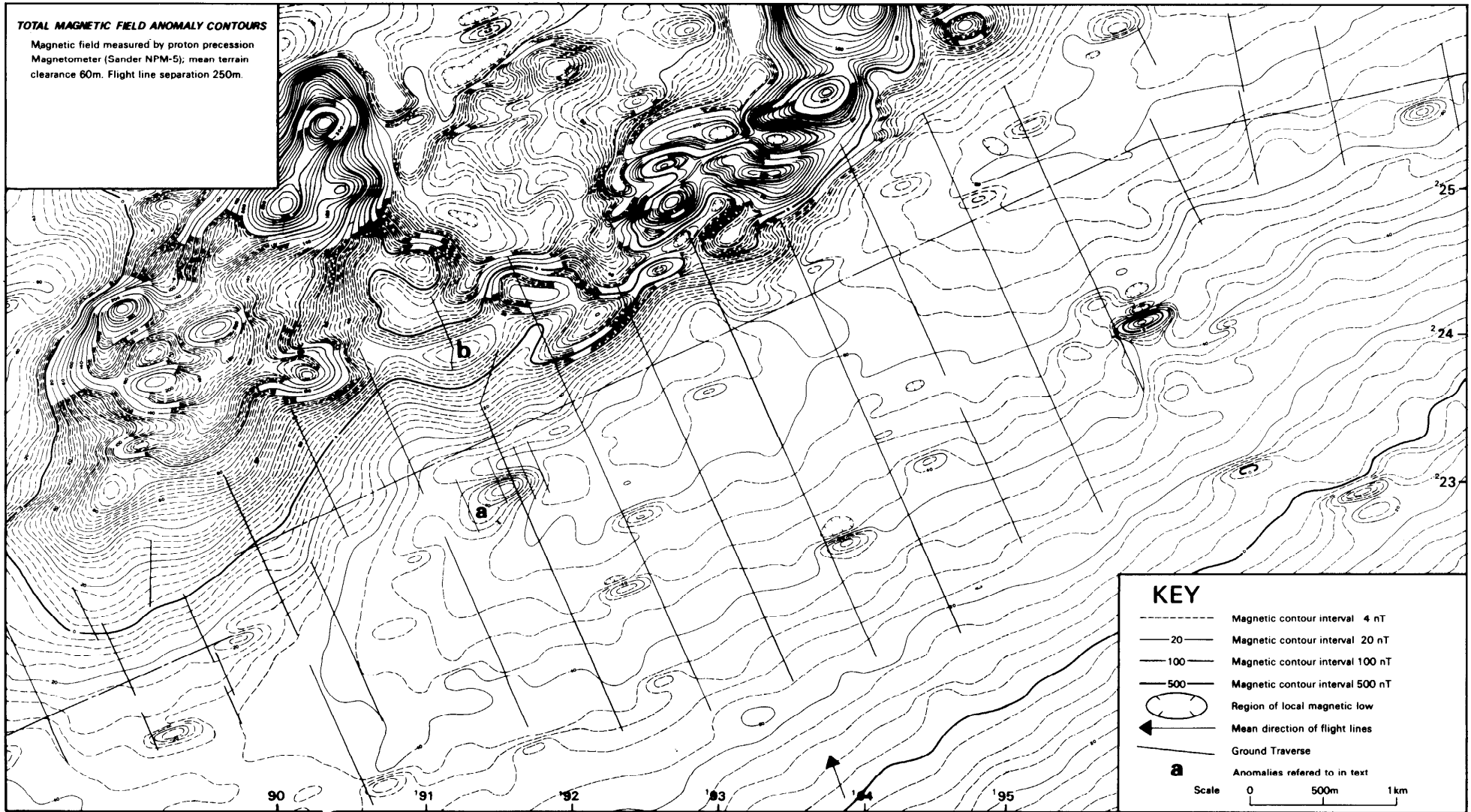


Figure 7 Aeromagnetic map of the area around Treffgarne and the location of geophysical survey lines



Figure 8 Airborne VLF map of the area around Treffgarne

(Fig. 8). The VLF-EM results show a large narrow anomaly, indicative of an artificial source, following a dirt track across the hillside and it was therefore presumed to arise from a buried pipe. The magnetic anomaly however, is a broad feature, with a width of up to 200 m and a limited strike length, indicated by the ground traverses, of about 300 m. The source of this anomaly is unexplained, but it could arise from a small shallow igneous intrusion. A similar magnetic anomaly lies within the main block of aeromagnetic anomalies ('b' in Fig. 7), could reflect a similar small intrusion.

Airborne and Ground VLF-EM

The results of the airborne VLF-EM survey are shown (Fig. 8) as a map of the intensity of the horizontal component of the VLF field (VLF-IH), measured as a percentage of the normal field (100%). Low VLF-IH values indicate electrically resistive rocks, whilst high values indicate conductive rocks, faults or thick overburden. The data are distorted over roads, buildings and powerlines.

Generally in the Treffgarne survey area there are no particularly strong VLF-IH anomalies and maximum variation (10%) occurs over the intrusive rocks in the north. In the southern half of the survey area, where land use is most developed and ground traverses are widely spaced it is difficult to deduce a relationship between VLF-IH, apparent resistivity and geology because of poor exposure and 'noise'.

Ground VLF-EM results were severely affected by noise from the numerous fences, powerlines, pipes and other man-made objects. Profiles show few natural anomalies and with the large line spacing it is impossible to trace features along strike. The positions of the main

ground anomalies are marked on the VLF contour map (Fig. 8). Some anomalies correlate with the northern edge of the Ordovician outcrop, but generally the ground VLF-EM method was only useful in defining the electrical interference from visible and buried man-made conductors to help in the assessment and validation of the IP survey results.

IP Surveys

A generalised map showing the locations of the main elongated zone of higher chargeability values is shown in Fig. 9.

The Roch Rhyolite Group in the Treffgarne area is characterised by relatively high resistivity and high chargeability, with values commonly exceeding 4000 ohm-m and 35 ms respectively. Maximum resistivity occurs over hill tops, but the anomalies are too large to be produced by topographic distortion alone. In comparison, the rest of the survey area has low background resistivity and chargeability, and contains few anomalies. The zone of high chargeability and resistivity anomalies (more than 700 ohm-m to 1000 ohm-m) is coincident with the outcrop of the Roch Rhyolite Group. In some areas the boundary of these rocks is quite well defined, but in many places the change in resistivity is more gradual, and the problem of interference from artificial sources combined with the large line spacing makes confident geological interpretation difficult.

Four areas of high chargeability values were examined using more detailed geophysical surveys and three of these were subsequently investigated by drilling. Data compilation maps for resistivity and chargeability are included in the Data Package.

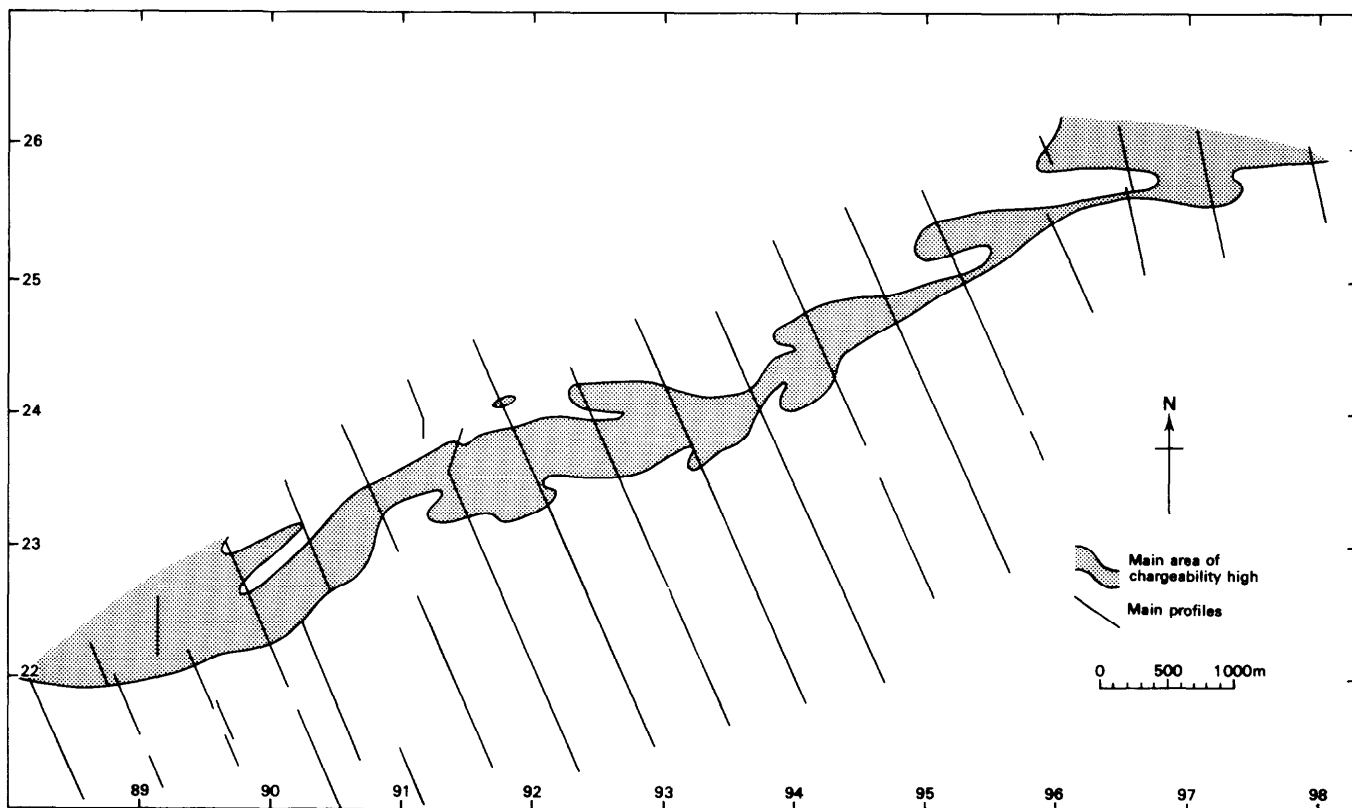


Figure 9 Chargeability anomaly map of the Treffgarne area

DRILLING

Three boreholes were drilled to investigate areas of high chargeability delineated by the IP/resistivity survey. The 3 holes were drilled by BGS staff using a JKS-300 rig. Lithological logs, graphical logs of the geochemical data and mineralogy notes on the borehole samples are available in the Data Package.

Lithology

Borehole one intersected rhyolites, fine acid tuffs, thin ash bands, volcanic breccias and cherty tuffs. Silicified rhyolites at the top of the hole pass down into fine grain acid tuffs composed of a dominant grey/green tuff, usually with abundant disseminated pyrite, and a lighter more acid tuff which contains little or no pyrite. Towards the base of the hole a particularly hard granular cherty volcanic rock was encountered. Vesicles are present locally, sometimes containing zeolites, and some sections are brecciated.

Boreholes two and three intersected lithologically similar sequences of laminated siltstones and silty mudstones. In borehole two a sequence of dark pyritiferous mudstones were recovered which were not present in borehole three. A thin fine-grained tuff was recorded in borehole two while two felsic intrusions were present in borehole three. All the igneous rocks recovered from the two boreholes contained abundant fine-grained pyrite. Disseminated pyrite is also present throughout the sedimentary succession and at least three phases of quartz veining, containing pyrite, were also recorded. Much of the core recovered contains evidence of hydrothermal alteration in the form of bleaching, sericitisation and chloritisation. The more brecciated and altered sections are more intensely pyritised than the less altered more quartz-rich siltstones.

Palaeontology

Thirty samples from borehole two were examined for microfossils. Although none were discovered (Dr S. G. Molyneux pers. comm.) a fragment of a macrofossil was found which was identified as part of a trilobite. Although objectively undeterminable Dr A. W. A. Rushton (pers. comm.) considered it to be most probably part of a juvenile olenid. This discovery clearly precludes a Precambrian age for the Nant-y-Coy Formation. As both geological mapping and drill data indicates that no major discontinuity exists between the sedimentary rocks of the Nant-y-Coy Formation and the underlying rhyolites, it is most improbable that any part of the Roch Rhyolite Group is of Precambrian age. If the trilobite is accepted as an olenid it indicates an Upper Cambrian or Lower Ordovician age (Merioneth, Tremadoc, Arenig or Llanvirn Series). The sample resembles material from the Carmarthen Formation (Lower Arenig Series), but better material is needed to confirm this suggestion (Dr A. W. A. Rushton pers. comm.).

Mineralogy

The rocks from borehole one, all of which are highly altered, contain quartz + pyrophyllite +/- corundum +/- alunite +/- barite +/- kaolinite +/- illite/sericite +/- pyrite +/- Ti-oxides (fine leucocane or anatase).

The sequence of laminated siltstones and mudstones from boreholes two and three consist mainly of quartz and mica. Electron probe scans indicate the darker ovoid blebs contain more Fe, suggesting a higher chlorite content.

Chloritisation is most intense marginal to the veins or in areas of extensive veining. Disseminated pyrite is ubiquitous but is often concentrated in organic rich laminae or coarser quartzose laminae. This pyrite while possibly of syngenetic origin, has clearly undergone some recrystallisation.

Veins cutting all lithologies contain quartz, chlorite, muscovite, pyrite and in one sample tourmaline. The veins show a complex internal structure. In many cases a thin, subsequently disrupted, pyrite veinlet forms the centre of the vein bounded by a fringe-like growth of quartz and/or pyrite. These fringes, growing perpendicular to the vein margin, are often multiphase and curvilinear indicating syndeformational growth. Late stage traces of chalcopyrite often infill fractures in vein pyrite.

Geochemistry

Samples from all of the core drilled were submitted for analysis. Individual samples were selected on lithological changes in the core with a maximum sample length of 3 m. The core was split on site and subsequent crushing, mixing and fine grinding undertaken in the laboratory. A total of 202 samples were submitted for XRF analysis for SiO₂, Al₂O₃, TiO₂, Fe₂O₃, MgO, CaO, Na₂O, K₂O, MnO, P₂O₅, As, Ba, Cr, Cu, Mo, Ni, Nb, Pb, Rb, S, Sb, Sr, V, Zn and Zr. 40 samples from the three boreholes were submitted for Au analysis.

Geochemical data for borehole one indicates that the volcanic rocks are severely depleted in Na, Ca, K and probably Mg and Mn. High levels of S and Fe are fixed in pyrite. Relatively high levels of Ba and Sr in the acid volcanic rocks occur within highly altered sections depleted in Na, Ca and K. High levels of Al₂O₃ coupled with very low Ca + Na + K contents are reflected in the common occurrence of corundum which is most probably a product of alteration. Ti/Zr ratios show little variation and are generally lower than those reported for surface rocks.

The sedimentary rocks recovered from boreholes two and three are very similar in composition and are thus probably part of the same sequence. Both strike faulting and the lack of a marker horizon makes correlation between the two boreholes difficult. The mudstone sequence in borehole two contains higher levels of Fe, S, Sr and Zn than the overlying siltstones and silty mudstones succession but concentrations of other elements determined in the two lithologies are very similar. The felsic intrusions cut by borehole three and the thin tuff band cut by borehole two are most probably comagmatic with the acid volcanic rocks.

Geophysical borehole logs

Geophysical logs were run in boreholes two and three (logs included in the Data Package) using IP polarization (measuring chargeability in milliseconds), apparent resistivity (ohm-metres), spontaneous potential (SP in millivolts), single point resistance (SPR in ohms) and natural gamma radiation.

The IP/resistivity logs were run with a sonde of BGS design, with identical instrumentation to that used for the surface IP/resistivity survey. A pole-dipole electrode array was used with a 0.3 m potential dipole and a 1m spacing between the centre of the dipole and the current electrode. Observations of chargeability and apparent resistivity were made at 2 m intervals. The gamma, SP and SPR logs were run with a hand-winch logger (Mt. Sopris 100-C), with a paper chart recorder (1:100 scale).

The IP and resistivity logs clearly identify rocks of high apparent resistivity and chargeability and log signatures in each hole suggest that some hole to hole correlation may be possible. The SPR logs show features analogous to those on the IP/resistivity logs. The SP and gamma logs do not identify any features that can be cross-correlated between the two boreholes. However, the gamma logs do clearly identify the felsites in borehole three.

DISCUSSION

The age of the Roch Rhyolite Group and their relationship to other rocks in the area has always been uncertain. Thomas and Cox (1924) first considered an Arenig age for the volcanic rocks but finally placed them in the Precambrian. This was because although the Roch Rhyolite Group appeared to overlie the Brunel Beds conformably in the River Cleddau section, in exposures to the east Brunel Beds pass upwards into Tetraraptus Beds. Thomas and Cox (1924) were not able to reconcile on an Arenig age for the Roch Rhyolite Group with such a sudden attenuation of both the rhyolites and the associated Nant-y-Coy Formation towards the east.

Data presented in this report strongly suggests an Arenig age for the Roch Rhyolite Group. The evidence for this is based on the trilobite discovered in mudstones, thought to be part of the Nant-y-Coy Formation, in borehole two. Remapping, particularly in the River Cleddau section indicates no major break in passing from the Brunel Beds to the Roch Rhyolite Group and this appears to be an ascending sequence. Lithologically the Brunel Beds and the Nant-y-Coy Formation are very similar, except that rocks of the Nant-y-Coy Formation are intensely altered, pyritised and bleached. It is therefore proposed that the Brunel Beds and the Nant-y-Coy Formation are, at least in part, lateral equivalents, thus accounting for the apparent rapid attenuation of the beds. Considering the viscous nature of rhyolite lavas and their localised outcrop pattern a sudden attenuation to the east of these rocks is not considered unusual.

Additional evidence of age is provided by the aeromagnetic data (Fig. 7) The volcanic rocks of Precambrian age are magnetic, whereas, in common with the Cambro-Ordovician succession, the Roch volcanics and associated sedimentary rocks (Roch Rhyolite Group) are non-magnetic. Also, the magnetic data supports the presence of a steep fault dividing the Roch Rhyolite Group from the Precambrian rocks.

It is not clear if the volcanics of the Roch Rhyolite Group represent submarine or sub-aerial eruption but as volcanic rocks are surrounded by siltstones and silty mudstones of assumed marine origin it is probable that much of the volcanism was submarine. The original composition of the acid volcanics is difficult to determine due to the extreme alteration but they probably ranged from dacites to rhyolites.

Volcanic activity in Wales persisted from late Proterozoic to Silurian times (Stillman and Francis, 1979). During most of the Cambrian little volcanic activity was recorded but in the Tremadocian eruptions began on a large scale. The earliest post-Cambrian volcanism within the area investigated is represented by the Treffgarne Volcanic Group which show similarities with the Rhobell Fawr volcanism in North Wales (Bevins and others, 1984). It has been suggested that this early, predominantly andesitic, phase of Ordovician volcanism was

similar to that found in modern volcanic arcs and occurred in a similar tectonic setting. It is not clear whether the younger acid volcanism recorded in the Brunel Beds and Roch Rhyolite Group, is part of the same episode, or a pre-cursor of the bimodal volcanism of Llanvirn age typified by the Fishguard Volcanic Group and believed to have been formed within a marginal basin.

The Nant-y-Coy Formation may represent sediments deposited in a back-arc basin. Dark fine-grained pyritiferous mudstones seen towards the base of one of the boreholes suggests a relatively deep water environment, whereas quartzitic beds showing ripple marks and lensed beds, elsewhere in the Formation, suggest shallow water. Volcanoclastic material, which is common within the Nant-y-Coy sequence, is derived from contemporaneous volcanic activity. The Roch Rhyolite Group has undergone intense alteration which has resulted in silicification, unusually low total Na + Ca + K concentrations and high levels of Ba, Sr, Fe and S. This is reflected in the mineralogy of the rocks, notably the presence of corundum, baryte and abundant pyrite. Pyrite may be of both syngenetic and hydrothermal origin within the Nant-y-Coy Formation. Syngenetic pyrite is concentrated within thin layers within the mudstone sequence. In the acid volcanics it is finely disseminated, particularly in the rhyolites and the dark acid tuffs. In both acid volcanics and sedimentary sequences pyrite occurs in veins and veinlets and on joints.

In assessing the style of mineralisation comparisons can be drawn with the 'Kuroko' type or island arc exhalative model for ore deposition. Similarities can be drawn with other southern Caledonian volcanogenic base metal deposits of Ordovician age, notably the Avoca deposit in Ireland (Badham, 1978) and the Parys Mountain deposit in Anglesey (Pointon and Ixer, 1980). As at Treffgarne the volcanic rocks are intensely altered, with silicification and extensive pyritisation. In general the Roch Rhyolite group contain more alumina and less Mg and Na + Ca + K than analyses of comparable lithologies associated with these deposits.

CONCLUSIONS

1 Exploration in the Treffgarne area has led to the identification of a zone of intense hydrothermal alteration associated with abundant disseminated pyrite within acid volcanic and sedimentary rocks of the Roch Rhyolite Group. The alteration and mineralisation are thought to be volcanogenic in origin. Results on which these conclusions are based are contained in the Data Package.

2 Evidence arising from remapping, litho-geochemistry and the discovery of a fossil in the Nant-y-Coy Formation suggests that the Roch Rhyolite Group are of Lower Ordovician age and not, as previously thought Precambrian. An Ordovician age for the volcanism is considered to improve the mineral potential of the group because of the known association of Ordovician volcanism with mineralisation in the southern Caledonides.

3 The altered acid volcanics are characterised by exceptionally low total $\text{Na}_2\text{O} + \text{CaO} + \text{K}_2\text{O}$, high Al_2O_3 , Fe, S and locally Sr and Ba. This is reflected in the mineralogy by the presence of corundum, baryte and abundant pyrite. The associated highly altered sedimentary and pyroclastic rocks of the Nant-y-Coy Formation are characterised by intense sericitisation and the presence of numerous veins and stringers of quartz and pyrite.

4 A belt of high chargeability and resistivity is caused by highly altered rocks of the Roch Rhyolite Group containing disseminated pyrite. Results of profiling soundings and down-hole geophysical surveys confirm the existence of a high resistivity layer 30–40 m thick. At the extreme north-west and north-east edge of the area high chargeability is attributed to black shales and mudstones.

5 The majority of Cu, Pb and Zn anomalies in soil samples are related to secondary enrichment processes. Elevated levels of Cu in some of the overburden samples derived from till overlying the Nant-y-Coy Formation may be due to alteration and mineralisation within these rocks as the area lies within the zone of high chargeability.

6 The geology and structure of the area remains poorly understood. Further investigation of the Roch Rhyolite Group is required to locate the centre of volcanism, confirm the age of the rocks and to investigate in more detail the chemistry, alteration and mineralisation. A combination of local and regional studies to elucidate the structure of the area is merited and a more detailed examination of the Roch Rhyolite Group and the Brunel Beds, is needed to clarify their age relationships.

ACKNOWLEDGEMENTS

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